The development of in-situ and prefabricated masonry processes using high performance mortars

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Declaration

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Dedicated to Bonny, Kelly, Daisy, Millie, Eva and Grace with whom we have spent so much of our lives and many happy days walking in the countryside.
Abstract

There has been a steady but continuous decline in the use of clay brickwork in the United Kingdom over the past 100 years due to preferences being given to alternative materials and changes in construction processes.

The significant reduction in brick use started with the decline in use of clay bricks as a material for structural brickwork notably in civil engineering structures and as an inner leaf material for cavity walls when it was largely replaced by concrete blocks and aircrete blocks.

This project addresses new markets for clay brickwork and specifically the development of in-situ thin joint clay brickwork techniques used in the UK. Prefabricated masonry is then considered and three prefabrication processes developed and evaluated.

Manual bricklaying of prefabricated cavity and single skin walls is described as is a robotic manufacturing technique which can facilitate single leaf and cavity walls with openings and with return corner details. A new flat- bed masonry fabrication technique is discussed and developed along with a simple test procedure to ensure continued evaluation of manufactured masonry.

A number of case studies are documented with details of the processes, building structure types and the eventual outcome from each project.

Both the flat bed prefabrication method and the test are simple, economical and require low capital expenditure and it is anticipated that these processes may provide successful alternatives to the various systems which have been developed over the years but have not been widely received both worldwide and particularly in the UK.
# Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Introduction and objectives</strong></td>
<td>1</td>
</tr>
<tr>
<td>1.1 Introduction</td>
<td></td>
</tr>
<tr>
<td>1.2 Background</td>
<td></td>
</tr>
<tr>
<td>1.3 Objectives</td>
<td></td>
</tr>
<tr>
<td>2. <strong>Historical background and Literature search</strong></td>
<td>5</td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>5</td>
</tr>
<tr>
<td>2.2 Historical of masonry – general background</td>
<td>5</td>
</tr>
<tr>
<td>2.2.1 The development of structural masonry</td>
<td>7</td>
</tr>
<tr>
<td>2.3 Masonry materials</td>
<td>8</td>
</tr>
<tr>
<td>2.3.1 Clay bricks – natural materials, manufacturing processes</td>
<td>8</td>
</tr>
<tr>
<td>(their influence on good design, specification and construction)</td>
<td></td>
</tr>
<tr>
<td>2.3.2 Aggregate blocks</td>
<td>15</td>
</tr>
<tr>
<td>2.3.3 Aircrète blocks</td>
<td>16</td>
</tr>
<tr>
<td>2.3.4 Stone</td>
<td>18</td>
</tr>
<tr>
<td>2.4 The evolution and development of the cavity wall in UK construction</td>
<td>19</td>
</tr>
<tr>
<td>2.5 Modern regulations and legislation and its influence on the masonry</td>
<td>22</td>
</tr>
<tr>
<td>industry and on construction</td>
<td></td>
</tr>
<tr>
<td>2.6 Sustainability, carbon reduction and the Code for Sustainable Homes</td>
<td>25</td>
</tr>
<tr>
<td>2.6.1 Code for Sustainable Homes</td>
<td>25</td>
</tr>
<tr>
<td>2.7 Building Legislation and the development of cavity walls</td>
<td>27</td>
</tr>
<tr>
<td>2.7.1 Part L Building Regulations</td>
<td>27</td>
</tr>
<tr>
<td>2.7.2 Domestic buildings</td>
<td>28</td>
</tr>
<tr>
<td>2.7.3 Target Emission Rate (TER)</td>
<td>29</td>
</tr>
<tr>
<td>2.7.4 Target Fabric Energy Efficiency (TFEE) rate</td>
<td>30</td>
</tr>
<tr>
<td>2.7.5 Multiple occupancy buildings</td>
<td>30</td>
</tr>
<tr>
<td>2.7.6 Thermal bridges</td>
<td>30</td>
</tr>
<tr>
<td>2.7.7 U value solutions</td>
<td>32</td>
</tr>
<tr>
<td>2.7.8 Summary of the legislative developments</td>
<td>33</td>
</tr>
<tr>
<td>2.7.9 What do these legislative changes mean to the design and</td>
<td>34</td>
</tr>
<tr>
<td>construction of cavity walls.</td>
<td></td>
</tr>
<tr>
<td>2.8 Markets for clay brick and early product development</td>
<td>36</td>
</tr>
<tr>
<td>2.8.1 Introduction</td>
<td>36</td>
</tr>
<tr>
<td>2.8.2 Walling solutions investigated</td>
<td>37</td>
</tr>
</tbody>
</table>
2.9 Structural brickwork 41
2.10 Prefabricated brickwork 44
  2.10.1 Prefabricated masonry – unsuccessful processes 45
  2.10.1.1 European systems 44
  2.10.1.2 American systems 47
  2.10.1.3 Prefabricated masonry – recent developments 48
  2.10.1.4 Existing Prefabricated masonry processes in Europe 49
2.11 Summary of literature review 51

3. Thin Joint Adhesive masonry – development and use in the UK. 54
  3.1 Introduction. 54
    3.1.1 Thin joint adhesive brickwork – a Dutch masonry system. 54
    3.1.2 Development of the thin joint mortar system in the UK 55
    3.1.3 Application method of glue mortar and visual appearance. 56
    3.1.4 Structural properties of thin joint masonry – overview. 58
    3.1.5 Material and structural testing. 59
    3.1.6 Background to the development of the thin joint adhesive system in the UK - market opportunity leading to the first case study. 59

3.2 Case studies of thin joint adhesive masonry. 64
  3.2.1 Case study no 1 – University of West of England 64
    3.2.1.1 Introduction 64
    3.2.1.2 Overview 64
    3.2.1.3 Project details 64
    3.2.1.4 Development objectives – observations, results & conclusions 68
    3.2.1.5 Conclusions 74

  3.2.2 Case study no 2 – Private development, Tuxford, 75
    3.2.2.1 Introduction 75
    3.2.2.2 Development objectives 75
    3.2.2.3 Structural design 76
    3.2.2.4 Architectural detailing 76
    3.2.2.5 Brickwork properties 76
    3.2.2.6 Blockwork properties 76
    3.2.2.7 Cavity wall insulation and wall ties 78
    3.2.2.8 Masonry construction process 78
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2.2.9</td>
<td>Conclusions and lessons learnt</td>
<td>81</td>
</tr>
<tr>
<td>3.2.3</td>
<td>Case study no 3 - Private individually designed house using structural masonry, Thaxted, Essex</td>
<td>83</td>
</tr>
<tr>
<td>3.2.3.1</td>
<td>Background / design brief</td>
<td>83</td>
</tr>
<tr>
<td>3.2.3.2</td>
<td>Groundworks, foundations and superstructure construction</td>
<td>84</td>
</tr>
<tr>
<td>3.2.3.3</td>
<td>Discussion</td>
<td>92</td>
</tr>
<tr>
<td>3.2.3.4</td>
<td>Lessons learnt</td>
<td>95</td>
</tr>
<tr>
<td>3.2.3.5</td>
<td>Material properties and testing</td>
<td>97</td>
</tr>
<tr>
<td>3.2.4</td>
<td>Case study no 4 University of Hertfordshire, Digital Laboratory</td>
<td>101</td>
</tr>
<tr>
<td>3.2.4.1</td>
<td>Introduction</td>
<td>101</td>
</tr>
<tr>
<td>3.2.4.2</td>
<td>Lessons learnt</td>
<td>103</td>
</tr>
<tr>
<td>3.2.4.3</td>
<td>Site issues</td>
<td>104</td>
</tr>
<tr>
<td>3.2.4.4</td>
<td>Contractual issues</td>
<td>105</td>
</tr>
<tr>
<td>3.2.4.5</td>
<td>Conclusion</td>
<td>105</td>
</tr>
<tr>
<td>3.2.5</td>
<td>Case study no 5 Carnival Arts Centre, 3 St Mary’s Road, Luton</td>
<td>106</td>
</tr>
<tr>
<td>3.2.5.1</td>
<td>Introduction</td>
<td>106</td>
</tr>
<tr>
<td>3.2.5.2</td>
<td>Construction work on site</td>
<td>107</td>
</tr>
<tr>
<td>3.2.5.3</td>
<td>Architectural appraisal</td>
<td>108</td>
</tr>
<tr>
<td>3.2.5.4</td>
<td>Lessons learnt</td>
<td>110</td>
</tr>
<tr>
<td>3.2.5.5</td>
<td>Conclusions</td>
<td>111</td>
</tr>
<tr>
<td>3.3</td>
<td>Summary and appraisal of thin joint adhesive masonry in-situ</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td>techniques in the UK based upon the overall conclusions relating to performance of the process in the Case Studies</td>
<td></td>
</tr>
<tr>
<td>3.3.1</td>
<td>Appearance and performance</td>
<td>112</td>
</tr>
<tr>
<td>3.3.2</td>
<td>Thin joint masonry – work on site</td>
<td>112</td>
</tr>
<tr>
<td>3.3.3</td>
<td>Construction and workmanship and the in-situ process</td>
<td>115</td>
</tr>
</tbody>
</table>

4. Market for prefabrication

4.1 Introduction

4.2 Market statistics for walling and cladding materials

4.3 Market for prefabrication – proposals for prefabricated masonry manufacture

4.4 Sustainability
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>Target market and sales projection</td>
<td>128</td>
</tr>
<tr>
<td>4.6</td>
<td>Hanson Eco House BRE Offsite 2007</td>
<td>129</td>
</tr>
<tr>
<td>4.7</td>
<td>Competitive overview</td>
<td>129</td>
</tr>
<tr>
<td>4.8</td>
<td>Risks</td>
<td>133</td>
</tr>
<tr>
<td>4.8.1</td>
<td>Technical</td>
<td>133</td>
</tr>
<tr>
<td>4.8.2</td>
<td>Costs</td>
<td>134</td>
</tr>
<tr>
<td>4.8.3</td>
<td>Volumetric construction and imports</td>
<td>134</td>
</tr>
<tr>
<td>4.8.4</td>
<td>Public and specifier attitudes</td>
<td>134</td>
</tr>
<tr>
<td>4.8.5</td>
<td>Skills, quality and quality control</td>
<td>135</td>
</tr>
<tr>
<td>4.8.6</td>
<td>Accreditation</td>
<td>135</td>
</tr>
<tr>
<td>4.8.7</td>
<td>Change of government</td>
<td>135</td>
</tr>
<tr>
<td>4.9</td>
<td>The potential for manufactured masonry processes</td>
<td>136</td>
</tr>
<tr>
<td>4.10</td>
<td>Opportunities</td>
<td>137</td>
</tr>
<tr>
<td>4.10.1</td>
<td>Other housing</td>
<td>137</td>
</tr>
<tr>
<td>4.10.2</td>
<td>Single skin</td>
<td>137</td>
</tr>
<tr>
<td>4.10.3</td>
<td>Other sectors</td>
<td>137</td>
</tr>
<tr>
<td>4.11</td>
<td>Case studies - Summary of thin joint adhesive masonry in-situ techniques as a background to prefabrication</td>
<td>138</td>
</tr>
<tr>
<td>4.12</td>
<td>Background to prefabricated masonry</td>
<td>139</td>
</tr>
<tr>
<td>4.13</td>
<td>Prefabrication processes to consider</td>
<td>140</td>
</tr>
<tr>
<td>4.14</td>
<td>Conclusions to Chapter 4</td>
<td>144</td>
</tr>
<tr>
<td>5.</td>
<td><strong>Manually prefabricated masonry &amp; case studies</strong></td>
<td>146</td>
</tr>
<tr>
<td>5.1</td>
<td>Introduction</td>
<td>146</td>
</tr>
<tr>
<td>5.1.1</td>
<td>Factory built panel processes – plant and equipment</td>
<td>149</td>
</tr>
<tr>
<td>5.1.2</td>
<td>Factory built process – working environment</td>
<td>150</td>
</tr>
<tr>
<td>5.1.3</td>
<td>Factory location and suitability</td>
<td>151</td>
</tr>
<tr>
<td>5.1.4</td>
<td>Moveable working platform – steel trolley on rollers</td>
<td>151</td>
</tr>
<tr>
<td>5.1.5</td>
<td>Panel development using masonry plinth bases – preparation of the working area</td>
<td>152</td>
</tr>
<tr>
<td>5.1.6</td>
<td>Manufacture / construction of panels – working access</td>
<td>154</td>
</tr>
<tr>
<td>5.1.7</td>
<td>Health and safety – good working practice</td>
<td>154</td>
</tr>
<tr>
<td>5.1.8</td>
<td>Lifting and removal of panels from factory floor to storage area</td>
<td>155</td>
</tr>
<tr>
<td>5.1.9</td>
<td>Setting out and set up of panel construction – factory layout</td>
<td>157</td>
</tr>
<tr>
<td>5.1.10</td>
<td>Maximising factory output</td>
<td>158</td>
</tr>
<tr>
<td>5.1.11</td>
<td>Factory layout – benefits of manually built factory panels</td>
<td>163</td>
</tr>
<tr>
<td>5.1.12</td>
<td>Design and detailing of prefabricated panels</td>
<td>165</td>
</tr>
</tbody>
</table>
5.2 Prefabricated masonry panels – Case studies

5.2.1 Case study no 6 – Development of Hanson House for the BRE Offsite 2005 Exhibition

5.2.1.1 Introduction
5.2.1.2 Wall construction
5.2.1.3 Movement, lifting and handling
5.2.1.4 Conclusions / lessons learnt

5.2.2 Case study no 7 - The Hanson EcoHouse™ and Hanson QuickBuild™ walling system

5.2.2.1 Introduction
5.2.2.2 The Hanson EcoHouse™ – Development ideas
5.2.2.3 Hanson QuickBuild™ walling system
5.2.2.4 Design concept – superstructure
5.2.2.5 Design to the Code for Sustainable Homes
5.2.2.6 Conclusions
5.2.2.7 Further development work and construction details

5.2.3 Case study no 8 - Case study No 8, Lawn House, Private domestic dwelling, Burbage Leicestershire.

5.2.3.1 Introduction
5.2.3.2 Prefabricated panel manufacture, Hanson Stewartby Workshop.
5.2.3.3 On-site installation of masonry panels and construction details.
5.2.3.4 Conclusions

5.2.4 Case Study no 9 - Carlisle flood defence system

5.2.4.1 Introduction
5.2.4.2 Flood wall construction
5.2.4.3 Comparison of flood wall construction processes
5.2.4.4 Prefabricated panel design and detailing requirements for the typical flood wall section.
5.2.4.5 Preliminary trial walls – manufacturing techniques, location and set up.
5.2.4.6 Panel production output
5.2.4.7 Strength, structural integrity and robustness
5.2.4.8 Initial testing
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2.4.9 Initial strength trials of masonry panels</td>
<td>221</td>
</tr>
<tr>
<td>5.2.4.10 Storage of panels, handling and transportation</td>
<td>222</td>
</tr>
<tr>
<td>5.2.4.11 Carlisle and Caldew river flood defence scheme – construction sequence</td>
<td>224</td>
</tr>
<tr>
<td>5.2.4.12 Conclusion and summary</td>
<td>226</td>
</tr>
<tr>
<td>5.2.4.13 Further stillage development</td>
<td>226</td>
</tr>
<tr>
<td>5.3 Summary and conclusions to Chapter 5</td>
<td>228</td>
</tr>
<tr>
<td>6. Robotic processes for factory prefabrication</td>
<td>230</td>
</tr>
<tr>
<td>6.1 Introduction</td>
<td>230</td>
</tr>
<tr>
<td>6.2 Background to the requirement and development of the automated manufacturing process</td>
<td>230</td>
</tr>
<tr>
<td>6.3 Capital proposal for prefabricated robotic masonry manufacturing process</td>
<td>233</td>
</tr>
<tr>
<td>6.4 Design specification and requirements for robotic construction of single leaf and insulated masonry cavity walls.</td>
<td>236</td>
</tr>
<tr>
<td>6.5 Preliminary design proposals and the manufacturing sequence</td>
<td>241</td>
</tr>
<tr>
<td>6.6 Lingl machinery process on which proposed UK robotic system is based</td>
<td>244</td>
</tr>
<tr>
<td>6.7 Handling and storage</td>
<td>245</td>
</tr>
<tr>
<td>6.8 Opportunities for masonry constructed by high volume robotic prefabrication</td>
<td>247</td>
</tr>
<tr>
<td>6.8.1 Other housing</td>
<td>247</td>
</tr>
<tr>
<td>6.8.2 Single skin</td>
<td>247</td>
</tr>
<tr>
<td>6.8.3 Other sectors</td>
<td>247</td>
</tr>
<tr>
<td>6.9 Summary</td>
<td>247</td>
</tr>
<tr>
<td>6.9.1 Financial summary</td>
<td>247</td>
</tr>
<tr>
<td>6.9.2 Market</td>
<td>247</td>
</tr>
<tr>
<td>6.9.3 Design and technical information</td>
<td>247</td>
</tr>
<tr>
<td>6.10 Conclusions</td>
<td>247</td>
</tr>
<tr>
<td>7. Development of a simplified masonry wall prefabrication process</td>
<td>250</td>
</tr>
<tr>
<td>7.1 Introduction</td>
<td>250</td>
</tr>
<tr>
<td>7.2 Background to the flat bed manufacturing process development.</td>
<td>251</td>
</tr>
<tr>
<td>7.3 Development brief</td>
<td>253</td>
</tr>
<tr>
<td>7.4 Trial panels - Work undertaken at Hanson Derby Pre Cast Works : April - June 2009- basic mould box and materials</td>
<td>255</td>
</tr>
<tr>
<td>7.4.1 Trial no 1 – Composite brick slip / concrete panel – Engineering quality bricks</td>
<td>260</td>
</tr>
<tr>
<td>7.4.2</td>
<td>Trial no 2 - Composite full brick / concrete panel including 327mm (1½ brick) return. Stock brick panel 900mm wide x 8 courses high, 100mm concrete backing</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>7.4.3</td>
<td>Trial no 3 – Insulated composite cavity wall with prefabricated inner and outer leaves. Two insulation types were trialled - Kingspan phenolic foam and Knauf mineral wool.</td>
</tr>
<tr>
<td>7.4.4</td>
<td>Trial no 4 self compacting concrete on reinforced brick / concrete pier section</td>
</tr>
<tr>
<td>7.4.5</td>
<td>Trial no 5 - Small panel – stock brick, high performance polymer modified adhesive mortar (Omnicol Type C mortar with high water content) poured on to panel and brushed into joints</td>
</tr>
<tr>
<td>7.4.6</td>
<td>Trial no 6 – Sept 09 Small panel – stock bricks set face up in the mould box, thin layer Omnicol mortar poured into panel joints. Thermo mass base with 3mm polystyrene bed to accommodate bricks</td>
</tr>
<tr>
<td>7.4.7</td>
<td>Trial no 7 Sept 09 - Determination of suitable joint sealants for base of the mould.</td>
</tr>
<tr>
<td>7.4.8</td>
<td>Trial no 8 - October 09 – 3m panel with standard Hanson Kirton Facing Brick</td>
</tr>
<tr>
<td>7.4.9</td>
<td>Trial no 9 – Fabrication of corner panel assembly and production sequence</td>
</tr>
<tr>
<td>7.4.10</td>
<td>Trial no 10 Dec 09 - 6m long x 1.5m high decorative panel</td>
</tr>
<tr>
<td>7.4.11</td>
<td>Development of a combined lifting beam, temporary prop system and transportation storage racking system.</td>
</tr>
<tr>
<td>7.4.12</td>
<td>Flexible lifting beam with variable height adjustment system for panel restraint</td>
</tr>
<tr>
<td>7.4.13</td>
<td>Summary to chapter 7</td>
</tr>
</tbody>
</table>

### Chapter 8: Testing

#### 8.1 Introduction

#### 8.2 Comparison of compressive and flexural strength properties for various mortar types and mix compositions

8.2.1 Results, observations and discussion

#### 8.3 Omnicol mortar tests – influence of water content on mortar performance properties (samples tested at 3 days after casting)

8.3.1 Test specification

8.3.2 Observations and discussion of results
8.3.3 Comparison of the performance of Omnifix C mortar made at 22% and 25% water content. (Tested at 1 day old up to 14 days)

8.3.4 Mortar testing – Conclusions

8.4 Flexural strength and Wallette tests

8.4.1 Hanson Wallette testing programme

8.4.2 Flexural strength tests

8.4.3 Results of the flexural strength tests

8.4.4 Conclusion and observations on flexural strength wallette testing

8.5 Simplified stack / pier test – piers made by bricklayer / trowel technique

8.5.1 Background to development of stack beams.

8.5.2 Building of brick stack piers

8.5.3 Preparation of the pier beam for testing

8.5.4 Loading of pier beams

8.5.5 Pier construction times

8.5.6 Observations

8.5.7 Structural testing of manually made stack beams

8.5.8 Conclusions relating to hand made stack samples – workability and structural performance.

8.5.9 Further development of the brick stack samples.

8.6 Flexural strength test – stack piers made by horizontal mould box and mortar mix with various water contents

8.6.1 Fabrication of stack test box

8.6.2 Preliminary trial tests

8.7 Conclusions

9. Conclusions

10. References

11. Appendix (refer to electronic copies)

11.1 Material data

11.2 Reports and research papers
## Index of Figures

**Note:** figures / photographs have been sourced by the author unless otherwise noted.

### Chapter 2

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Geological map of the UK showing clay types. Butterley Brick Ltd.</td>
<td>8</td>
</tr>
<tr>
<td>2.2</td>
<td>Extruded wirecut engineering type bricks</td>
<td>10</td>
</tr>
<tr>
<td>2.3</td>
<td>Soft mud facing bricks</td>
<td>11</td>
</tr>
<tr>
<td>2.4</td>
<td>London Brick Company – Flettons</td>
<td>12</td>
</tr>
<tr>
<td>2.5</td>
<td>Location of the construction “team”, Butterley Brick Ltd</td>
<td>13</td>
</tr>
<tr>
<td>2.6</td>
<td>Specifications to achieve the TER and TFEE rates (Approved Doc L1 A 2013)</td>
<td>29</td>
</tr>
<tr>
<td>2.7</td>
<td>(a) Insulation thicknesses required to achieve specific U values (Thermalite)</td>
<td>32</td>
</tr>
<tr>
<td>2.8</td>
<td>(b) Insulation thicknesses required to achieve specific U values (Aggregate)</td>
<td>32</td>
</tr>
<tr>
<td>2.7</td>
<td>The effect of reduced U values on the cavity wall thicknesses from 1970 up to 2007</td>
<td>34</td>
</tr>
<tr>
<td>2.9</td>
<td>The reduction in internal floor space due to increased cavity thicknesses required to accommodate insulation</td>
<td>35</td>
</tr>
<tr>
<td>2.10</td>
<td>Combination masonry unit comprising aggregate block, Styrofoam insulation and clay half brick thick outer facing. Hanson</td>
<td>38</td>
</tr>
<tr>
<td>2.11</td>
<td>Six storey timber framed structure with single leaf continuous clay brickwork. BRE Cardington, TF2000.</td>
<td>38</td>
</tr>
<tr>
<td>2.12</td>
<td>Composite brick slip cladding panel. Hanson Wonderwall</td>
<td>39</td>
</tr>
<tr>
<td>2.13</td>
<td>Brick slip composite panel on timber framed substructure. Hanson Wonderwall literature.</td>
<td>40</td>
</tr>
<tr>
<td>2.14</td>
<td>Brick slip cladding to 1950 style properties with pebbledash walling. Hanson Wonderwall literature</td>
<td>40</td>
</tr>
<tr>
<td>2.15</td>
<td>Henry Dyke patent for prefabricated brick panel, Thomas 1973 Study on Brickwork prefabrication, BDA</td>
<td>45</td>
</tr>
<tr>
<td>2.16</td>
<td>Harold Waud. prefabrication process patented in 1971, Thomas. Study of prefabricated brickwork.</td>
<td>45</td>
</tr>
<tr>
<td>2.17</td>
<td>Rheingold system 1965. Study of Prefabrication, BDA</td>
<td>46</td>
</tr>
<tr>
<td>2.18</td>
<td>James Beattie Bell slots formed in special cut bricks for prefabrication. Study of prefabrication, BDA</td>
<td>46</td>
</tr>
<tr>
<td>2.19</td>
<td>Caldwell’s costly assembly process. Study of prefabrication, BDA</td>
<td>46</td>
</tr>
<tr>
<td>2.20</td>
<td>Detail of the Danilith wall, floor and ground beam construction.</td>
<td>50</td>
</tr>
</tbody>
</table>
Chapter 3

3.1 Architectural elevations and superstructure construction
(a) Main elevation showing stack bonded brickwork & full height glass panels.
(b) Gable end constructed with straw bale system
(c) Superstructure of structural steel work and traditional blockwork inner leaf

3.2 Polyjet glue gun machine, pre bagged adhesive method of application in external brickwork.
(a) Polyjet pump and gun for application of the adhesive
(b) Application of adhesive mortar from single bead dispenser. Mortar is placed centrally or slightly to the rear of the bed so that bricks are pressed from rear 6towards front and the mortar pushed forward
(c) Adhesive delivered as 25kg pre bagged mix. Add water within mixer

3.3 (a) – (e) Completed brickwork superstructure and architectural detailing
External leaf 290mm long bricks x 65mm high x 90mm deep. Stack bonded thin joint masonry with bed and perpend joints = 7mm

3.4 Dimensional variations of purpose made blocks for co-ordination with thin joint brickwork.
(a) Standard brick and block dimensions with 10mm bed and perpend joints
(b) Standard brick and non standard block heights (205mm) for use with thin joint system

3.5 (a) Applying glue bead to thin joint brickwork base bed joint
(b) Laying bricks

3.6 The bricklaying process.
(a) Positioning the glue beads
(b) Application of glue joints to the brick perpends prior to laying units in

3.7 (a) Construction of the blockwork inner leaf using thin joint adhesive prior to building of clay brick outer leaf.
(b) Block laying to inner leaf using trowel and high strength glue mortar

3.8 Bricklaying and blocklaying process.

3.9 The glued brickwork / blockwork process.
(a) Ground floor blockwork with door and window frames positioned during construction.
(b) The completed external brickwork shell.

3.10 The two completed detached houses, Tuxford, Nottinghamshire.

3.11 Typical elevation and cross section showing spine wall with “lean to” building structure

3.12 (a) – (d) Images of the model used to assist in understanding the design
principles.

3.13 (a) to (f) View of the spine wall with crosswalls in place. Diaphragm spine wall showing cross rib.

3.14 (a) to (f) Construction of the masonry superstructure

3.15 (a) Buttress wall being post tensioned
(b) Completed buttressed wall supporting timber frame.

3.16 (a) to (d) timber superstructure under construction

3.17 (a) to (c) The completed house with lake in the foreground, Thaxted, Essex

3.18 (a) – (c) Typical views of external façade.

3.19 rendered image of building layout (Ash Sakula 2007)

3.20 (a) – (b) typical construction details are shown (Ash Sakula 2008)

3.21 (a) – (c) Part elevation of masonry panel, general elevations and close up view of brickwork detail illustrating thin black mortar joints, the use of curved brickwork and the colour detail of the blue and cream bricks

Chapter 4

4.1 UK wall cladding market by area installed, 2008 – 2018 (AMA research)


4.3 Brick & block delivery changes month by month, 2010 – 2013 (CPA)

4.4 UK Wall cladding market share 2013 (BDA)

4.5 Cladding by product type – area installed (m2) (AMA 2014)

4.6 Cladding by product type – value (£), (AMA 2014)

4.7 Market value for modular systems (AMA Research 2013)

4.8 Market for volumetric construction

Chapter 5

5.1 Dutch thin joint brickwork.

5.2 Conventional brickwork with 10mm joints.

5.3 Sample panels of various bricks laid with thin joint adhesive.
(Trials at Hanson Waingroves Brickworks - 2003).
(a) Standard UK format buff engineering bricks with 5mm joints.
(b) UK pavers laid on edge with 3mm joints.
(c) Stock bricks with 3mm joints.
(d) Rough stock bricks with 3mm maximum joints

5.4 Fork lift trials with a 4m long x 1m high prefabricated panel.

5.5 Prefabricated single skin single storey height panel (Hanson Waingroves).

5.6 Prefabricated aggregate blockwork panels 215mm blocks laid on flat
and 100 mm conventional blockwork.

5.7 (a) – (c) Base plinths set up for panel construction showing single leaf and cavity walls (Hanson Waingroves).

5.8 Typical brick and block, insulated cavity wall (Hanson Waingroves).

5.9 Cavity wall in foreground, aircrète block wall to the rear. (Hanson Waingroves).

5.10 Plinth base with panel under construction. Brick recesses shown to receive slings.

5.11 Final check of lifting beam prior to lift.

5.12 Cavity wall being lifted off plinth base using sling straps.

5.13 Panel vertically lifted clear off plinth.

5.14 Typical plan layout of a brick wall panel production for four walls using 4 bricklayers, 1 labourer and 1 pump.

5.15 Plan view of cavity wall setting out details and layout plan.

5.16 Elevational details of proposed Hanson House.

5.17 Section through structure.

5.18 Prefabricated blockwork wall with phenolic foam insulation.

5.19 Prefabricated panels under construction.

5.20 Architects CAD render image of the Hanson house design.

5.21 A 3D view of superstructure illustrating the prefabricated walls, floor systems and basement.

5.22 Completed L shaped corner panel.

5.23 Completed T shaped panel.

5.24 Panels loaded on flat bed truck at Hanson Waingroves brickworks Derbyshire ready for transportation to BRE Watford.

5.25 (a) - (b) Moving L shaped corner blockwork panel from factory using two heavy duty forklift trucks and crane (Hanson Waingroves).

5.26 Installation of the lightweight cladding panel system Hanson Wonderwall.

5.27 (a) – (e) Lifting and installation procedure for the installation of prefabricated cavity walls (BRE Offsite 2005, Watford).

5.28 Architects conceptual CAD image.

5.29 Completed house, Hanson House at the BRE Offsite 2005 Exhibition.

5.30 Elevation of completed Hanson Eco House™

5.31 Design concept for the Eco House™

(a) Design concept for the Eco House™ (T P Bennett Architects).

(b) Sketches for the brick kiln “chimney” concept (T P Bennett).

(c) Principles of thermal mass and natural ventilation (TP Bennett).

5.32 Trial prefabricated insulated panel.
5.33 Panel being lifted using lifting beam and slings. 183
5.34 Locating a panel at the BRE site. 183
5.35 Overall design concept -2 storey structure with an edge beam at 1st floor supporting the 1st floor storey walls. (T P Bennett). 185
5.36 Cross section demonstrating the thermal mass / natural ventilation process. (T P Bennett). 185
5.37 Front and rear elevations with prefabricated steel roof structure (Hanson 2007). 186
5.38 First floor and ground floor plans (Hanson 2007). 186
5.39 Completed house in stack bonded external brickwork. 187
5.40 Temperature variations for buildings of low and high thermal mass (The concrete Centre 2007). 188
5.41 (a) – (b) Eco House temperature monitoring – results for the west facing wall taken both internally and externally. (Hanson & Farag PhD Research. 189
5.42 Prefabricated cavity wall with glazed windows and internal plastered finish. The panel includes built in electric wiring. 192
5.43 (a) - (b) External cavity wall connection – straps are used to tie internal leaves of the connecting panels. Wall ties connect the inner and outer leaves of each prefabricated panel. A compressible movement joint is used at the external brickwork junction. (Hanson Design Services 2007). 193
5.44 Foundation details for the QuickBuild™ system. (Hanson Design Services 2007). 193
5.45 Construction / fabrication details as prepared for a typical cavity wall showing location of wall ties, brick bonding pattern and bed joint reinforcement. (Hanson Design Services 2007). 194
5.47 (a) – (d) Architects plans and elevations (Penny Shankar, Architect (2010). 196
5.48 (a) Views of factory with panels under construction 199
5.48 (b) Blockwork inner leaf complete with brickwork under construction. Openings with concrete lintels shown 199
5.48 (c) – (d) Panel being removed with brick and blockwork the latter where the garage is positioned. 196
5.48 (e) - (f) Panel being removed from plinth on which it was constructed. The vertical recess in brickwork to accommodate the square rainwater downpipe can be seen at mid-point. 199
5.49 (a) Typical corner connection to accommodate rain water downpipe. 200
5.49 (b) Completed corner connection with down pipe. 200
5.50 The prefabricated panels were constructed, lifted and delivered to site 201
without any damage, weighing up to seven tonnes each and measuring up to nine metres in length.

5.51 Moving the panel on to site

5.52 Panels located with temporary propping shown

5.53 Panel located on brickwork above dpc.

5.45 DPC on top of blue engineering bricks.

5.55 Cavity wall arrangement and detail

5.56 Internal and external walls located and tied together across joint.

5.57 The speed of construction demonstrates how quickly and efficiently mass housing can be constructed in the future provided that a repetitious system build process is used rather than an individual design.

5.58 The completed project, an individually designed house constructed with prefabricated walls and pre cast floor systems and achieving Code For Sustainable Homes Level 6.

5.59 Single leaf brickwork panel constructed in factory environment.

5.60 Conventional in-situ cast reinforced concrete retaining.

5.61 Insitu cast reinforced concrete flood retaining wall.

5.62 (a) Conventional sheet piled flood defence wall with traditionally constructed masonry.

5.62 (b) Sheet piled flood defence wall with prefabricated masonry panels.

5.63 Typical cross section survey at river embankment. (Volker Stevin 2008)

5.64 Working drawings of plan and cross section through flood defence wall. (Volker Stevin 2008).

5.65 Typical prefabricated brickwork panel detail illustrating tie locations and bed joint reinforcement.

5.66 (a) Factory made panel being lifted by overhead crane

5.66 (b) Completed panel in setting out jig

5.67 (a) Part of timber stillage.

5.67 (b) General arrangement of storage frame with masonry panels in position and lifting frames for moving from factory to lorry.

5.68 (a) to (d) Lifting and handling of panels.

5.69 Sheet piling and concrete backfill in position.

5.70 (a) – (b) Steel sheet piling in position with a prefabricated single leaf wall located and concrete backfill poured.

5.71 (a) Temporary props supporting walls.

(b) Completed wall with stripped formwork props.
5.73 The completed flood defence Scheme. 227

Chapter 6

6.1 Veto- Vitz fabricated walling system. 231
6.2 Danilith wall construction detail. 231
6.3 Danilith wall panels during final production and storage stage. 231
6.4 Danilith completed house. 232
6.5 Robotic blockwork assembly as used in Verbo production process. 232
6.6 Number of housing starts 235
   (HBF - private, social and local authority) 2005 – 2014
6.7 Preliminary design scheme for robotic manufacturing system for single 240
   leaf and insulated cavity walls. View from masonry loading area and panel
   assembly setting machine
6.8 Bricks and blocks hand selected and placed on conveyor 241
6.9 Inspection platform overlooking wall assembly area and setting machine 242
6.10 Completed panels roll off assembly line and moved for storage 242
6.11 Robotic system showing flow process from brick and block feed through to 243
   wall panel assembly
6.12 Possible options for panel fabrication on a single 9m run 245
6.13 Panel support system during movement and storage 246

Chapter 7

7.1 Typical pre cast floor unit manufacturing process. 253
7.2 Basic timber mould for test panels. 255
7.3 MBrick Versaliner template in mould. 257
7.4 Composite panel - brick slip and concrete. 260
7.5 (a) Section through brick slip / concrete. 261
   (b) Completed composite brick slip panel. 261
7.6 Full bricks set in base of mould. 263
7.7 Completed sample with mould formwork stripped back 263
7.8 Panel having being removed from mould 263
7.9 Mould base with sand used to form joint seal 263
7.10 Completed panel. 264
7.11 Assembly procedure for a composite insulated cavity wall. 267
   (a) Mould with dry set bricks in position. 267
   (b) Formwork structure. 267

xviii
(c) Insulation with restraint wall ties. 267
(d) Completed panel.

7.12 Completed composite insulated masonry panel 268
(a) Panel after removal from formwork mould showing front elevation 268
(b) Rear elevation – concrete face. 268
(c) End elevation. 268
(d) Top of panel concrete infill distorted by pour mould sealing.

7.13 Prefabricated pier trials with self-compacting concrete 271
(a) Clay bricks in timber mould 271
(b) Steel reinforcement with spacers 271
(c) Slump test for scc 272
(d) Measurement of slump 272
(e) Pouring self-compacting concrete mix into a mould 272
(f) Pour completed and mix vibrated. 272

7.14 (a) – (d) Preparation of sample mould boxes, placement of full clay bricks 275
and pouring in mortar.

7.15 Completed panel demonstrating finished quality. 276

7.16 Brick properties. 281

7.17 Mould box with dry laid bricks positioned face down. 282

7.18 Drawing details of trial panel. 283

7.19 Panel showing partial placement of mortar. 284

7.20 Full bond of mortar and bricks in joints and perforations. 284

7.21 Mould box after removal of panel. 286

7.22 (a) – (d) Removal and lifting of panel from the mould box. 287

7.23 (a) – (b) Completed panel after removal from mould box and low pressure 287
cleaning.

7.24 Prefabricated corner detail and assembly sequence. 289

7.25 Prefabricated walls assembled to form a “box” or planter wall. 289

7.26 Highlights the very good mortar / brick bond as the mortar has filled a 289
perforations.

7.27 (a) to (b) Corner details formed by toothed brickwork. 290

7.28 (a) Full bricks set into mould box, face side down. 292
(b) Detailed view of dry set clay facing bricks in mould box 292
(c) Completed panel of bricks and mortar in mould box. Mortar residue 293
shown on rear surface.
(d) Rotational lifting of panel to remove from mould. 293
(e) Panel lifted clear of mould box using slings on overhead crane. 293
(f) Completed panel with finished face cleaned with low pressure water jet wash.

7.29 Figure 7.29 lifting and storage – panels lifted from 4 lift points and stacked flat, each panel resting on bearers. This system is acceptable for reinforced pre cast concrete but not advisable for masonry.

7.30 Rotational lift followed by vertical lift out of mould box.

7.31 (a) – (d) lifting the panels from horizontal to vertical using rotational purpose made lifting rings or slings for vertical lifting.

7.32 Halfen details of rotational lifting mechanism and the recommended reinforcement requirement for concrete.

7.33 Cone stress breakout for concrete (Halfen Fixings)

7.34 Diagram of direct tensile strength evaluation (Halfen Fixings).

7.35 Possible panel failure - 90° shear during rotational lift (Halfen Fixings)

7.36 Lifting ring detail

7.37 Full panel being lifted using a load tested lifting beam

7.38 Purpose made lifting jig for single leaf walls

7.39 Restraint downstands to top of lifting jig used to ensure panel verticality during lifting.

7.40 Lifting plate located in wall panel perpend

7.41 Panel being removed from timber stillage

7.42 Timber stillages at factory with panels in place.

7.43 Timber stillage - detail layout of frames and end box construction

7.44 Lifting arm / stillage support and temporary prop system

7.45 Wall panel being supported by 3 lifters which have been placed in a propping position.

7.46 Plan, front elevation and end elevation of lifter / prop system in place on a single leaf wall.

7.47 Lifting units used for wall storage – the vertical posts fit into a base member and are then locked in place at the top to contain a number of panels. The system can be of such a size that it may be transportable on a flatbed lorry.

Chapter 8

8.1 Metal prism moulds used to make mortar samples for testing. Dimensions 40 mm x 40 mm x 250mm.

8.2 Mortar tensile test

8.3 Wallette testing rig set up for panel tested parallel to bed joints
8.4 Extract from Table NA.6, BS EN 1996-1 Characteristic flexural strength of masonry $f_{xk1}$ and $f_{xk2}$

8.5 Hanson Arden Special Reserve facing brick used in testing. (Hanson 2009)

8.6 Plywood mould box with removable side members. A typical box is set up to provide 3 brick stacks.

8.7 Completed mould box with bricks for three sample stacks dry laid and ready to receive high water addition Omnicol mortar.

8.8 Bricks placed into mould stack boxes.

8.9 Reproduced from Table NA.6, BS EN 1996-1 Characteristic flexural strength of masonry $f_{xk1}$ and $f_{xk2}$
<table>
<thead>
<tr>
<th>Chapter 8</th>
<th>Section</th>
</tr>
</thead>
</table>
| 8.3 | (a) Flexural strength test results – varying water content / 3 day test 315  
(b) Compressive strength test result - varying water content / 3 day test 315 |
| 8.4 | (a) Plain masonry wallettes – load parallel to bed joints 323  
(b) Plain masonry wallettes – load perpendicular to bed joints 323 |
| 8.5 | (a) Wallettes with bed joint reinforcement – load parallel to bed joints 324  
(b) Wallettes with bed joint reinforcement – load perpendicular to bed joints 324 |
| 8.6 | Orthogonal ration for brickwork 326 |
| 8.7 | Flexural strength tests using conventional mortar 326 |
| 8.8 | Loads applied to brick stack beams 331 |
| 8.9 | Build times for stack beams. 332 |
| 8.10 | Stacks of 3 brick types and one mortar, Omnicol C – build times 333 |
| 8.11 | Stacks of 3 brick types and one mortar, Omnicol C – build times 334 |
| 8.12 | Ultimate failure load and flexural strength results for stack beams. 336 |
| 8.13 | Ultimate failure load and flexural strength for stack beams (varying water absorption) 338 |
| 8.14 | Flat cast brick stacks 344 |

**Index of Graphs**

<table>
<thead>
<tr>
<th>Chapter 8</th>
<th>Graph</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>Compressive strength of mortar types over 28 days 311</td>
</tr>
<tr>
<td>8.2</td>
<td>Flexural strength of mortar types over 28 days 311</td>
</tr>
<tr>
<td>8.3</td>
<td>Ankerplast (now known as Omnicol) and Celcon Celfix compressive strengths for mortar tested at 1, 3, 7, 14, 28 days. (Oxford Brooke PII, 2003) 313</td>
</tr>
</tbody>
</table>
| 8.4 | (a) water content / flexural strength measured for various water contents from 19% to 25% 315  
(b) water content / comp strength measured for various water contents from 19% to 25% 315 |
| 8.5 | (a) compressive strength vs age at testing for various water content 317  
(b) flexural strength vs age at testing for various water content 317 |
| 8.6 | Mean wallette flexural strength – unreinforced brickwork 323 |
| 8.7 | Mean wallette flexural strength with bed joint reinforcement 324 |
| 8.8 | Stack build times for various mortar types. 333 |
| 8.9 | Stack build times for 3 bricks types of water absorption categories >12%, between 12 and 7% and less <7%and 1 morta. Stack strengths at 3 and 7 days 334 |
| 8.10 | Sample failure loads 336 |
| 8.11 | Flexural strength of individual stacks 337 |
8.12 Comparison of mean and characteristic flexural strength for Measham stock brick and various mortar types
8.13 Stack beam mean flexural strength
8.14 Brick stack flexural and characteristic strengths
8.15 Mean flexural strength of flat cast brick stacks with different water contents
8.16 Mean flexural strength of hand made brick stacks with one mortar type and three different brick types.
8.17 Tensile flexural strength of flat cast and hand made stacks
8.18 Comparison of flexural strengths for flat cast brick stacks of varying water content and a hand made stack

Glossary / Abbreviations

ACD Accredited Construction Details
BDA Brick Development Association
BRE Building Research Establishment
CERAM Ceramic Research Ltd – now known as Lucideon.
CSH Code for Sustainable Homes
CPA Construction Products Association
DCLG Department for Communities and Local Government
DER Dwelling Emission Rate
DFEE Dwelling Fabric Energy Efficiency
dpc damp proof course
Dti Department of Trade and Industry (grant funding)
FEE Fabric Energy Efficiency
HBF Home Builders Federation
HCA Homes and Community Agency
HSR Housing Standards Review
KPI Key Performance Indicators
LBC London Brick Company
MHVR Mechanical heat and ventilation recovery
MMA Modern Masonry Alliance
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMC</td>
<td>Modern Methods of Construction</td>
<td></td>
</tr>
<tr>
<td>M4i</td>
<td>Movement For Innovation</td>
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</tr>
<tr>
<td>MBP</td>
<td>Mineral Producers Association</td>
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<tr>
<td>OBU</td>
<td>Oxford Brooke University</td>
<td></td>
</tr>
<tr>
<td>ODPM</td>
<td>Office of the Deputy Prime Minister</td>
<td></td>
</tr>
<tr>
<td>ONS</td>
<td>Office of National Statistics</td>
<td></td>
</tr>
<tr>
<td>PFA</td>
<td>Pulverised fuel ash</td>
<td></td>
</tr>
<tr>
<td>PII</td>
<td>Partners in Innovation</td>
<td></td>
</tr>
<tr>
<td>RIBA</td>
<td>Royal Institute of British Architects</td>
<td></td>
</tr>
<tr>
<td>SAP</td>
<td>Standard Assessment Procedure</td>
<td></td>
</tr>
<tr>
<td>SCI</td>
<td>Steel Construction Institute</td>
<td></td>
</tr>
<tr>
<td>SIPS</td>
<td>Structural Insulated Panel system</td>
<td></td>
</tr>
<tr>
<td>TRADA</td>
<td>Timber Research and Development Association</td>
<td></td>
</tr>
<tr>
<td>TER</td>
<td>Target Emission Rate</td>
<td></td>
</tr>
<tr>
<td>TFEE</td>
<td>Target Fabric Energy Efficiency</td>
<td></td>
</tr>
<tr>
<td>UWE</td>
<td>University of West of England</td>
<td></td>
</tr>
<tr>
<td>ZCH</td>
<td>Zero Carbon Hub</td>
<td></td>
</tr>
</tbody>
</table>

### Units and Symbols / description

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Psi) (psi)</td>
<td>Linear thermal transmittance</td>
<td>W/mK</td>
</tr>
<tr>
<td>(y)</td>
<td>Heat loss in non-repeating thermal bridging areas of building</td>
<td>W/m²K</td>
</tr>
<tr>
<td>(\rho)</td>
<td>Density</td>
<td>kg/m³</td>
</tr>
<tr>
<td>(F)</td>
<td>Frost rating to BS EN 771</td>
<td></td>
</tr>
<tr>
<td>(K)</td>
<td>Thermal conductivity</td>
<td>W/m.K</td>
</tr>
<tr>
<td>(N/mm²)</td>
<td>Stress (direct, tensile or compressive)</td>
<td>N/mm²</td>
</tr>
<tr>
<td>(\sigma)</td>
<td>Stress</td>
<td>N/mm²</td>
</tr>
<tr>
<td>(f_{x1})</td>
<td>Flexural strength of masonry in direction 1</td>
<td>N/mm²</td>
</tr>
<tr>
<td>(f_{x2})</td>
<td>Flexural strength of masonry in direction 2</td>
<td>N/mm²</td>
</tr>
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<td>(f_{xk})</td>
<td>Characteristic flexural strength</td>
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<td>Soluble salts rating to BS EN 771</td>
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<td>Heat loss</td>
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Chapter 1 Introduction

1.1 Introduction
This research considers the steady but continued decline in the use of clay brickwork over the past decades and addresses innovative design and construction processes which may provide a means to increasing the market share of masonry and work some way towards achieving the volumes or quantities of brick that were previously experienced.

1.2 Background
The quantity of clay bricks used in UK construction across all sectors has reduced from 8 billion standard bricks per annum to 4 billion some thirty years ago (ONS 2012), (CPA, 2012). At the start of the 21st century the figure was further reduced to 2 billion and then to approximately 1.5 billion bricks in the present day. Whilst brick volumes used are again increasing, the steady but continuous decline over the decades has not been due entirely to trends in the economy (including the very recent worst recession in living memory). It is due more to changes in architectural trends and style, perception about sustainability and the use of alternative cladding materials such as glass, timber, plastic and various new hybrid / composite materials.

This thesis addresses ways in which the market for masonry – and brickwork specifically – may be increased towards the levels previously enjoyed. Consideration is given to design processes, alternative construction and bricklaying techniques, prefabricated masonry techniques and specifically the development of a factory prefabrication method which is versatile, cost effective and efficient whilst producing traditional looking vernacular masonry. Masonry testing methods are considered and a simplified set of standard factory tests proposed which will ensure that the quality and structural performance of any prefabricated components will comply with the design requirements.

The unique appearance of masonry is brought about specifically because of the way in which it is constructed. In the case of clay brickwork, masonry comprises small units (clay bricks) which were originally developed to be of such dimensions and proportions as to be readily handled by holding in one hand whilst using the other to hold a trowel and apply mortar. This concept has remained unchanged for hundreds of years and although the dimensions vary, bricks are almost always of the proportions one : half : third in respect of length: breadth: height.
This is an ergonomically comfortable shape to hold and it enables easy dimensional coordination and setting out with a minimum amount of cutting at corners and openings. It also allows for a versatile masonry bonding configuration essential for structural integrity.

The method of constructing masonry has changed little relying as it does on a skilled craftsmen using a trowel to place mortar both on the horizontal line of bricks and on the ends of each brick to form vertical joints. It is a specialist skill and it is a craft which is an art form when the highest quality masonry is constructed. With the introduction of the cavity wall and the concrete block inner leaf becoming the standard external masonry wall, a further masonry process was introduced. However this still relies heavily on craft skill even though the blocks are twice the length and three times the height of a clay brick.

The early part of this thesis looks at the development and changes in cavity wall construction due to the availability of new building materials and also changes in legislation. The introduction and potential development of thin joint adhesive masonry systems in the UK after their success in continental Europe is then considered. The procedure relies upon use of a pump and gun process rather than just a trowel trade. A series of tests and the production of a design and construction specification were developed as part of a “Partners in Innovation” (Oxford Brooke, 2004) project and this was followed by a series of live projects providing case studies from which the in-situ thin joint construction process was evaluated (Chapter 3 of this thesis).

Further alternative developments with the thin joint system were addressed and these looked specifically towards a number of prefabrication techniques. Prefabricated or pre built panels of masonry were developed as a means of removing traditional techniques of brick laying which some deem to be a relatively slow and costly process, prone to human error and giving inconsistency in quality and appearance. It is seen as a trade or craft and from time to time it is looked upon as a construction technique which might be best replaced by off site building systems.

Prefabrication enables high volume output and consistent quality at what ought to be a competitive cost. In reality various forms of prefabricated masonry panels have been developed in many parts of the World but have not yet achieved the criteria required to bring about widespread mass production at a competitive cost. The result is that these systems have not progressed. Nor has widespread acceptance of such methods been achieved. The work carried out towards this thesis has shown on numerous occasions that
a variety of prefabricated masonry systems, whilst achieving many of the design requirements, still fall short when compared with the site construction methods.

Panel types vary and those which have been used with success incorporate bricks of very consistent dimensions and regularity in shape such as engineering type clay units. However, the true appeal of brickwork is often the irregularity in shape and the uniqueness of each unit which gives a traditional vernacular appearance and hand crafted finish. This aesthetic quality can be achieved in both small and in expansive areas of walling.

It is this uniqueness which if achieved by prefabrication processes would raise interest levels and draw from a much wider client base. Many systems are of composite construction ie a reinforced concrete sub structure with half bricks cast into the concrete. It is this which gives a relatively slow and costly process.

Traditional masonry may be deemed by some to be old hat, but when we consider its benefits it is a formidable process to compete with. Three thousand years of the same construction technique can’t be wrong!

1.3 Objectives
The objective of this thesis is to develop an efficient and economical system or process of automated masonry construction. This requires knowledge of several aspects of masonry manufacture and the key objectives of the thesis are outlined below. The following areas have been addressed:-

- Review masonry material, structures and techniques for construction
- The development of high performance mortars for in-situ masonry construction
- Management and development of case studies for in-situ construction using high performance mortars
- A review of wall prefabrication techniques and development of prefabricated masonry processes
- Direct development of case studies of prefabricated masonry structures using high performance mortars
- The development of a simplified manufacturing method of prefabricated masonry panel construction
- Masonry testing and a simplified factory based testing programme.
- Conclusions and future research proposals
At the start of this work it was thought that a new on-site process of bricklaying may provide a suitable alternative to trowel techniques. A number of live projects were constructed using this system and were thought to be a success (some becoming award winning buildings), but never-the-less there were too many issues which provided the contractors with concerns about reliability, acceptability of the techniques, vulnerability to weather conditions and overall cost.

The way forward became apparent at an early stage in development and that involved prefabrication and a full design, supply and installation package taking liability from the contractor and putting it into the hands of the masonry fabrication specialists.

This suggestion was not so radical, as many other major construction systems and components are supplied as a full package e.g. steel frames, foundations, timber frames, cladding panels, to name but a few.

Developing the prefabricated processes, the masonry package and identifying the right market for it proved to be the main objective.

The key areas of research and development work prepared for and documented within this thesis are as outlined below:-

- Adaptation of the in-situ European thin joint masonry process for use in UK construction
- Development of manually prefabricated single leaf and insulated cavity walls
- The development of a flat bed cast masonry process
- The development of a simplified testing process which evaluates the structural properties of both manually factory made and flat bed cast masonry

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Chapter 2 – Literature review

2.1 Introduction

This chapter considers the historical background to masonry and the development of modern wall construction. It highlights the material and design parameters which are in turn influenced by continuing changes in construction legislation with respect to structural design, sustainability and the wall performance in terms of resistance to sound and robust details, thermal insulation and thermal bridging at wall / floor intersections.

Throughout the history of wall development there have never been so many ongoing legislative changes relating to the building performance as has occurred in the last 20 years. Targets for meeting certain design and performance criteria were scheduled to improve building performance which would be ongoing over a number of years and during that time revisions to those targets have been implemented when the original demands were subsequently deemed to be too ambitious or uneconomical to achieve.

These drivers for legislative change provided the opportunity to consider new or improved masonry wall solutions initially as alternative on site processes and then as prefabrication methods. Building legislation ensured that the construction industry would take notice of alternative building processes.

These changes were set against a background of steady but continuous decline in the sales of masonry products, specifically clay bricks.

2.2 History of masonry – general background

The term masonry refers to natural stone, clay brick and various forms of concrete block, aircrete block and calcium silicate bricks – joined together with mortar, a material composing of lime and / or cement and an aggregate, typically sand, which bonds masonry units together but also separates them or keeps a distance between them accommodating any dimensional discrepancies that will inevitably exist particularly in the firing of naturally occurring material such as clay.

Bricks are one of the oldest known building materials dating back to 7000 BC where they were first found in southern Turkey and around Jericho. The first bricks were sun dried mud bricks which was a feasible building material in hot climates with low rainfall. Fired bricks were found to be more resistant to harsher weather conditions, which made them...
much more reliable for use in permanent buildings, where mud bricks would not have been sufficient. Fired bricks were also useful for absorbing any heat generated throughout the day, then releasing it at night. (www.brickdirectory.co.uk)

The Babylonians and then the Romans developed the technique of firing clay, subjecting units to temperatures which would transform the body structure from dried material through an irreversible transformation into a vitrified “glassy” material. Dried clay has almost all moisture removed whilst fired units have moisture driven off accompanied by an irreversible transformation or vitrification of the body structure resulting in clay fired bricks.

In the UK the popularity of the material can be traced to the revival of brick making in eastern England in the late 13th and early 14th centuries. This was a direct result of lack of local stone, an increasing shortage of good timber, and the influence of Europe where brick work was used extensively. By the Tudor period the brick makers and brick layers had emerged as separate craftsmen well able to rival the masons. From unsophisticated early work, brick building entered its heyday, rivalling stone in its popularity as a structural material. (www.brickdirectory.co.uk)

Bricks were generally made on site in wood, heather or turf fired clamps by itinerant workers. Not only were standard bricks produced but also many in extravagant and elaborate shapes, epitomised by those that formed the spiral twisted chimney stacks for which the period is renowned. The Tudors further patterned their brickwork by inserting headers over burnt or vitrified bricks into the walling. These dark surfaces ranging from deep purple to slate in colour, were laid carefully in quarter brick offsets in mainly English Bond or English Cross-Bond, to form a diaper or chequered pattern within the predominantly red brick work (Lynch 1993)

All masonry was first used in massive, thick external leaves – best illustrated in the stately homes and castles which are still abundant today. The outer wall of these structures would be typically 300 – 500 mm of solid brick or stone bonded with lime mortar in what were relatively thin joints being no greater than 5mm. Design generally followed a rule of thumb approach.

The late 17th and early 18th centuries (the Georgian Period 1714-1830) were a high point in the use of brick. Their manufacture was much improved, with blended clay, better moulding and even more firing which lead to greater consistency in shape and size. The colours of bricks changed in popularity from red, purple or grey bricks fashionable in the
late 17th century until 1730, when brownish or pinkish grey stocks replaced the hot colours. These were followed in the mid-18th century by grey stocks, and by 1800, the production of yellow marl or London stocks, which were closer to the stone colour desired for a classical facade. Brickwork was generally of a very high standard, in mainly Flemish bond although header bond was also popular in the early 18th century. (Lynch 1993).

Victorian brickwork saw a period of revivalism in domestic architecture and industrial building. The former seeking a return to "medievalism" and other exotic building forms as a relief from the unspirituality of the machine age. The latter, for the infrastructure of factories, warehouses, railway bridges and so on all largely met through the cheap use of bricks. During this period, a greater number of bricks were made and laid than during all the previous periods. Brick manufacturing methods had improved in all respects including quality, accuracy, regularity and in range of colours available. From the mid-18th century onwards the manufacturing process, like many others, was becoming mechanised. This enabled deeper clays to be used for pressing into dense bricks for use on civil engineering works. And with improvements in travel and communications, bricks could be transported over wide areas which removed the traditional local variations. (Lynch 1993)

Georgian and Victorian houses still provide a significant percentage of UK housing stock. These are typically constructed with 215mm (9") solid brickwork and lime mortar. The use of lime mortars provides masonry which is flexible and seldom experiences any cracking due to material expansion / contraction as the lime mortar used was more flexible rather than hard brittle material as are todays cement rich mortars. (Holmes et al, 1990). (Lynch 1993). Masonry provided a major structural element of the building, taking the load from floors and roof down to foundations which were also commonly constructed in stepped brickwork. Most Victorian houses had cellars (basements) for storing coal or timber for fuel – the prime source of heating for the fires built in almost every room. Add to this the boundary walls to such properties, the clay engineering brick pavements and the very extensive brickwork used in canal and railway engineering structures and it is not difficult to see why brick usage (always measured in numbers of bricks) was in excess of 10 billion per annum during the Industrial Revolution and the Victorian era. (Lynch 1993)

2.2.1 The development of structural masonry
There are several ways in which masonry is exploited for its structural properties. Some of these techniques have been periodically fashionable. However with the introduction of other materials structural masonry has never been extensively used as a modern structural material, but one which is the exception rather than the norm.
2.3 Masonry materials

2.3.1 Clay bricks – natural materials, manufacturing processes and their influence on good design, specification and construction

There are some key issues relating to clay product design and construction which are not applicable to concrete blocks of either aggregate or aircrete types. In the case of blockwork the products have a clearly defined performance specification relating to structural, thermal, acoustic and fire resistance parameters. The block specification in accordance with the appropriate European standard (BS EN 771, 2003) will be relevant regardless of the location of manufacture. This being the case the place of product manufacture and material storage for distribution becomes critical in terms of transportation costs as all other parameters will be satisfied.

Although all clay facing bricks are made out of clay it is an extremely varied material. A geological map of the United Kingdom (Figure 2.1) shows the range and diversity of rock / material / clay types. (Butterley Brick 1980). The geological sequence is such that exposed strata become younger as we move from the North West of the British Isles down to the South East. Broadly speaking geologically older materials display superior structural properties and produce fired clay bricks of greater durability. The clay properties are simply defined by their mineralogical structure.

Making hard durable clay bricks relies on the following fundamental process. (Ibstock technical literature 2012):
Winning the clay: quarrying from relevant clay strata in a manner which ensures no pollution to the natural material from non-clay material. Harmful impurities which affect the body of the clay include lime and highly compressive particles of rock.

Raw material is filtered (screened) and ground between rollers to remove lime type particles. A suitable volume of water is then added to the prepared material which is then passed through a machine to produce the brick shape. This is done in different ways:

1) Extrusion
2) Pressed, semi dry pressed
3) Slop mud moulded
4) Hand made.

Extrusion is probably the most common process and it entails forcing a rectangular column of wet clay through a die to give a continuous length of material which is 215mm wide x 102mm high ie the plan area of a brick, as laid. In actual fact this column of clay is larger than the 215 x 102mm finished dimensions as an allowance has to be made for the shrinkage which takes place during the drying and firing process. A kiln is a furnace oven or heated enclosure used for burning or firing brick or other clay material. Brick kilns can be classified into four categories, on the basis of how they are operated (Butterley Brick 1980):

1. Intermittent or periodic kilns that consist of a single firing chamber. The intermittent kilns are loaded with green bricks, which are fired and allowed to cool before unloading, in preparation of the next loading and firing. This type of kiln is capable of firing only one loading of bricks at a time.

2. Semi-continuous kilns where two or more intermittent kilns are inter-connected by flues and dampers to allow the heat from the cooling bricks in one kiln to dry and pre-heat the bricks in another. The kilns are alternated being unloaded once the heat from the cooling bricks has been used to dry and pre-heat the bricks in the second kiln that is then fired up to top temperature.

3. Continuous kilns where the firing zone moves through the bricks in the kiln without stopping. Green bricks are loaded in front on the firing zone and fired bricks removed behind it. These kilns run day and night, with the fire never going out, except for seasonal or maintenance stoppages.
4. Tunnel Kilns in which the bricks are placed on trollies and move through the hottest part of the kiln at a predetermined rate. This is a form of continuous kiln, but with stationary rather than moving firing zone.

During the extrusion process a number of perforations are forced into the clay column by locating metal rods within the extrusion. The perforations may be from 3 large holes, say 30mm diameter to 10 or 14 smaller holes. The perforations ensure that the full body of the brick will be dried and then fired evenly. Failure to achieve even or uniform drying and firing will lead to cracks forming in the clay. The bricks are finally formed by a series of thin metal wires positioned at uniform spacing along the column, cutting through and giving the final brick shape.

Pressed and semi pressed. In this method of manufacture wet clay is formed into the brick shape by pressing into a mould box. (Jones T 1996)

Brick properties are dictated by the raw material properties and this is true not only of the physical aspects but also the aesthetics in terms of colour, texture and shape. In general all clay bricks are generally aesthetically pleasing and durable.

Bricks which were historically defined as “engineering bricks” (BS3921 1974) tend to be made from clays found in the North West midlands up to the North West (Figure 2.1) of the UK. These are usually carbonaceous shales in areas once rich in coal. They are extruded, uniform, and rectangular in shape, (figure 2.2) of high strength (>70 N/mm²) and low water absorption (<7%). They have perforations in them (at least 3 large holes as a minimum up to 14 small holes), the format depending on the most suitable firing process for the clay type.) Inspection of the newly formed unfired and undried brick of this type will show a unit that is very hard and dense. These bricks when extruded and handled are very difficult to compress.

It is interesting to note that certain brickworks were created by the owners of coal mines, particularly in the North Midlands and South Yorkshire. Geologically the clay in these areas is found as an overlying strata to coal. The mining companies would quarry the clay
which was first perceived as an unwanted by-product but eventually used to make clay brick in locally created brickworks. The bricks were initially used as building material for the mines i.e. the offices, factory buildings and the shaft linings. It was only a secondary consideration where the bricks were sold commercially in addition to the lucrative mining industry. (Christiansen 1990)

Bricks made of clay from the south east of the British Isles i.e. Weald, Gault, and Sussex clays are manufactured by a different process, usually machine thrown or pressed which gives a very wet bodied unit. When wet i.e. prior to drying and firing they are of a very soft consistency. They are typically referred to as “stock” bricks and they appear to be of a heavily creased surface texture of slightly irregular shape similar to that achieved by a more traditional handmade or hand thrown brick. (Figure 2.3). Stock bricks are considered to have a relatively low compressive strength (15 N/mm²) and high water absorption (between 12% and 20%)

![Figure 2.3 Soft mud facing bricks](image)

Whilst all high strength bricks are resistant to the action of weathering i.e. prolonged saturation and cyclic freeze / thaw, the softer bricks may or may not be as frost resistant depending on the natural material and the pore structure of the finished units. Some open pored textured stock bricks have excellent resistance to frost as they readily let water escape when saturated without freezing which would force part of the brick face to be removed. (Ibstock, 2013).

Within the Midlands area there are a mixture of clays including Etruria Marl – which gives high strength durable bricks, Keuper Marl – which may be classed as having intermediate properties and the coal measure shale products which vary depending on the production process.

Although clay is a natural material there are often other minerals added to try and change the properties including colour and durability. Shale will improve strength and manganese will create darker bricks. Certain stock bricks such as those manufactured by the Milton Hall Brick Company at Star Lane and Cherry Orchard works near Rochford were made from clay which was taken from just below the top soil of agricultural flat land of Essex
close to the sea and the Thames Estuary (Lynch 1993). The resulting products are known by such names as “First Hards” and “Second Hards” (Milton Hall 1985) and were typically red or yellow. Each colour type came out of the same kiln but the colour and colour variation was a result of where in the kiln the bricks were positioned. These kilns were built in the open, and exposed to the elements. Each Kiln was loaded with bricks (that had first been dried in dryers) until there was no space inside. This was done purely by physical manual labour in all weathers. Once full, the kiln “door” was built up out of bricks and sealed with a plaster type render. The kiln was lit and it remained in a state of firing the bricks for several days at the end of which the door was dismantled and the bricks removed and sorted into their respective brand types. This process relied on the skill of the labourers who by eye selected pure yellows, yellows with a dark purple flash or a deeper orangey yellow with much colour variation. These types became the First Hards, Second Hards, Georgian and Multi. (Milton Hall, 1985) The durability of the product and the consistency of colour was reflected in the cost of the end product. It was not unusual to see men removing bricks from a kiln where the temperatures exceeded 40°C while outside of the kiln snow or driving rain was accompanied by temperatures below zero. This type of operation could still be witnessed in the 1990's

Two other clay types are used which have a certain individuality. Firstly the fireclay material which provides a white or cream coloured brick of good strength and durability. However this material may be prone to higher than average expansion properties that will be manifested in completed brickwork as vertical hairline cracks. Fireclay is also mixed with other clay types in order to attain the benefit of several material properties.

The other unique clay type is Lower Oxford Clay, LBC Fletton, (Figure 2.4). It is unique because it contains fossil fuels so that after initial heating takes place in the kiln, the bricks will self-ignite making them economical to produce. The Lower Oxford Clay has for over 100 years been used to produce significant volumes of bricks. (Hillier 1981)

With experience it is easy to recognise what type of clay comes from a specific area by looking at the older local buildings. Almost every town or district would have had its own
local brickyard because all parts of the UK generally have a clay material which is suitable for making bricks. Also the transportation infrastructure was such that it was not practical, nor even desirable, to transport heavy goods over long distances. Hence bricks were used “locally” usually being moved by horse and cart, and later on by canal barge. Only since the middle of the last century have bricks been transported over a more widespread area.

Over the past forty years many of the thousands of small local brickworks began to be bought out, closed down and generally absorbed into the rapidly growing conglomerates of today. With national companies emerging from this cottage industry the commercial strategy was to sell a diversity of bricks from all parts of the country into areas where they had never been seen before (BDA 1985).

Whilst this commercial approach helped to revive interest in brick’s aesthetic qualities and to introduce new product types to different areas it also increased the need to improve familiarity with what to many local bricklayers was a totally different product.

Historically bricks would be used for projects which were geographically close to their source of manufacture. Consequently the builder and the architect would be familiar with their properties and characteristics.

Not only were bricks distributed nationwide. In a modern building project the whole construction team may come from all over the country (Figure 2.5). As such this means that not everyone will be familiar with the products and this necessitates manufacturers making sure that they provide information relating to engineering properties, aesthetics and bricklaying techniques as early as is possible to avoid any future disputes.

That being said, because of sustainability issues, there is a trend to consider materials that are manufactured locally again. (BRE Global 2008), (Anderson et el 2014), (BES 6001 2014).

Most masons will have worked with blue or red engineering bricks for specific parts of a masonry construction such as work below ground or up to dpc level. However bricklayers
from the Midlands, or the north of England, had often never seen a "stock" brick which far from being of crisp regular appearance was soft, crumbly and most irregular of shape. Architects too had often become used to certain brick types but were not aware of the varied properties of new and unfamiliar products. It was not unusual even into the 1980’s for a designer to demand a brick which had the soft texture typical of a Kent Weald Clay but with the sharp edged precise dimensions of a Staffordshire Blue. (Butterley Brick 1985)

This issue served to underline the uniqueness of clay brick - a general term for a very varied group of products - and made significant demands on brick manufacturer’s technical staff as the trades and professions needed to rapidly learn the differences in the brick types.

Architects needed to be convinced about the durability aspects – soft bricks can still be durable and frost resistant since water escapes from the open pored structure as easily as it is absorbed into it thereby not blowing the face off the unit as can happen with some bricks when expanding water cannot escape (BDA, 1987).

Clerks of Works often raised the greatest controversy over the dimensional tolerances of bricks – stock bricks have a very varied range of sizes whereas dense engineering bricks are more consistent. Brick size variation is governed by appearance and it is more important that units have a material consistency and that dimensional irregularities are in the mortar. Dimensional variations are only critical when certain building setting out details such as piers are necessary. However it is the writer’s experience that a good bricklayer will build good brickwork even with inferior bricks. A bad bricklayer will not build good brickwork even with first class products.

Consider the quality of Victorian masonry which exploits the idea of brick laying as a craft, or an art. Examples of such fine work are to be found in every town and village. It is not only the likes of St Pancras station or the Natural History museum that show off such excellence. Many of the Victorian terraced dwellings also display superb workmanship in both the general brickwork and in the detailing incorporating special shaped bricks (Lynch 1993, BS 4729 1985) with chamfered, mitred and “bull nose” edged units. Traditional brick arches are a fine example of this level of craftsmanship.(Ibstock 2013, BDA 1985)

Whilst mentioning bricklayers and referring again to the issue of brick types, one of the learning processes that has to be put across is bricklaying in respect of mortar types and their water content. Dense solid heavy engineering units will have a tendency to float if
layed on a bed of mortar which is too wet or workable. Not only is there a problem in getting adhesion between brick and mortar, but it also becomes difficult to lay too many courses in the same working period as the lower courses will start to compress forcing mortar out of the joints. Conversely bricks of a high absorption will soak water out of a mortar mix which therefore needs to be wet enough to accommodate this high initial rate of absorption or suction rate. (Hanson 1992, Hanson 2007)

When comparing brick types with regards to the problem of masonry expansion / contraction there is a common misconception that high strength bricks, being strong, won’t expand much whereas stock bricks will. (BDA 1987, CP121 1970, BS 5628 1985). This is incorrect as stock bricks tend to have a very low global expansion rate whilst red engineering clays have a much greater propensity to cause cracking in finished masonry. Clay bricks always experience long term expansion, never shrinkage, which is a characteristic of cement based materials such as concrete or concrete blocks. Cracking in clay brick walls is usually due to a lack of understanding of the expansion properties of the materials.

In this project consideration is given to a modern and innovative method of building masonry. When considering using clay bricks and brickwork with this more innovative building process where thin joint adhesive mortar is applied by pump and gun, or prefabricated masonry with high performance glue mortar, the first step was to ensure a compatibility of clay product types with the thin joint adhesive mortars. This is examined in more detail in Chapter 3, thin joint masonry.

2.3.2 Aggregate Blocks
Aggregate blocks were developed over 100 years ago. They comprise cement and aggregate. The aggregate types vary but will, along with the mix proportion of cement determine the physical properties of the unit including density, compressive strength and flexural strength. The different types available relate directly to performance requirements ie strength, durability, sound, thermal performance and fire resistance. Background blocks (Hanson 2007) manufactured to BS EN 771-3 from crushed rock or gravel aggregates to BS EN 12620 and Portland cement are dense aggregate blocks which can be used in virtually any part of a building above or below ground, in normal conditions. Their performance makes them especially applicable to partition and separating walls where good sound insulating qualities and high strengths are required. (Hanson 2009)
Some blocks are especially suitable for rendering and plastering, as they have a relatively low suction background. They can be either smooth or rough in texture, depending upon the manufacturing location. As such, the correct specification for the applied finishes should be provided. In the case of dense sand / cement plasters applied to smooth blocks, it is recommended that, in addition to raking out of the joints, an adhesive slurry, spattered ash or stipple coat is applied to the block surface prior to the application of the first undercoat. The high strengths and close internal texture of background blocks mean that excellent fixing can be achieved using a variety of patent fixings. Background blocks are not intended to be left fair faced or painted.

Aggregate blocks come with a variety of performance specifications to cover required loading conditions, thermal performance and when used below ground in resistance to sulphates and aggressive salts. Block finishes vary and can accommodate a plastered finish, paint finish or be left fair faced.

Mean compressive strengths range from 2.8 N/mm² up to 30.0 N/mm²
 Thermal conductivity - 1.32 W/m.K internal, 1.42 W/m.K external
 Dry density: from 1000 kg/m³ to over 2000 kg/m³

All aggregate blocks are used in UK construction with conventional cement / sand mortars laid by traditional trowel techniques. They have not been considered for thin joint construction or for prefabricated masonry and the reasons for this relate to the block surface textured finishes, the dimensional accuracy and lack of design and technical information relating to performance as well as construction and buildability. However research has been carried out by Hanson Kirton Laboratory in conjunction with Kingston University (Fried 2006) and also by (Kanyeto 2006). This thesis investigates further both thin joint mortar techniques with aggregate blockwork and prefabricated aggregate blockwork panel construction processes. Refer this thesis, chapter 5

2.3.3 Aircrere Blocks
Aircrere (Autoclaved Aerated Concrete) was developed in Sweden in 1924 as an alternative to building timber framed structures and first used in the UK in the late 1950’s. Currently over 30 million cubic metres of Aircrere (of different densities) is produced annually worldwide of which 3 million cubic metres are produced in the UK – and this represents a third of all concrete blocks used in the UK construction / building industry.

Aircrere consists of 60 - 85% of air by volume (70-85% for low density Aircrere). The solid material is a crystalline binder called Tobermorite, which is a combination of Lime and
Silica but quartz and small quantities of other minerals also exist. Tobermorite is formed of silicium dioxide, calcium oxide and H$_2$O and this provides the relatively high compressive strength and stability of Aircrete in spite of the high proportion of pores and lack of coarse aggregate in this construction material. The raw materials used to make Aircrete are lime, sand (quartz), and water. Often cement or anhydrites are also used and sometimes, fly ash and ground blast furnace slag are used as an alternative to quartz.  (Van Boggeleln 2014)

A simple but precise description of aircrete and the manufacturing process is given by the Concrete Society and quoted as follows. “Aircrete blocks are produced by the mixing of Fly ash, also known as pulverised fuel ash (pfa), and/or finely ground sand with cement and/or lime slurry into which a small quantity of aluminium powder is added. The slurry is discharged to partly fill large steel moulds where a reaction between the aluminium powder and alkaline environment in the mix takes place to generate tiny bubbles that stabilise to form the Aircrete cellular structure. The slurry rises and sets to form a firm but relatively soft ‘cake’, which is then cut into the desired rectangular solid block size by tensioned wires on cutting frames. Curing takes place in autoclaves under steam and pressure before the blocks are removed, packaged and ready for use.”

Thin joint or thin layer mortar combined with aircrete blocks provides an innovative building system that improves thermal performance and air tightness when compared to conventional blockwork which uses 10mm mortar joints. The thin joint aircrete process also reduces site waste and the build process which makes use of a scoop rather than a trowel will increase build times and productivity on site. Some manufacturers also produce large format aircrete blocks, up to twice the size of a standard format block, which further enhance build times due to m$^2$ greater coverage. The thin layer mortar is a pre-mixed cement based product, which requires water to be added to produce easily applied mortar. As a replacement to traditional sand/cement mortar, it allows the depth of the mortar to be reduced from the conventional 10mm to 3mm or less. In order for the thin joint aircrete system to work efficiently it is necessary to have dimensionally accurate blocks i.e. square and to a close enough dimensional tolerance that application of the thin layer mortar provides a consistent and even joint.

The thin joint aircrete system has been trialled by Hanson Thermalite (formerly Marley Thermalite) for the production of prefabricated wall panels which were used to construct a building of domestic dimensions. The panels were produced at the Hams Hall Thermalite factory (Hanson Thermalite 2012) and transported within the site and erected. The
procedure was fully documented and times for production, transport, handling and erection carefully recorded in an attempt to prove that such a technique would be economically viable and worthy of commercial development. However circumstances and a reluctance to invest in system development prevented further progress.

To date the in-situ thin joint technique is a recognised Modern Method of Construction and the process is used on UK construction sites. It must be said here that in spite of the obvious benefits of speed, quality and performance, the market share for thin joint aircrete systems has not exceeded 3% nationally and this uptake has been with singular contractors who have elected to use the system.

Following on from the initial work by Thermalite, Hanson Building Products carried out further tests in conjunction with Surrey University (Ali, 2009) and with their own prefabrication development of single leaf and cavity wall inner leaf.

2.3.4 Stone.
Nothing is done to natural stone as a material to change its properties or condition for use. It is quarried and then “dressed” i.e. cut and shaped to the desired format and size ready for construction in vernacular form there being little difference in the construction techniques over the centuries.

There are many stone types available for construction. Broader groups / types of significant stone include granite, sandstone, limestone and marble which can be found extensively all over the world.

Characteristics of stone types will be affected by the geological formation. For example marble is a dolomitised limestone i.e. limestone which has been subjected to very high geological pressures such that its properties are changed – usually increased strength.

Many areas such as national parks or cities still have legislative planning requirements enforcing the use of local stone in order to ensure consistency in an architectural style and material where that material has been prevalent over many hundreds of years e.g. Bath, York, Edinburgh.

Properties of stone vary not only from rock type to rock type but even within the same group name. This is particularly true of sandstone which displays aesthetic and weathering qualities that are very diverse from area to area.
It is this diversity in properties which makes evaluation of structural properties difficult to predict and means that under modern legislation each individual stone type may require structural testing to evaluate its fitness for purpose. This is particularly the case when considering natural stone for true prefabricated panels of the sort developed by Hanson rather than composite stone / concrete masonry

However it is more likely that stone will be used on the basis of historic experience and reliance is often quite rightly placed on local knowledge of a material which will have been used in the vicinity of its extraction over a very long period for example Stancliffe Stone.

2.4 The evolution and development of the cavity wall in UK construction

Between the wars wall technology started to change and the solid 9” leaf was replaced by two single leaves comprising of 100mm (4”) units, invariably clay brick with a 25mm (1”) air gap in between. This provided a relatively simple but improved external barrier to the elements, particularly the dampness which was often the cause of chronic illness and disease. The complete wall of this construction format still acted as a structural wall. (English Heritage)

With early cavity construction the two leaves of walling were often tied together with bricks bonded into both leaves of the wall. These early cavity walls may not be easy to recognise by the brick bond alone as the ends of the brick ties cannot be easily distinguished from face-work. ‘Headers’ visible on the elevation may either be specials tying the two leaves together or ‘snapped headers’ put in to imitate solid construction. Measurement of the wall thickness together with a careful assessment of the construction needs to be carried out to ensure the wall has a continuous cavity. (English Heritage Energy Efficiency and Historic buildings) – (Cavity walls 2012)

Eventually the cavity was increased being typically 50mm (2") of air space with a facing quality brick on the outside and a “common” brick on the inside.

The cavity wall can best be described as consisting of two masonry leaves tied together but separated by a continuous airspace. The outer leaf acts as a ‘protective skin’ against the elements, principally driving rain. It works in conjunction with the inner leaf which serves as a dry construction to carry the interior finishes. The two leaves need to be tied
together for structural stability and to help carry the loads imposed on them by upper floors and the roof.

The use of cavity wall construction became increasingly common particularly for the house building boom of the inter-war years where developers saw its economic advantages over solid wall construction. Around 80% of the existing housing in the UK is now estimated to be of cavity wall construction. (English Heritage 2012)

Early cavity walls used facing bricks throughout but this scenario progressed to the use of facing quality bricks on the outer leaf and a “common” brick on the inside. The common bricks (known typically as “commons”) used for the inner leaf possessed all the necessary engineering or physical properties required of an internal leaf but did not have such a high quality finish aesthetically and sometimes dimensionally. Although initially all bricks were sourced locally for any construction, internal leaves of cavity walls and also internal walls within the building were often built using bricks of Lower Oxford Clay, better known as Fletton clay, named after the village near Peterborough from which a small brickworks developed. As mentioned earlier, this clay unlike all other clay types was unique. At a certain temperature in the firing process the raw material which contained fossil fuels would self-ignite due to the oil within its composition. Such a benefit meant that Fletton bricks could be manufactured at considerably less cost than all other clay bricks. Lower Oxford clay and the Fletton were soon to become synonymous with The London Brick Company which in its heyday was the biggest brick maker in the World. At peak times in British building construction, notably after the First and Second World Wars production of bricks was at its highest since the Industrial Revolution and at a number of the many London Brick brickworks it was not unusual to have 8 million bricks despatched from a single factory every day. (Hillier 1981)

Cement based building blocks were not widely used until the 1900’s and the clay brick formed the most abundant building material in all parts of the developed world until only several decades ago when wall performance requirements were changed. Facing bricks were used in abundance and Fletton commons even more so for both inner leaves of cavity walls and for internal wall construction.

Technological developments often evolve slowly in the construction industry and it is not unusual for new and innovative products to take several years to become accepted by the construction team who are understandably risk averse and very conscious of relative costs when comparing a new idea with an established and reliable building process.
But from time to time a significant technological leap forward happens and an idea may be widely and unanimously accepted almost overnight. This was the case with the concrete block or “breeze block”. Early developments of this product date back to the early 1900’s. This comprises a low cement content unit (cement : aggregate mix of approximately 1 : 15) using a lightweight aggregate. Units were made of such dimensions that the face size and weight was equivalent to six clay bricks. Once it was recognised for its benefits including cost and speed of construction, it’s use for the inner leaf of the the cavity was such that it rapidly replaced clay brick as the inner leaf of a cavity wall and the internal walling material.

As a result the UK brick market went from around 8 billion per annum down to 4 billion per annum in the late 1900’s and it seems unlikely to recover to those original production levels again. (Home Builders Federation, 2014), (Construction Products Association, 2014). Clay bricks are marketed on their aesthetic qualities, durability and low maintenance. The structural benefits of clay brickwork are seldom exploited in conventional modern day construction although there are numerous structural brickwork solutions that have consistently displayed the benefits of the technique both in terms of a solution and economy such as fin and diaphragm walls (Curtin et al 2008) and off the frame masonry cladding such as Winterton House (Bird1994).

Modern concrete aggregate blocks described in section 2.4 of this chapter are also used in masonry housebuilding. Fundamentally their composition is of cement and aggregate. Their performance depends on both the cement content and the type of aggregate. Basic blocks are manufactured for internal use and it is their low cost and relatively rapid construction which provided the obvious benefits. Additionally and more recently, strength, sound resistance and thermal performance have become important design criteria.

Interestingly in the past few decades as thermal insulation has become a critical design parameter, all masonry types have only a minimal contribution to a walls thermal performance. This is achieved using such products as Styrofoam, phenolic foam, mineral wool, polystyrene – the insulation material contributing in excess of 85% of the external wall's U value. (Celcon Block 2012), (Hanson Thermalite 2013)

Block specification is therefore usually assessed on compressive strength. Aesthetically it is also possible to get exterior quality blocks – of increased frost resistance, and also paint grade which allows for a painted or rendered finish (Hanson, 2007) but as a general rule blocks are specified for technical performance.
This leads to a second market change and construction development resulting from the introduction of the aircrête block (previously described). Again it is the blocks performance criteria which is critical but the distinct advantage over aggregate blocks is in their lower density and unit weight which makes laying and handling even easier. This allows increased laying output. (Celcon Block 2013), (Hanson Thermalite), (W. van Boggelen 2014)

Typical densities and conductivity values for aircrête and aggregate blocks are as follows:- (Hanson 2015). Typically the lower the density, the lower the thermal conductivity.

<table>
<thead>
<tr>
<th>Aircrête blocks</th>
<th>density (kg/m³)</th>
<th>conductivity (w/m K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbo</td>
<td>470</td>
<td>0.11</td>
</tr>
<tr>
<td>Sheild</td>
<td>600</td>
<td>0.15</td>
</tr>
<tr>
<td>Hi Strength</td>
<td>730</td>
<td>0.18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aggregate blocks</th>
<th>density (kg/m³)</th>
<th>conductivity (w/m K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fenlite</td>
<td>1350</td>
<td>0.48</td>
</tr>
<tr>
<td>Evalast</td>
<td>1990</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Note- all block types are from Hanson Building Products.

2.5 Modern regulations and legislation and its influence on the masonry industry and on construction

Since the early 1990’s major changes have and still are taking place with building legislation and sustainability policies (Kyoto 1997), (Rio 1992, 2012). Building Regulations’ changes, the introduction of the Code for Sustainable Homes (BRE 2007) and government directives on construction policies along with a drive towards innovative construction and prefabrication. (Egan 1998). Some of these activities have been sustained and are only undergoing modifications to enable achievable and realistic targets in their directives. Other ideas such as the Code for Sustainable Homes and the drive towards, Modern Methods of Construction (2006) are being ignored by house builders and architects or modified to enable realistic targets for practical construction.

Some of the ideas put forward have been underpinned by a political agenda of the government of the time (Modern Methods of Construction 2005, Code for Sustainable Homes 2007). What is certain is that when addressing the declining market for clay bricks from the mid 90’s the issues relating to legislation had strong influence on the innovative construction systems being promoted which were typically perceived as timber frame,
lightweight steel and volumetric units, none of which included masonry other than as an external cladding. (Modern Methods of Construction 2005).

Masonry (particularly concrete blocks) met with strong competition from lightweight steel framed buildings and also timber framed building manufacturers (SCI Trade Association information, TRADA information). The framed structures were not themselves a competitive threat since single leaf clay brickwork could provide an external skin. Indeed some research was carried out by the writer to evaluate performance of single leaf clay brickwork when compared to lightweight framed structures (Hanson, Corus, Oxford Brookes) (2001) - both reinforced concrete and timber framed multi storey projects. (Oxford Brookes 2001), (TRADA 2005). In the case of clay brick the competition and cause of reduced market share was due to an architectural preference for external finished cladding and render systems to lightweight steel and timber framed structures which demonstrated speed of on-site construction / installation.

It must also be stated that the various “drivers” for change and improvement did indeed help promote clay brickwork although in the early days the question was asked “what could brickwork possibly achieve as an innovative product?” This only went to underpin how established masonry has been as a material.

The first ideas towards building and contractual change were brought about by the Latham Report, (Latham 1994). This was followed by Rethinking Construction (Egan 1998) and its follow on publication. These documents attempted to highlight the unprofessional manner in which construction was procured, managed and carried out reflecting a culture which was based on low tenders with profits gained through a claims culture, inefficiency in construction, excessive site waste and lack of co-ordination. Rethinking Construction (Egan 1998) attempted to bring about radical change in the construction process and to highlight the fact that 80% of site inputs are repeated. Sustainable construction has also started to receive attention particularly around the issue of global warming and the massive contribution made by the construction industry to carbon emissions.

Another driver towards construction change was the Movement for Innovation (M4i) which was formed in November 1998 to implement, across the whole of the industry, the recommendations contained in The Government Task Force's report 'Rethinking Construction' (Egan 1998). The report proposed the creation of a 'movement for change' which would be a group of dynamic people inspired by the need for change. Since the beginning of 2004, M4i became part of (Constructing Excellence 1998) which is the single
organisation charged with driving the change agenda in construction. It exists to improve industry performance in order to produce a better built environment and is a cross-sector, cross-supply chain, member led organisation operating for the good of industry and its stakeholders.

The Movement For Innovation was set up to see improvement in construction, in value for money, profitability, reliability and respect for people, through demonstration of best practice and innovation. Within M4i there were 180 Demonstration Projects submitted by construction clients and contractors who were committed to innovating in the way that they delivered projects and in benchmarking their performance using the pan-industry headline Key Performance Indicators (KPI’s). Evidence of the benefits of best practice measures and innovations in practice has been captured and illustrated by these projects.

M4i was seeking to achieve annual improvements year on year of

- 10% reduction in cost and construction time
- 20% reduction in defects and accidents
- 10% increase in productivity and profitability
- 20% increase in predictability of project performance.

These quantitative reductions were based on what the M4i Committee considerd to be realistically achievable. The aforementioned targets were based on practical assessment of fair but realistic achievements and it was expected that these achievements would be realized through four complementary avenues for innovation and change:

- Product development
- Project implementation
- Partnering the supply chain and
- Production of components.

The Movement was involved in a range of services which include Clusters, Working Groups, M4i Board, M4i Team, M4i Clubs. Whilst the objectives were commendable and much was improved by its existence, the continued achievement of the set targets was not sustained and was never really possible.

At this time the manufacturing industry made great efforts in improving energy saving processes which were incorporated into brick production in terms of kiln firing techniques and thermal efficiency. There was also the ability to change fuel type in order that the most economic fuels would be used at any given time. The reuse of heat and power, as for
example the drawing off of hot air from cooling bricks for use to assist the drying of green, or recently made bricks prior to firing.

Indeed it is a credit to the brick industry that in spite of escalating fuel costs over the past two decades, the price of bricks has remained almost the same. This situation was brought about as much as anything by the pressure of the industry's major customer the National Housebuilder. It is only since 2012 that prices have risen to enable respectable profit levels again.

2.6 Sustainability, carbon reduction and the Code for Sustainable Homes

The greatest influence on modern day construction has been the introduction and general enforcement of carbon /energy reduction policies and revised modern building legislation. These new regulations which are still in a transition period in working towards a desired “zero carbon” design have specifically influenced the design of the cavity wall.

2.6.1 Code for Sustainable Homes

The Code for Sustainable Homes (2007), is a method for assessing and certifying the sustainable design and construction of new homes. It was introduced to help reduce UK carbon emissions and create more sustainable homes. It was part of a package of measures including; Building A Greener Future (2007) and Planning Policy Statement (2011).

The Code became operational in 2007. Its implementation is managed by BRE Global. In 2008, the code became temporarily mandatory with the introduction of Home Information Packs. Sellers were required to issue buyers of newly constructed homes a sustainability certificate (either a Code for Sustainable Homes certificate or a nil-rated certificate). However, in 2010 the requirement for Home Information Packs was suspended along with the requirement for a sustainability certificate. The Code is still operational, but its implementation is now voluntary. It can become mandatory in England, Wales and Northern Ireland if it is a requirement of a local authority’s local plan, or where affordable housing is funded by the Homes and Community Agency. The Code for Sustainable Homes: Technical Guide (2010), which is nearly 300 pages long sets out the technical requirements of the Code, along with details of the assessment process. The Code
requires assessment of the performance of new dwellings both during design and once construction is complete. It measures sustainability against nine categories:

- Energy and carbon dioxide emissions.
- Water.
- Materials.
- Surface water run-off.
- Waste.
- Pollution.
- Health and well-being.
- Management.
- Ecology.

Each category represents a known source of environmental impact for which mitigation measures can be cost-effectively implemented. Performance targets are set for each area, and these targets are more demanding than those required by the Building Regulations. Credits are awarded depending on the performance of the dwelling in each area, and weightings are then applied to adjust their relative values.

In addition, mandatory minimum performance standards are set for seven specific areas.

- Environmental impact of materials.
- Management of surface water run-off.
- Storage of non-recyclable and recyclable waste.
- Emission rates.
- Indoor water use.
- Fabric energy efficiency
- Lifetime homes.

A certificate is then issued which illustrates the overall rating achieved by the dwelling by using a row of 1 to 6 stars.

Assessments of dwellings are carried out by Code assessors who are trained, monitored and registered by Code service providers such as BRE Global and Stroma Ltd. Future changes may result in the abolition of the Code for Sustainable Homes and the introduction of national housing standards in their place. These national housing standards would then be incorporated into the building regulations. This is welcomed by some as a simplification of the current two-tier system. Others suggest it is a “one size fits all” approach that removes power from local authorities to set local standards. The recommendation, however, was strongly criticised in the Environmental Audit Committee -
Eighth Report Code for Sustainable Homes and the Housing Standards Review (HSR) in November 2013. In March 2014, in response to the HSR’s comments the government confirmed that it intended to wind down the Code for Sustainable Homes, with many of its requirements being consolidated into a national framework centered on the Building Regulations (Government web site 2014)

Following this in June 2014, BRE announced that it would develop a voluntary sustainability standard for new homes. “A voluntary system comes in the wake of government's plan to axe the Code for Sustainable Homes from 22 June 2014.” This situation is confusing given that the standard for zero-carbon homes, to be introduced in 2016 has been set at level 5 of the existing code. These requirements, will still impact on the use of brickwork in the UK.

2.7 Building Legislation and the development of cavity walls – Part L Building Regulations

The EU’s carbon reduction plan sets an ambitious target for energy efficiency, with the aim that by 2020 emissions will be 20% lower than 1990 levels (Kyoto & EU 2020, 2014)

To help deliver this, the Energy Performance of Buildings Directive (EPBD) requires member states to ensure that from the end of 2020 all new buildings are ‘nearly zero-energy’. In respect of housing, the UK government has reaffirmed its commitment to the earlier and more challenging deadline of 2016, although this may in reality get pushed back.

The intention is that from 2016 emissions from new homes would have to be offset through a combination of fabric energy efficiency, onsite low-carbon heat/power systems, and a range of additional, mostly offsite systems known as Allowable Solutions, for which a scheme is already in development. Allowable Solutions will bridge the gap between what is achievable at a dwelling level and the further uplift needed to achieve EPBD requirements.

2.7.1 Part L Changes

The new Approved Document came into effect on 6th April 2014 in England and applies to works from that date, unless work has already started on site, or a formal application was submitted prior to this date (with the requirement that works start on site before April 2015). The new Approved Document L 2013 highlights the next step towards the challenge of zero carbon homes and low carbon non-domestic buildings.
For now, the 2013 edition of Part L for new housing requires a more modest 6% reduction in emissions across the mix of dwelling types. Significantly, a minimum standard for fabric energy efficiency is also set; ensuring that new homes cannot rely too heavily on low-carbon heat and power systems to achieve compliance. This underpins the government’s ‘fabric first’ approach to reducing emissions i.e. to focus on correct working practice, good quality in construction and the prevention of drafts and air leakage by use of sound building details.

To allow for flexibility in the design, there has been no change in limiting fabric U values. In the case of walls, the maximum U-value would remain as 0.30 W/m²K, although in practice, U-values less than this will be required. The maximum air permeability is also retained as 10 m³/h/m² at 50 Pa. In addition, there are no changes to the air permeability testing rates.

2.7.2 Domestic Buildings

The main change from Part L introduces an additional target, called the fabric energy efficiency (FEE) rate, for the dwelling in addition to setting a new CO₂ target. The purpose of this additional requirement is to ensure that a design has good levels of fabric insulation that is a long lasting and permanent solution rather than one which relies on renewable energy sources as the main route to compliance with relatively poorly insulated elements. There are two basic criteria that must now be met:

1. The calculated rate of CO₂ emissions from the dwelling (the Dwelling Emission Rate, DER) must not be greater than the Target Emission Rate (TER) - which is the case for Part L 2010. (MMA 2013)

2. The calculated Dwelling Fabric Energy Efficiency (DFEE) rate must not be greater than the Target Fabric Energy Efficiency (TFEE) rate.

The TER is expressed in terms of the mass of CO₂ emitted, in units of kg per m² of floor area per year. The TFEE rate is expressed in terms of the amount of energy consumed in units of kWh per m² of floor area per year.

Both the TFEE rate and TER for individual dwellings must be calculated using the new Standard Assessment Procedure, SAP,2012. (BRE 2012).
2.7.3 Target Emission Rate (TER)

The TER is calculated from the CO\textsubscript{2} emissions of a notional dwelling of the same size and shape as the actual dwelling with specific performance criteria set to the reference values (as summarised in figure 2.6). This is similar to the 2010 approach except that the notional dwelling is now based on reference values which have been set at a level which will provide the targeted 6% reduction in CO\textsubscript{2} (when adopted in their entirety) rather than on the historic 2002 notional building with improvement factors applied.

As such, one means of achieving the TER would be to adopt the parameters in the notional dwelling for the actual dwelling. However, the guidance is not prescriptive and the actual dwelling emission rate can be based on any other solution as long as the TER is not exceeded and the guidance from the other parts of the Approved Document are followed.

<table>
<thead>
<tr>
<th>Element or system</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening areas (windows and doors)</td>
<td>Same as actual dwelling up to maximum proportion of 25% of total floor area</td>
</tr>
<tr>
<td>External walls</td>
<td>0.18 W/m\textsuperscript{2}K</td>
</tr>
<tr>
<td>Party walls</td>
<td>0.0 W/m\textsuperscript{2}K</td>
</tr>
<tr>
<td>Floor</td>
<td>0.13 W/m\textsuperscript{2}K</td>
</tr>
<tr>
<td>Roof</td>
<td>0.13 W/m\textsuperscript{2}K</td>
</tr>
<tr>
<td>Windows, roof windows, glazed rooflights and glazed doors</td>
<td>1.4 W/m\textsuperscript{2}K (whole window value), g-value = 0.63</td>
</tr>
<tr>
<td>Opaque doors</td>
<td>1.0 W/m\textsuperscript{2}K</td>
</tr>
<tr>
<td>Semi-glazed doors</td>
<td>1.2 W/m\textsuperscript{2}K</td>
</tr>
<tr>
<td>Airtightness</td>
<td>5.0 m\textsuperscript{3}/(h.m\textsuperscript{2})</td>
</tr>
<tr>
<td>Thermal mass parameter (TMP)</td>
<td>Medium (250 kJ/m\textsuperscript{2}K)</td>
</tr>
<tr>
<td>Linear thermal transmittance</td>
<td>Standardised psi values – see SAP Appendix R, unless the actual dwelling uses the default y-value of 0.15 W/m\textsuperscript{2}K, in which case the y-value for the notional dwelling is 0.05 W/m\textsuperscript{2}K</td>
</tr>
<tr>
<td>Ventilation type</td>
<td>Natural (with extract fans)</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>None</td>
</tr>
<tr>
<td>Heating system</td>
<td>Gas boiler with radiators. Room sealed. Fan flue, SEDBUK 2009 89.5% efficient</td>
</tr>
<tr>
<td>Controls</td>
<td>Time and temperature zone control with weather compensation. Modulating boiler with interlock</td>
</tr>
<tr>
<td>Hot water storage system</td>
<td>Stored hot water from boiler for houses (instantaneous combination boilers for apartments). Thermostat controlled. Separate time control for space and water heating.</td>
</tr>
<tr>
<td>Primary pipework</td>
<td>Fully insulated</td>
</tr>
<tr>
<td>Hot water cylinder loss factor (if specified)</td>
<td>Declared loss factor equal or better than 0.85 x (0.2 + 0.051 V\textsuperscript{2}) kWh/day</td>
</tr>
<tr>
<td>Secondary space heating</td>
<td>None</td>
</tr>
<tr>
<td>Low-energy lighting</td>
<td>100% low-energy lighting</td>
</tr>
</tbody>
</table>

Figure 2.6 Summary of the specifications to achieve the TER and TFEE rates. (U values) Ref Table 4 Approved Document L1A 2013
In prefabricated masonry and in particular prefabricated brickwork the requirements of the external wall material will be the most important. But other factors such as window and door types, air tightness and the connection between walls when assembled can be influenced by prefabrication in a factory environment.

2.7.4 Target Fabric Energy Efficiency (TFEE) rate

The TFEE is calculated by determining the fabric energy efficiency of the same notional dwelling as detailed above and relaxing the figure by 15% to give the TFEE rate. This represents a mandatory minimum performance of the building fabric and is derived only from the reference values for the external fabric, windows and doors, air tightness and linear thermal transmittance. The TFEE is not influenced by the heating fuel, lighting or ventilation strategy.

2.7.5 Multiple occupancy buildings

Where a building contains more than one dwelling (such as in a terrace of houses or in a block of flats), compliance can be achieved if either

a) every individual dwelling has a DFEE and DER rate that is no greater than its corresponding TFEE and TER rate.

or

b) the average DFEE and DER is no greater than the average TFEE and TER. The average values are the floor-area-weighted averages of all the individual dwelling values. When adopting the average approach, it will still be necessary to provide information for each individual dwelling.

2.7.6 Thermal Bridges

The energy lost through thermal bridges (defined as a material which enables heat flow or transfer across or through an insulation layer ie wall ties or masonry materials) can be very significant. The building fabric has to be constructed so that there are no reasonably avoidable thermal bridges in the insulation layers caused by gaps within the various elements, at the joints between elements, and at the edges of elements such as those around window and door openings.

The Approved Document recognises that reasonable provision would be to:

a) Adopt approved design details such as the Department for Communities and Local Government (DCLG) Accredited Construction Details, in which case the calculated linear
thermal transmittance values can be used directly in the Dwelling Emission Rate (DER) calculation, or

b) Calculate the linear thermal transmittances and temperature factors following the recognised guidance in BR 497 (Ward & Sanders 2010). The linear thermal transmittance – or ψ (psi) values (W/mK) can be used directly in the DER calculation. Reasonable provision for the temperature factors is that they should achieve a performance no worse than that set out in BRE IP 1/06; or

c) The y-value is a proxy for the heat loss through the non-repeating thermal bridging areas of a building. The conservative default y value is 0.15 (W/m²K) in the DER calculation. (ACD 2012)

The use of calculated ψ values for Aircrete Products Association (APA) aircrte would be covered by the Constructive Details Handbook and the CBA details for Aggregate Concrete Blocks, so helping to avoid the need to adopt onerous default values. “ψ” is that value which describes the heat loss associated with a thermal bridge.

Where the approved design details are not available for all junctions, the corresponding values in the ‘Default’ column of Table K1 in SAP2012 can be used for those junctions for which a linear thermal transmittance is not available.

Alternatively, the linear thermal transmittance of these junctions can be calculated as in (b) above.

When adopting the approaches in (a) and (b), the builder would be required to demonstrate that their construction procedures achieve the required standard of consistency by an appropriate system of site inspection. One way of achieving this would be to produce a report demonstrating that the relevant checklists associated with the details have been completed and show satisfactory results.

Significant improvements to the DER figure can be made by adopting the use of industry sponsored calculated ψ values, these constructions developed by the APA and CBA offer significant benefits over the DCLG Accredited Construction Details or the default y-value of 0.15 in the DER calculation.

The industry ψ values can be downloaded from either of the following web sites:-

- [http://constructivedetails.co.uk/resources/](http://constructivedetails.co.uk/resources/)
- [http://www.cba-blocks.org.uk/tech/thermal-bridge.html](http://www.cba-blocks.org.uk/tech/thermal-bridge.html)
2.7.7 U value solutions

There will be a range of U-values that can be used to achieve compliance with Part L, examples of typical wall constructions giving U-values ranging from 0.30 to 0.15 W/m²K are given in Figures 2.7(a) and (b)

Typically, when adopting a fabric first approach (Zero Carbon Hub 2013) to demonstrate compliance and satisfying the TFEE requirement wall U values in the order of 0.18 to 0.25W/m²K will produce an economical house design without the need for expensive renewable technologies.

**Thermalite**

Minimum thickness of insulation in mm required to achieve illustrated U-values

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<thead>
<tr>
<th>Full Fill Construction</th>
<th>Inner Leaf Block</th>
<th>Insulation Conductivity</th>
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Figure 2.7(a) Insulation thicknesses required to achieve specific U values

**Aggregate Block**

Minimum thickness of insulation in mm required to achieve illustrated U-values

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<tr>
<th>Full Fill Construction</th>
<th>Inner Leaf Block</th>
<th>Insulation Conductivity</th>
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Figure 2.7(b) Insulation thicknesses required to achieve specific U values
2.7.8 Summary of the legislative developments

a. The Part L challenge

Meeting the fabric energy efficiency requirements of Part L places the same demands on all forms of housing construction and materials, i.e. Part L/SAP compliance does not favour one approach over another. In respect of concrete and masonry construction, existing materials and systems can meet both the new and anticipated future demands of Part L.

b. Thermal bridging details

The level of fabric performance now required by Part L makes thermal bridging an increasingly important aspect of the overall design; the difference between older construction details and newer, more efficient details can be quite significant in terms of dwelling performance. This is true for all forms of construction and, to assist house builders and designers, the concrete and masonry sector has developed a broad range of high-performance details that are freely available. Their use provides a low-cost means of optimising performance and will allow greater flexibility with other aspects of the design.

c. Flexibility of approach

Basing a design specification on that used for the notional dwelling in SAP will ensure compliance and provides a good starting point, but may not be the most cost-effective or practical approach. In practice, the optimal balance between fabric performance and the use of onsite low carbon heat/power systems varies to some extent between dwelling type. More specifically, it will depend on how much of the external envelope is exposed - dwellings with a large exposed area, such as detached homes, will benefit most from improvements to the fabric.

d. Low-carbon heat/power systems

Part L compliance can be achieved without the need for renewables or mechanical ventilation with heat recovery (MVHR), as demonstrated by the specification for the notional dwelling used to set the CO₂ and energy targets. However, the use of photovoltaics (PV), for example, may enable the fabric specification to be relaxed up to the limits set by the new target fabric energy efficiency (TFEE) requirement. Similarly, low carbon heat/power systems such as flue gas heat recovery and MVHR will permit a less demanding fabric specification to be used, although not to the same extent as PV.
e. Cavity walls

U-values for external walls are likely to be in the range of 0.18-0.25 W/m²K. As a consequence, cavities will typically be around 100-150 mm; a much smaller increase in width than many anticipated when the drive towards zero carbon homes began a few years ago.

f. Overheating in new dwellings

As homes become more highly insulated and airtight, the risk of overheating has become a more significant problem. The thermal mass provided by concrete and masonry dwellings can help to lower the risk, providing there is adequate provision for ventilation. The SAP overheating check recognises this benefit, and gives a reduction in internal temperature of up to 3.5°C in heavyweight homes. (Zero Carbon Hub 2013)

2.7.9 What do these legislative changes mean to the design and construction of cavity walls.

Continued legislative changes in the required U value have led to a current figure of 0.3 W/m²K (Building Regulations 2010) for walls. In order to achieve this it has become necessary to increase the cavity wall overall thickness to accommodate an increase in the cavity width and an increase in the thermal insulation within that cavity. The modern cavity wall typically has an overall thickness of 102mm outer brick leaf and 100mm thick aircrrete inner leaf. However the cavity is now expected to be up to 200mm thick and to include within that space 100mm of high performance insulation material.

Figure 2.8 The effect of reduced U values on the cavity wall thicknesses from 1970 up to 2007
The increase in cavity wall thickness has compromised the overall foot print of a domestic wall and this is best illustrated in figures 2.8 and 2.9.

- the cavity wall thickness has increased from 262mm up to 375mm over the past 40 years.
- The wall U value has reduced from 1.0 W/m²/min in 1970 to 0.18 W/m²/min in 2007
- Significantly for large and multiple developments the effective floor area on a pair of semi-detached houses has been reduced due to the wall thickness by 3.7m². In other words for every 50 houses built in 1970 we could only build 49 houses today, the difference being lost to the increased wall thickness.

![Figure 2.9 The reduction in internal floor space due to increased cavity thicknesses required to accommodate insulation](image)

There are a number of distinct advantages in constructing prefabricated masonry cavity walls in improving the overall wall performance.
These include:-

1. Improved structural properties when compared with in-situ built walls leads to a reduced number of wall ties and hence thermal bridging

2. Air tightness is consistently higher for prefabricated masonry than Building Control requirements (Part L1A requires an air tightness of maximum 10 m³/hr/m² air loss at a pressure of 50 Pa) as there is superior workmanship and consequently improved wall connections / joints

3. The consistently fully filled mortar joints in prefabricated masonry reduce air leakage

4. Improved insulation materials such as vacuum insulation (Kingspan 2014) will enable the reduction in cavity width towards that constructed in the 1970’s but with thermal performance equivalent to that currently attained with the wider cavity and the much thicker insulation. (Rogatzki 2007)

2.8 Markets for clay brick and early product development.

2.8.1 Introduction

The steady but continued decline in the use of clay masonry within the United Kingdom has led to an investigation into ways in which to rejuvenate interest in what is perceived of as a very traditional labour intensive building method relying on highly skilled craftsmen. At the time of this thesis there was also an increasing shortage of skilled craftsmen. Furthermore, this perception about brickwork was underpinned by the (Latham 1994) and (Egan 1998) reports concerning the poor state of the construction industry, the way it was administered and how projects were delivered in the UK. Coupled with this was a drive to encourage the development of new and innovative methods of construction which might reduce build costs, improve quality and so produce more reliable build programmes.

Various alternative materials and building systems were considered by the brick industry for improving the clay masonry market in the late 1990's. Some of these are highlighted below and were developed by the author who in 1998 established the “Hanson Future Build” group, an organisation set up to promote brickwork. The objective of Future Build was to investigate alternative and innovative products or walling solutions which might create interest from designers and contractors. The remit was very broad and encompassed new build and refurbishment and included clay facing bricks, clay blocks, clay slips and concrete aggregate blocks and consideration was given to any realistic and practical proposals.
2.8.2 Walling solutions investigated

1. Competition from timber frame housing in the early 1980s led the clay brick industry to try to develop a brick-based house building system that was more efficient than the traditional cavity wall. The result used a single leaf 102 mm brick wall to which insulation was directly attached using dabs of waterproof adhesive with plasterboard fixed to the inside. Although a number of successful prototype houses were built such as CERAM’s Traditional Plus system, the method did not achieve commercial success. Brick manufacturers produced 9” square solid units (London Brick with the Phorpes brick and Redland with the Calculon brick). However, in the light of increased insulation requirements in the late 1990s, the system was re-evaluated.

Two problems remained unsolved in the original system. One was the slenderness of the wall during construction, requiring propping, and the other was the lack of a simple yet effective floor connection detail. To solve the slenderness problem, special 140 mm by 290mm bricks were made. Provision of a central grip hole to make handling easier also solved the floor connection problem by allowing a special joist hanger to be built into the slot. For the foundations, a variation on a pile and ground beam foundation system was developed and optimised to suit the 140mm brickwork. The system has not realised any commercial success and continued changes to current legislation do not present favourable circumstances for future development.

2. Calculon clay bricks, V bricks and “through the wall bricks”, the latter having been developed by the author were introduced in an attempt to promote brick use. These were considered as a means to reintroducing single leaf masonry but with an inner face of insulated dry lining. The intention was to reduce the masonry build from two leaves back to one leaf as was the case prior to the cavity wall. Comparative cost, quality and time benefits were promoted but apart from a small number of case study projects the method has not been embraced by the industry.

3. Composite masonry units comprising a combination of two bricks long (440 mm) plus Styrofoam insulation and a 440 mm long x 65 mm high aggregate concrete block have been developed in an attempt to promote masonry use (figure 2.10). The insulation was moulded into a profile which enabled the Combi Block to be dry laid and then pointed with a gun system. The process was fast and efficient and could be built by a non-bricklaying semi-skilled operative. The system was not a success due to the
prohibitive cost of the manufacturing set up and impracticalities with the construction details as was identified by the Hanson Future Build (1998).

4. An investigation was made into the design and construction of a six storey timber framed structure (figure 2.11) with a single skin cladding. Various aspects were studied. In the case of brickwork the key aspects were:

   a. Consideration of constructing the single leaf wall for the full height of the building without use of shelf angle support normally required to reduce differential movement [www.brick.ork.uk](http://www.brick.ork.uk) – (Brick Development Association), Multi Storey Timber Frame Building

   b. Consideration of various brickwork types ie low, medium and high rate expansion products

   c. The masonry contribution to improving the stiffness of the superstructure in reducing the action of sway by a shielding effect. (Edgell G 2000) – see further discussion below.

   d. Accidental damage and partial collapse

   e. Differential movement of timber and masonry (Enjily 2000)
Chapter 2 – Literature Review

The investigative work was carried out at BRE Cardington, the giant airship hanger formerly used to house the R100 and R101 airships. This large open structure was considered to be a suitable space with a controlled environment in which to test and monitor a number of full sized buildings. This included the construction of a six storey timber framed building which had the layout of a typical apartment block and was monitored over two years for movement and general building performance. Key findings from this work include:-

I. The stiffening effect of both the brickwork outer leaf and the plasterboard lining were considerable

II. The independent testing company, CERAM carried out additional work for this project which included the construction of a lab built structure. The failure load for the this lab built structure = 6.2 kN/m² far exceeding the serviceability loads.

III. The overall stiffness of the Cardington building was greater than the Ceram lab structure.

IV. Up to 80% of applied load to the timber frame at Cardington was resisted by the brickwork before the application of plasterboard.

V. Interestingly the plasterboard wall finishes added further stiffness to the superstructure.

5. Investigations into a single leaf brickwork cladding to lightweight steel multi storey structures was also studied. The objective here was to establish the total differential movement between a continuous unsupported single external leaf of clay brickwork constructed for the full height of the framed structure for building heights of up to 6 storeys which amounts to up to 20m full height. If the differential movement could be accommodated without any cracking of masonry being incurred this would enable building construction without the use of stainless steel support shelf angles at the normally required vertical spacing of every 3 storeys. The findings of this work demonstrated that such a construction process was achievable with correct detailing and the cost savings made in excluding shelf angles and the pistol bricks required were significant, up to 20% on cladding costs. Work to investigate the design and details for lightweight steel framed structures with an external brick leaf (Hanson, Corus, Oxford Brookes, Brick Development Association 2001)
6. The feasibility of lightweight composite non-structural insulated cladding panel with brick slip finish was also investigated (figure 2.12). Several variants of this type of construction have been developed by the brick industry. They typically comprise a thin brick slip finish which is fixed either by adhesive of mechanical means to a backing element which itself is fixed mechanically to a substructure (figure 2.13). This system was developed in America and patented in the UK by John Thompson. The author further developed this system which resulted in the production of the “Wonderwall” panel which included improved fire resistant insulation. The new system is now sold as a cladding to both refurbishment projects and to lightweight framed structures. Other cladding systems in the UK serve the same purpose.

Initial Research indicated there was a potential market for thin brick cladding systems to a much greater degree than is currently the case particularly with the amount of refurbished 1950’s dwellings that were in need of a face lift (figure 2.14). As it is, the cost of thin composite cladding systems is prohibitive of wider use and it is only in specific circumstances such as refurbishment where planners demand a brick finish, or with cladding to lightweight structures particularly in areas that have difficult access for delivery of materials such as bricks and blocks, that these specialist systems are beneficial.

7. The use of high performance mortars in brick and block in-situ construction has also been investigated. Thin joint adhesive masonry systems have been in use for over 20 years. Specifically, aerated concrete block manufacturers have established thin joint glued blockwork both on the continent and in the UK. (Celcon 2013), (Thermalite 2013). Glued in-situ brickwork has been in use in Belgium and Holland for a similar period of time. Its introduction to the UK occurred in the early 1990’s but it was never a success at that time due to the lack of information, training and preparation about the use of the system. Subsequently interest in the UK has been rekindled and as a result a number
Chapter 2 – Literature Review

of projects in the UK have been carried out. This updated technique forms a key part of this dissertation and is documented in the following chapters in greater detail.

8. Prefabricated masonry. Little has been constructed in the UK (or indeed internationally) in prefabricated masonry and developments in this procedure are documented below and in the following chapters. This work forms part of the main work of this dissertation but some background to developments are given below.

2.9 Structural Brickwork

Historically brickwork was used as a structural / loadbearing material. However the introduction of the cavity wall led to clay brickwork being no more than an aesthetic and durable cladding which was only required to support its own weight since the inner leaf of the cavity wall (constructed of lower load carrying capacity concrete or aircrete blocks) supported the load from floors and the roof. In non-housing structures the development of structural steelwork and reinforced concrete meant that masonry was no longer used for the superstructure of warehouses and factories. In civil engineering works brick was replaced as a structural material by steel and concrete such that the wide use of bricks in the construction of canals, railways, bridges and tunnels was no longer so prevalent as had occurred in the Victorian age.

Since that time much has been done to try and promote structural masonry and to encourage more extensive use in many sectors of the industry. Some minor successes have occurred over the past four decades including the promotion and development of fin and diaphragm walls, the use of load bearing masonry with external walls and cross walls replacing framed superstructures, and the introduction of reinforced and post tensioned brickwork.

Fin walls are fundamentally cavity walls of brick and usually block construction with enlarged brick piers in the outer brickwork leaf. The dimensions of the fins and the frequency of their spacing depends on the dimensions of the structure. Diaphragm walls comprise a two leaf wall with the inner and outer leaves joined by cross ribs. The overall width of the wall and the frequency of the cross ribs will depend on the height of the structure. Both wall types are designed as propped cantilevers, the roof and roof beams providing a rigid or stiff plate forming the prop.
With regards to the fin and diaphragm walls there was no facility available for the design of such walls other than to follow specialist masonry design guidance available from various sources (Curtin et al 2010, BDA 1984). A number of buildings were successfully designed and constructed and cost comparisons made with what would have been a more conventional approach which would have included virtually the same masonry requirements but the addition of a portal framed superstructure or at least the use of steel columns and their associated fixings, baseplates and pad foundations. The structural masonry options require a simple foundation of strip or reinforced strip footing due to the lower and more uniform load distribution rather than the high concentrated loads of columns.

Fired (vitrified) clay masonry possesses very high compression strength properties similar to concrete or natural aggregates. However it is relatively weak in tension based on the bond between the interface of clay units and mortar. It is for this reason that it had been so successful as a massive load resisting element when used in bridges, buildings, tunnels and other structure types. Interestingly, early design codes such as CP111 paid little attention to the tensile properties of masonry stating only the maximum direct tensile strength that could be allowed for.

However a minor revival of structural masonry in the late 1960s resulted in the development of a design process which enabled flexural strength to be evaluated. Extensive testing led to the production of allowable flexural (bending) tensile strength figures being determined for a range of clay and concrete masonry types. Additionally some work was undertaken to establish the correlation between the yield line theory (Johansen 1972) used for determining the lateral capacity of reinforced concrete panels and a similar design approach for plain masonry panels when subjected to bending from lateral loading (Hendry 1987). Other researchers began to experimentally investigate the strength of masonry wall panels subject to lateral loads. The aim of the programme of work was to provide experimental results for the verification of theoretical methods (Edgell 2005, West et al.,1977), such that design provisions could be incorporated into the draft standard that would later become the Code of Practice for the use of masonry (BSI, 1978).

This information allowed engineers for the first time to check the lateral load carrying capacity of panels, and was first published in BS 5628 in 1978; the information is now accepted and included within EC6.
In the 1980’s there was a move to promote off the frame cladding for multi storey buildings. This is where a solid brickwork wall usually 215m thick is constructed in conjunction with a framed superstructure (Bird 1994). The masonry is literally built “off or away from the frame” i.e. in front of it and continues from foundation level for the full height of the building without incorporating expensive stainless steel shelf angles which in conventional construction provide support to the outer leaf of the cavity at every third storey height. The blockwork inner leaf in these buildings is usually supported off the edge beams at each storey level. The off the frame cladding approach although using a 215mm brickwork solid leaf, sits directly on its own strip footing or trench fill foundation and with its self-weight removed from the superstructure the system demonstrates cost savings due to lower beam and column sizes being necessary. Additionally the shelf angle cost and installation is saved. Architecturally the 215mm wall enables construction in a variety of brick bonds which can include various combinations of headers and stretchers and the openings may be designed as true loadbearing elements without the need for steel lintels. (BDA 1988)

From time to time a number of one-off masonry design solutions occur such as the refurbishment of Winterton House (Bird et al1994). In this case a multi storey structure was dismantled to leave only the original skeleton of steelwork and the reinforced concrete lift shaft / staircase. The building was originally designed such that to re clad it and to provide new floors and all the appropriate services would have meant that the original steel frame was not capable of supporting the new applied load. The solution (Bird 1994) was to provide a solid off the frame clay brick external wall which “cloaked” the superstructure and in addition was post tensioned such that load from the superstructure, along with its refurbished floors and new mechanical and electrical installation was partly transferred back to it. The walls comprised 215 mm thick brickwork for the top 16 storeys. Below this level the brickwork was 327 mm thick. Following completion of the building the masonry was monitored for long term movement (Bingel 1994)

Reinforced brickwork is considered a specialised area of masonry design with the key issue historically relating to the durability and cover to the reinforcement. A number of projects including reinforced brickwork have proved successful and although the economics of reinforced brickwork is questionable it is a beneficial solution for such structures as retaining walls where a brick façade finish is desirable. If the brickwork can be incorporated as the structural component as well as the finished cladding this becomes a viable solution. (BDA 1988). Post tensioned brickwork is relatively easy to achieve
initially although there are reservations regarding the post tensioning process and the subsequent relaxation of post tensioned rods.

At the time of writing this thesis construction brick is starting to enjoy a more sustained revival, albeit at a level well below in its heyday, by exploiting its structural properties and also making demands on the finished appearance the likes of which have not been seen recently such as the Tate Modern extension and the London School of Economics extension. In many cases heavily textured facades are being requested by architects and these are being constructed as composite concrete / brick elements. To date it has not been possible to provide a cost effective pure masonry solution.

When considered for an appropriate building type, structural masonry solutions could show considerable savings when compared with frame alternatives which still include masonry walls but only as infill. Including the frame can result in an increase in structural costs of up to 25% and increase in overall build costs of 5-8%.

Almost all structural masonry solutions considered by Future Build involved in-situ construction since this has always been considered the appropriate method of assembling masonry. The use of prefabricated masonry may provide alternatives and this approach is now considered.

2.10 Prefabricated masonry
Prefabricated masonry has never been widely used in Europe or America although numerous attempts at using it have been made. This section briefly summarises past attempts to commercialise prefabricated masonry then describes systems currently in use in the USA and Europe.

It is important to differentiate between prefabricated masonry construction and composite concrete panels which comprise reinforced concrete cast onto pre-cut brick slips in horizontal beds such as Trent Concrete (2013) and Techcrete (2013). Whilst these techniques are successful, they are considerably more expensive and are usually incorporated into longer spanning structural members. The process of prefabricated masonry as documented in this thesis does not use composite brick / concrete but only mortar filled joints of masonry.
2.10.1 Prefabricated masonry – unsuccessful processes

2.10.1.1 European systems

An extensive number of patented prefabricated systems have been sourced which have not evolved into successful or widely used processes:

An English mechanical engineer, J Henry Dyke, first patented a method of producing glued brickwork panels in 1933 (Thomas 1973) but this process was not taken up with any serious commitment within the UK (figure 2.15). It was however progressed by the Dutch and lead to the more recent automated processes (Berrgraaf, 2007, Verbo, 2006)

Panel systems developed including the Butterley Brick Harold Waud, (Thomas 1973) and London Brick Company Phorpes (Thomas 1973) were never progressed to a commercial level of large scale mass production.

The Butterley / Harold Waud 1971 system used a clamping technique and was limited to 3 holed bricks which were manufactured at the Kirton brickworks. The process was restricted to panel dimensions of no more than 1.0m wide x 2.4m high which limits its use to specific building details. The process also incorporated a lot of steel reinforcement which makes the

**Figure 2.15** Henry Dyke patent for prefabricated brick panel, (Thomas 1973). Study on prefabrication, BDA

**Figure 2.16** Harold Waud prefabrication process patented in 1971, Thomas. Study of prefabricated brickwork, BDA
technique cost prohibitive. Additionally the panel dimensions limited architectural choice for building design. Although they were single storey height they were only approximately 1m wide (figure 2.16).

The Rheinhold Magnus Elgenstiena system from 1965 was based on a double brick wall. Composite construction of bricks, truss reinforcement, clay blocks and special shaped bricks to accommodate main vertical steel was required. Figure 2.17 illustrates the method. The complexity of this system meant that it was too expensive for wider use.

James Beattie Bell developed a system in 1969 – that required bricks to be perforated and to have preformed slots. Reinforcement was also necessary (figure 2.18).

Caldwell 1966, developed a system which like many of the systems patented relies on a brick format which requires costly alterations to the brick manufacturing process. This complexity meant that its commercial use was limited. (Figure 2.19).
2.10.1.2 American Systems

A review for the Brick Development Association (Thomas 1973) highlighted American prefabrication companies. It also gives a good account of prefabrication manufacturers in Europe. All of the companies referred to in this document are either no longer in business or if they are they do not make prefabricated masonry.

The following extract from Masonry Construction United States 1999 also refers back to “Masonry Past and Present”. It is quoted here at length as the information outlines precisely what the problem was at the turn of the 21st century which had lead to the demise in prefabricated masonry.

William Palmer jr – Masonry Construction 1999
Some construction methods are used only in isolated areas of the country. Not too many years ago, the majority of tilt-up projects were in Florida, Texas and California; that changed for tilt-up. In masonry construction, prefabricated brick panels fall into this category of isolated use. Prefabricated brick panels are conventionally-built masonry walls or elements that are hung onto the building as panels. These panels are prebuilt masonry, not precast panels with embedded thin brick. Why is a system that has proven viable and profitable used so infrequently in most of the country? Conventional wisdom says that there is a lack of knowledge and experience. Perhaps the investment in equipment and facilities is more than most masonry contractors want to make, or there could be some lingering concerns over the problems encountered by Sarabond panels.{see notes below on Sarabond} In the Pacific Northwest, KPFF Consulting Engineers, Seattle; and two construction firms: Barkshire Panels Systems, Federal Way, Wash.; and L.C. Pardue, Portland, Ore., have been using brick panels for over 20 years. In Ohio and surrounding states, Vet-Ovitz Masonry Systems, Brunswick, Ohio, has been building with brick panels for over 30 years. “I think there is more work in this area because of the competition between us and Barkshire,” says Lenny Pardue, explaining that customers feel more comfortable when there is a choice. “Barkshire is our only competition,” he continues, but emphasizes that “we almost never compete for the same job.” This is because most brick panel jobs are negotiated rather than competitively bid.

Fred Galassi of Barkshire stresses that, “Our competition is not conventional laid-in-place brick. "Rather, brick panels compete with other “skin systems” such as glass, metal or precast panels. “We usually are competitive with precast panels, but when there are articulations on the panel then brick is cheaper," he says. John Tawrey of KPFF agrees, “Brick panels usually are less expensive than precast panels or conventional brick, but more than EIFS.” KPFF has designed this system for use on more than 75 buildings from Los Angeles to the Canadian border and east to Boise, Idaho.

Extract from “The Power of Prefabricated Brick Panels - Their advantages over laid-in-place brick (Palmer, 1999)

Of the Companies mentioned in Palmers article, Veto Vitz now appear to specialise only in Paving and at the time of writing this thesis (2013) Barkshire was up for sale and have no visible web site displaying evidence of prefabricated panel manufacture.
Additional types of prefabricated panels have been sourced in the US Patent library, all of which employ a common theme, i.e. a complex process of bricks which are hence required to have a complex shape in order to accommodate extensive reinforcement which is contained within the panels. Such systems, whilst providing a sound and well-made panel, show no evidence of consideration for the practical as the processes would be very costly to set up and they make use of clay bricks that are not currently manufactured by standard processes thereby adding considerable cost to the production.

Clearly there have been problems in implementing commercially viable prefabricated masonry building systems. Palmers article (above) mentions the material referred to as Sarabond (Fischer 1992). Sarabond is described in a Masonry Technical Note (Brixmet 1992) written by H C Fischer, Consultant to Cement Concrete and Masonry. “A classical case of potential problems arising from the use of an admixture for mortar is that of Sarabond. About 25 years ago, the Dow Chemical Co. announced and began marketing a very effective bonding agent for masonry called Sarabond. Its use enhanced bond strength of the mortar/unit interface by several or more orders of magnitude. This proprietary product was composed essentially of an organic material named polyvinylidene chloride. This product was considered “safe” because the chloride was not present in the same form as the chloride in calcium chloride and thereby was not of corrosion potential to metals. However, over a period of several to perhaps a dozen years this chemical degraded and liberated free chloride ions that attacked metal reinforcing bars and ties. Corrosion products created expansive forces that caused some brickwork to break loose and fall from structures! When this occurred at several or more stories above ground level, posing a real safety hazard, the extent of concern and alarm was huge! Litigation persists although the product was, of course, withdrawn from the market.”

2.10.1.3 Prefabricated masonry – recent developments

Investigative work has been carried out (Fanning A 1999, 2000, 2001) on manufacturing processes particularly in the United States. – Fanning refers to the book “Masonry Past and Present” by the American Society of Testing and Materials. This provides an excellent account of developments in the US up to 1975 in the use of pump and gun dispensed mortars both for in-situ masonry construction and factory built masonry panels. Further, Dutch Consulting Engineer Harrie Vekemans has been involved in the marketing and promotion of both glued thin joint brickwork and in prefabrication having carried out design and testing work on a number of projects in Holland (Vekemans H and Ruben M 2002)
Hogg (2002) investigated the properties of thin joint glued brickwork as a prefabricated material and its role in the UK construction industry. She presented a comprehensive overview on prefabricated and manufactured masonry processes and gave an excellent account of the background and developments up until 2004. The thesis includes references to masonry and to composite processes including concrete and concrete with brick slips. Part of the work included in Hogg’s thesis refers to publications and test programmes in which the author of this work was involved. Reference is also made to two important works. There has been a review of prefabrication (Fisher K 1992) followed by an update on that review (Edgell G 1999) and a further review (BIA 2001).

Fisher and Edgell's findings can be briefly summarised as follows.

### 2.10.1.4 Existing prefabricated masonry processes in Europe

In Europe there are a number of prefabricators of masonry although the systems and materials used would not be readily accepted in UK construction.

Holland and Belgium have a number of manufacturers who produce complete bespoke domestic dwellings. One manufacturer in Belgium (Danilith) make prefabricated houses including floors, walls and roofs and all the services and fittings are built within the structure in a factory environment. The system is not cheap and the Company, still a family run business designs each project individually in conjunction with each client. Cost is not considered to be a prime factor and the houses are erected in less than two weeks.

The walls of the Danilith house are complex comprising a composite sandwich panel of brick slips cast into reinforced concrete on insulation and lightweight concrete. (Figure 2.20) shows the construction details.

**Typical Loadbearing external wall construction**

- 280mm wide: U value 0.21 W/m²K
- 42mm cut half brick
- 58mm high density concrete =2350 kg/m³
- 100mm Recticel Bio Board insulation
- 100mm reinforced lightweight concrete density =1750 kg/m³
- or 300mm wide: U value 0.18 W/m²K
The services including power and heating, along with all of the openings and glazed panels are also built in in the factory. All of the factory processes are produced by a robotic assembly line coupled with flat cast concrete panelling.

This is not a true prefabricated masonry system and its cost would limit its use to a specific market, namely the upper end of the private housing sector. The system has now also been promoted in the UK for the past 10 years but to date not one house has been sold. The reasons for this relate to cost and a lack of confidence in a diverse system in spite of the high quality of materials and construction.

In Holland a similar type of system (Berggraaf) is produced i.e. a composite panelised process again for the specialist domestic market.

In Denmark houses using a robotic assembly procedure (Carlsberg Prefabrication) are built. In Holland (Verbo) single leaf clay blocks are also produced by a robotic process. Here clay units are placed onto a conveyor type system and automatically glued and set or assembled to make full size panels. This system saw an increasing production capacity up until approximately 2012. They are now no longer operating as an independent organisation and little information is available to indicate their current activities.

In addition in Germany prefabricated walls are manufactured again using a robotic process which builds single leaf walls of large format clay blocks. This is a system not dissimilar to the Dutch process previously mentioned. It is an efficient process but it is not set up to be able to manufacture UK style walls.

In summary, the interest in prefabricated masonry has declined. The main reason for this relates to production costs of the prefabrication processes and the total volume output. These aspects do not make the systems economically viable. In addition to this the worldwide recession hit hard on the construction industry with little money available from banks to finance developments either in housing, non-housing or civil engineering infrastructure.
Biggs (2006) undertook a review of prefabricated masonry. As this is one of the more recent reviews his conclusion is quoted below - which still summarises the current situation:

“There are numerous benefits associated with prefabricating masonry wall panels. Although this type of masonry construction is not familiar to most architects and engineers, there are several options available to designers and contractors to improve construction speed and cost on a project. However, there are also associated challenges that must be accommodated as listed in the paper. In the United States, creative contractors and engineers have found various means to adapt to prefabrication and provide masonry options to both precast concrete and metal wall panels. This is still a relatively new application for masonry and more innovations are inevitable.”

2.11 Summary of literature review

There is a continued decline in the use of clay brickwork due to the development of alternative building materials and construction systems.

The changes in construction have been brought about partly by architectural trends to use different materials as a cladding finish and partly in an attempt to keep in line with changes in building regulations which are driven by environmental and sustainability criteria.

Structural masonry as a design solution has never been considered to be a major option compared with steel and concrete and the design guidance available for masonry falls short of that for its counterpart materials even with the introduction of EC6.

The use of thin joint masonry systems were developed over 20 years ago and have been used with varying degrees of success depending on the country and the construction styles for that country. Thin joint systems and high performance mortars will be considered in the next chapter.

Prefabricated masonry has been used with varying degrees of success in many parts of the world (Biggs 2006, Thomas 1973, Fisher 1992) but a review of the literature on this matter shows that there has been a definitive decline in the number of company’s who manufacture true prefabricated masonry panels as opposed to composite masonry / concrete walls and few designers who elect to opt for the process. Prefabrication and possible manufacturing solutions are considered later in this work.

Where performance requirements are concerned, whether constructing traditional in-situ masonry or prefabricated panels, the three key criteria for designers and contractors will
be performance, cost and appearance. The order of priority for these will change depending on who you ask!

When masonry is the chosen construction all performance requirements will be judged against the standards set by traditional construction using brick layers.

With prefabrication there are a number of important matters that need to be addressed if one is to try and replicate the “traditional appearance” of masonry by a factory controlled output.

Prefabricated masonry may be seen as a contradiction to the vernacular craft since it is the very individuality of masonry which gives its appeal. It is partly for this reason that prefabricated masonry has not gained more widespread use.(Fisher 1002, Biggs 2006) Almost all existing prefabricated techniques involve either casting into concrete or building by robotic / automated processes where bricks are picked up by a machine, several at a time, and placed onto the wall.

Prefabrication often does not achieve the level of appearance required (Fisher 1992) – and the cost of prefabrication when including transportation and cranage appears to fall short of in-situ work. Therefore for prefabrication to be commercially viable it must satisfy the following criteria :-

- Structural properties to be superior or at least equal to traditional built masonry
- Appearance to replicate a vernacular craftsmanship rather than prefabricated “clinical appearance”
- Overall cost must be visibly competitive with traditional construction
- Wall performance in terms of durability and resistance to rain penetration should not be dependent on manual workmanship quality
- Ease of construction – a process which is straightforward, easily understood and accepted by the construction team

If prefabrication is done well the above criteria can be met and this will enable:-

- Consistently high quality
- Design supply and fix which is attractive to main contractors
- Increased output and speed of construction
• Minimal impact on local environment
• Cost effective transportation – combined component materials
• Walls may be better engineered to a particular specification.
• Introduction of finishes and services in the factory.
• Control of materials / performance to enhance U value etc
• Prefabricated brickwork to be used as load bearing elements.
Chapter 3 Thin joint masonry – development and use in the UK

3.1 Introduction

The steady but continued decline in the use of clay masonry within the United Kingdom as described in Chapter 2 led to an investigation into ways in which to rejuvenate interest in what had become perceived as a very traditional labour intensive building method relying on highly skilled craftsmen. This perception about brickwork and its reducing market share was underpinned by Government reports relating to the poor state of the construction industry, the way it was administered and how projects were delivered. Coupled with this was a drive to encourage the development of new and innovative methods of construction which might reduce build costs, improve quality and work to more reliable build programmes. Various alternative materials and building systems were considered by the brick industry in the late 1990’s for improving the clay masonry market (Chapter 2.8.1). In this chapter a detailed discussion of the use of thin joint masonry as a means of increasing brickwork market share is presented.

3.1.1 Thin joint adhesive brickwork – a Dutch masonry system

Thin joint adhesive brickwork originated more than 20 years ago in The Netherlands and the technique relies on joints which are formed using what is termed a “glue mortar” rather than traditional cement : sand mixes. Glue mortar has a high percentage of cement and very fine inert additives such as PFA. The mortar is applied by using a pump, hose and gun system i.e. a motorised mixing pump with a spiral mixing wheel which, when rotating, forces the mixed adhesive, or glue mortar down the hose to a gun. The gun trigger regulates the speed of rotation of the spiral mixer. The more the gun trigger is squeezed, the faster the spiral turns and the greater is the volume of dispensed mortar. The gun dispenses beads of material along the horizontal bed joints and on the perpends prior to the bricks being laid. Glue mortar is typically dispensed as two parallel beads although gun heads may vary to suit brick perforation formats or the brick suction rates. Single, two and four bead guns are operated. Many metres of bed joint adhesive can be laid in a rapid single operation, the nozzle dispensing relatively accurate and consistent quantities of mortar. Working conditions, speed of construction and overall quality are generally considered better than those of traditional mortar.

One of the major manufacturers of thin joint adhesive is the Belgian company formerly known as Ankerplast, latterly renamed Omnicol. The Ankerplast literature states that “thin joint adhesive brickwork has been used in European masonry in the search to improve brickwork and offer a new perspective to the client. The use of thin joint brickwork built with
glue mortars was introduced into the Netherlands construction market as both an interesting architectural medium and an easier way of producing brickwork. Like the UK and many other European countries, the Netherlands had experienced a shortage of skilled bricklayers and in an effort to overcome this situation, new methods of masonry construction were considered that attempted to deskill the craft of bricklaying whilst also providing a different finish to the masonry. Ankerplast literature (1999) goes on to say “Thin joint brickwork built with glue mortar (also known as thin layer mortar), which was applied through the use of a pump rather than a trowel, became a favourable choice and over the last decade thin joint brickwork has increased in popularity on the continent. The process is not only considered quicker and easier to construct, thanks to its mechanised mortar dispensing pump, but its structural properties and intensity of colour, due to the thinner joints, have also worked in its favour.”

It was anticipated that the use of thin joint brickwork would increase in popularity in the UK and with the Dutch already using it in prefabrication form, there was the potential for Britain to follow in the Netherlands’ footsteps.

3.1.2 Development of the thin joint mortar system in the UK

The glue mortar used to achieve thin joints is made up of a mixture of fine-grained sand along with a higher percentage of Portland cement when compared with traditional mortars (Ankerplast 1999). The glue mortar is then modified with a mixture of artificial resins and other specific components, which enhance the strength of the mortar, particularly its tensile strength.

A range of mortar types have been developed in Europe, one of which, Ankerfix PVM, is suitable for use with a wide range of brick types (Ankerplast 1999) and is produced in 3 different types (A, B & C) to accommodate the various water absorption rates of clay bricks. The glue mortar is “rheologic fixotropic” by nature, meaning that when in motion (as for example in a mixer) it will remain fluid until left to stand after which it will begin to set. On average it is stated that setting commences in approximately 4 minutes after the stationary glue is laid, which allows enough time for reasonable long runs of brickwork to be laid. Tests carried out (Ankerplast 1999) have produced the data shown in Table 3.1. The tests were carried out in accordance with BS EN 1015-11:1999.
Table 3.1 Thin joint brickwork strength data derived from using prism tests. (Ankerplast (1999))

These results suggest that glue mortar can create a bond of superior strength in comparison to conventional mortar. However it must be remembered that these results are published by the manufacturer and are provided for the purpose of guideline information only. Tests carried out on specific brick and glue type combinations will provide different results. Refer to Chapter 8 on Testing.

3.1.3 Application method of glue mortar and visual appearance

Due to the consistency, the fast drying rate and the requirement of uniform thin joints, it is considered by the manufacturers to be impractical to apply the glue mortar using a trowel (Ankerplast 1999). A typical mix is such that it has the consistency of a tile adhesive. The alternative as previously noted is to use a dispensing pump and gun specifically developed to carry out this operation.

In a wall construction the bricks are set out in the same manner as for traditional trowel laid units i.e. a first course is dry laid to check for size and spacing of units bearing in mind that the co-ordinating size of the brickwork will be based on the brick length plus a specific thin joint width which will vary from probably 3 mm to 5 mm. For example the co-ordinating size may be 215 mm brick length + 3 mm joint = 218 mm. Conventional UK brickwork has co-ordinating sizes of 215 mm + 10 mm joint. This discrepancy means thin joint masonry construction in the UK will require some adjustments to be compatible with conventional masonry.

Typically a line of bricks positioned end to end will be set up and the glue mortar will be applied in a continuous run down the line. In Belgium and Holland the thin joint system will have mortar bed thicknesses from as little as 3mm up to usually no more than 5mm. The perpends are often left unmortared and the bricks laid butt jointed. This is done in order to achieve an appearance of as little mortar as possible on the façade finish and to maximise the effect of the brick colour. In terms of aesthetics it was this particular aspect which was created to give an alternative visual impact based on the concept that brick presents rich
and vibrant colour and mortar tends to “tone down” with a grey finish – even in the case of coloured mortars the cement based material cannot present as strong a colour as the ceramic material. Fired clay will always produce rich, vibrant natural colours.

The European market for thin joint masonry brickwork was developed primarily based on this factor. Further, the glue mortar can reduce the presence of mortar joints from what in traditional 10mm bed and perpend joint brick masonry is approximately 18% of a square meter finish down to as little as 3% on elevation.

This change in brickwork appearance was the key criteria which attracted UK architects to the thin joint system. There is some irony in that traditionally it is the very fact that brickwork comprises bricks and ample sized joints that gives the particular fondness of architects for the material.

However at a time when new and creative facades were being sought this option appeared to have great potential as it enabled any brick type of any shape, size, colour and texture to have its finished appearance significantly changed by simply altering the joint size.

One aspect of the thin joint system that was not well received in the UK was the idea of butt jointing bricks with open perpends. The reason perpends were left open by the Dutch and Belgians was that there was no concern over the ingress of water through the unfilled joints as it was deemed acceptable to allow water to enter the outer leaf of brickwork and to run down the wall and drain away at the base or at appropriately placed cavity trays. The inner leaf on its own is thought sufficient to resist water ingress into the building structure.

Additionally leaving perpends unfilled reduced the material cost of the glue mortar (which is considerably more expensive than cement : sand mortar) and increased the bricklaying rate and daily output. Both of these facts provide an attractive case for the thin joint masonry system when comparing costs with the traditional methods.

Where brickwork is built with thin joints being applied to the perpends the bricks are first laid on end, back to back, prior to laying and a line of mortar is applied along the top of the row of units. These are then taken one by one and laid onto the pre mortared bed joint glue bead on the course below.

All development, testing and constructed thin joint glue mortar work and projects in the UK have employed mortared perpends. All members of the construction team including the architect, contractor and engineer are not in favour of unfilled perpends. Similarly manufacturers such as Hanson have not to date carried out any tests with unfilled perpend.
masonry; such is the impracticality of the system. When glued masonry is used in an otherwise traditional or conventional cavity wall construction it has been demonstrated (Sharp 2001) that the outer leaf will have considerably greater resistance to driving rain than conventional mortars. In the UK that was seen to be a particular advantage of the system and a test was developed which demonstrated resistance to rain penetration (Bowler, Sharp 1998).

3.1.4 Structural properties of thin joint masonry - overview

One of the major benefits of the thin joint adhesive system and the use of glue mortar is the improved structural performance of the brickwork. It has been demonstrated that the mortar has a rapid setting and hardening time with increased initial strength gain when compared with standard cement sand mortars.

Brickwork constructed with glue mortar has demonstrated both in practice and in laboratory simulated frost tests, where frost resistant bricks are used the brickwork is capable of withstanding prolonged saturation and repeated freeze / thaw cyclic frosting exhibiting excellent durability and excellent properties (Sharp 1992, Oxford Brooke 2004). Chapter 8, Testing, of this thesis documents results for flexural and compressive strengths for both brickwork and various mortar types.

Comparing the compressive and tensile strength of glue mortar with conventional mortars by testing prisms clearly demonstrates improved physical properties of the glue mortars.

In terms of masonry, extensive structural tests on wallets, brick couplets, stack beams and full size wall panels demonstrate improvements in compressive, flexural and shear strength.

Hence the overall improved performance of glued brickwork provides benefits in the structural design of masonry for the engineer.

With improved lateral load strength both parallel and perpendicular to the bed joints this enables increased limits on the allowable limiting dimensions of wall panels. This is not only true of stretcher bond built masonry but also stack bonding where it has been demonstrated that the strength in both directions is enhanced. (Chapter 8.4)

Improved overall structural performance means that it is possible to reduce wall tie frequency and to reduce or even eliminate the use of wind posts. It is also possible to construct openings without the need for lintels on certain spans.
It was considered an important aspect when introducing the thin joint system to UK designers to highlight benefits of structural design. It is necessary to ensure that structural engineers are satisfied with a material for which both the British Standards and Euro Code still have little design guidance. Accordingly the need to carry out tests and produce design data and guidance was essential. The current masonry code does contain information on thin joint masonry however, this information is more applicable to blockwork than to clay facing bricks particularly since the anticipated “thin joint” was going to be more than 3mm which is in fact the maximum thickness allowed in the code, this largely being due to variation in the clay brick size.

3.1.5 Material and structural testing

Tests have been carried out at laboratories (Oxford Brooke 2004) and by the Author in conjunction with Hanson Building Products laboratories on many of the physical properties of the bricks, glue mortar and bricks built with glue mortar. In addition test work has been undertaken on aggregate blocks, aggregate blockwork, aircrrete blocks and aircrrete blockwork. However the adhesive mortar for non clay units is different from the Omnicol pvm mix, and is an alternative called Omnicol ConFix. Confix is appropriate for aggregate concrete blocks although the Omnicol pvm adhesive will also work with this material. It is however an expensive alternative. Information is documented in Chapter 8 of this thesis.

3.1.6 Background to the development of the thin joint adhesive system in the UK - a market opportunity leading to the first case study.

Members of The Brick Development Association’s technical Brickwork Working Party recognised that investigation into the adaptation of the European thin joint adhesive process would present a potential opportunity for its manufacturing members to promote a new masonry system which, if proved acceptable, would be beneficial to architects, engineers and contractors alike and expand the use of bricks in the UK.

In spite of success in Europe, for the process to be accepted in the UK it would be necessary to consider three distinct sectors of the construction team

Design – It would be necessary to ensure that the properties of the glue mortar and of the constructed bricks and glue mortar had acceptable strength parameters to comply with UK design methods and indeed to satisfy UK engineers that the product was fit for purpose. This would either mean ensuring compliance with existing legislation, obtaining a BBA Certificate for the system, or producing documentation with design, detailing and construction processes clearly laid out for the end users.
Construction. – The claims made by Dutch manufacturers would have to be questioned when the products were used in accordance with UK construction practice. For example as already mentioned the brickwork would not be built in the UK without the inclusion of fully mortared vertical joints or perpends. Additionally it would be necessary to ensure that the glued brickwork would be able to marry in with standard or traditional products or details.

Workmanship and Buildability – The thin joint system using the pump and gun laying technique is claimed to be considerably faster than traditional trowel bricklaying. It was also stated that using the pump and gun eliminated the need for the level of craftsmen required for bricklaying. Evidence of this would need to be provided.

In addition to these key criteria it would be necessary to ensure that UK architects would find the scenario of having all brick and no joints visually appealing. There was also the practical aspect of how to deal with construction detailing of bricks and mortar where the co-ordinating sizes might not tie in with other components within the cavity wall, including ties, the inner leaf, lintels if used and doors and window openings.

UK design guidance did not lend itself to providing suitable information on thin joint masonry strength parameters since no test data was available to allow correlation between the thin joint adhesive, different brick dimensions and flexural strength. As is typically the case with masonry, apart from the use of sophisticated methods of structural analysis, testing would need to be carried out on wallette sample panels for both vertical and lateral loading. Wallette specimens are small walls usually built in a laboratory, tested in the vertical orientation in such a way as to give the compressive strength and the lateral tensile flexural capacity of masonry about axes parallel and perpendicular to the bed joints. (BS EN 1052, 1999)

The brick industry through its trade organisation the Brick Development Association (BDA) applied for and successfully won a three year programme funded by the Dti’s Partners in Innovation (PII) initiative and this commenced in 2001. The success of this funding was based on recognition of a need to improve national clay brick sales. The objective was simply to determine the properties of thin joint masonry and consider its application in the UK (Oxford Brooke 2004)

The objectives and main findings of this were:

- To review any work already undertaken in the UK and to consider the characteristics
and advantages of thin-joint glued brickwork.

- To examine the working practices and tests used in countries applying this technique which usually related to their national codes. Some of these practices are briefly discussed in this document and a list of publications is provided. Caution is required in transferring test results and code information to the UK.

- EuroCode 6: Design of Masonry Structures EN 1996-1-1 contains sections relating to brickwork using ‘thin layer mortar’. These were discussed in relation to UK requirements, in particular the difficulties invoked by the limitation to a maximum of 3mm thick joints. An increase to at least 4mm is recommended.

- To carry out tests on thin-joint mortar, brick couplets, prisms, wallets and panels in order to compare properties with conventional brick construction; these tests indicated enhanced mortar compressive strength, faster setting times, and enhanced panel compressive and flexural strength but in most cases these occurred only under certain conditions.

- To evaluate the appropriateness of available and potentially suitable wall ties in compression and tension. The thinness of the joints and the non-alignment of bed joints provide particular challenges. Two tie types are deemed suitable for UK conditions. Further action on production and testing was recommended.

- To study issues relating to site practice, when building with thin-joint glued brickwork. This would enable differences and difficulties to be compared with traditional brick construction techniques. Recommendations included specific training and an adjustment of work practices when this technique is used.

- To recommend detailing and architectural issues associated with dimensioning, pointing, expansion joints and other constructional issues.

- To determine the suitability of thin-joint techniques for brickwork prefabrication. Tests carried out by industry demonstrated the potential advantages of using this form of construction for production, lifting and transportation. (Oxford Brooke 2004).

The Dti Partners in Innovation project at Oxford Brooke was probably the most important milestone towards the development of thin joint adhesive masonry in the UK. (Oxford Brookes 2004). It was on the back of this work that considerable further research was and still is being undertaken in a continued drive towards the use of glued brickwork, particularly by the author towards the technical and commercial development of prefabricated masonry. (Rogatzki 2001)

Although all BDA member companies were invited to become involved in the project, none took up that offer with the exception of the author on behalf of Hanson who had previous
experience of the glued masonry system through the company acquisition of Desimpel, the Belgian brick producer.

The full report and an abridged version or technical promotional document are attached in the Appendix to this work as much of the testing is still relevant.

As this project was nearing completion, an opportunity arose to construct a new School of Architecture and Planning for The University of West of England (UWE). The Architect Craig White of White Design was interested in the thin-layer mortar system and the visual affect that might be achieved by its application. The UWE building was subsequently built and is referred to as Case Study No 1. Although this was not the first building constructed in the UK using the thin joint system with the pump and gun process, it was the first project to be successfully completed, all previous attempts being abandoned in favour of traditional techniques largely due to inadequate training and preparation of operatives prior to commencement on site.

In spite of the extensive knowledge gained from Oxford Brookes’ project (Oxford Brooke 2004) there were a number of aspects about thin joint adhesive masonry which could never be answered comprehensively until the first full construction project was under way. (White, 2004)

Some of the key points to consider regarding the on-site construction and operatives familiarisation included:

- Training and preparation in bricklaying with the polyjet pump and gun – this should not (as has often been the case) be a reactive arrangement whereby the contractor sends two or three operatives on a 1 hour familiarisation session with a sales representative the day before construction work is due to begin. Training needs to be prepared for in advance and if carried out correctly will usually involve at least 2 days which includes working knowledge of the polyjet pump and guidance on mortar application and brick laying.
- Actions to take with regards to daily cleaning, preparation and maintenance of the polyjet
- What to do in terms of repair and maintenance – contact details to be clearly displayed and available for site supervisors. These will include direct first contact details of maintenance engineers and preparation on courses of action in the event of problems. Quite often the maintenance specialist would visit the site on an emergency call out, only to find that the problem could have been resolved very quickly if the operatives had thought more about the issue in question.
Establishment of the skill level required to achieve the necessary quality. Claims that the thin layer adhesive system desskills the bricklaying process are not true. For good quality brickwork the operatives must be skilled craftsmen and they must be willing to embrace the thin joint system. What is correct to say is that the system enables a higher bricklaying output rate per day, but only in the hands of skilled bricklayers.

Daily work programming for a 2+1 gang – the labourer involved with thin joint systems tends to be as busy if not more so than the bricklayers.

It is essential that good care is taken of the polyjet pump and glue gun machine and it is cleaned out thoroughly after each use (Ankerplast 1999). Due to its fast drying and higher strength properties, any glue left to stand in the hose or drum will harden and cause problems the next time the pump is used. If the pump needs to be left for a while with the glue inside, the mixing paddles should always be kept going (in reverse) and the gun should be placed in a bucket of water. When resuming use of the machine it is advised that the glue in the length of the hose be discarded as it may have begun to set. Extreme temperatures need to be avoided and the hose should not be left to lie on surfaces that may cool or heat too much, again the mortar within the hose will be affected.

The following case studies provided an excellent test of the thin joint in-situ system in the UK in terms of construction, design approach, detailing and adaptation to UK construction practice, dealing with on-site conditions and attitude of contractors and bricklayers.

The projects were from a variety of building types including a standard pair of detached houses, two university buildings, an art college and a one off innovative house. All were in different locations and constructed under various contract types from design and build with a main contractor to a private self build with sub contract specialist brick laying teams.

The case studies are listed below and thereafter described in this thesis (Chapter 3.2.1. to 3.2.5.)

1. University of West of England, Bristol, Department of Architecture and Planning
2. Two private detached Houses, Tuxford, Nottinghamshire
3. The Old Stores, Thaxted, Essex
4. University of Hertfordshire, Computer Building
5. Luton Carnival Arts Centre
3.2 Case studies of thin joint adhesive masonry

3.2.1 Case study no. 1 - University of West of England, Bristol. Department of Architecture and Planning

Architect – White Design
Contractor – Willmott Dixon / Turners
Consulting Engineers – Buro Happold & Integral Design (formerly Mander Structural Design)

Completed 2002

3.2.1.1 Introduction
The School of Architecture and Planning incorporated a number of innovative construction systems and materials. Additionally there was a focus on environment and services facilities including lighting and use of grey water.

The concept was to produce an environmentally efficient building providing an appropriate setting for the training and development of architectural / planning students. The superstructure included two innovative wall systems ie the thin joint glued brickwork and the straw bale walls to the gable ends.

3.2.1.2 Overview – Introduction
The opportunity to construct what would be the first significant building in the UK to employ thin joint adhesive technology for clay masonry came about as a result of the Partners In Innovation project at Oxford Brooke. A structural engineering consultant (Mander Structural Design – now Integral Design) who was part of the Oxford Brookes team was also involved in the conceptual design for the UWE building and had concluded that the masonry façade layout – using large format stack bonded clay brickwork – would lend itself to the thin joint glued system. Indeed the format of masonry panels in terms of dimensions, regularity of shape and repetition would have given an ideal opportunity for prefabrication. However, although not a new idea in Europe, this was seen as too significant a leap forward when trying to win the confidence of both the client and the contractor bearing in mind that cost as always would be critical.

3.2.1.3 Project details
The building comprises a 3 storey structure with lecture rooms and studios. Internal layout includes a large open plan 2 storey area with natural roof lighting. Figure 3.1(a) – (c) shows the elevation, architectural detail of brickwork, roof structure and windows.
Superstructure – structural steel work mono pitch frame (Figure 3.1(a) – (c)).
Perimeter walls – end elevations – straw bale designed and developed by White Design and Integral Design.
Perimeter walls – front and rear elevations constructed alternately in glazed panels / masonry cavity wall panels.

Masonry wall details

| Internal leaf | – 100mm aggregate concrete block 415mm x 215mm |
| Mortar for inner leaf | – 1:1:6 standard designation (iii), (now class M4 BSEN 1996 – 1) |
| Inner leaf | - layed by traditional bricklaying / trowel techniques. |
| Cavity | – partial fill, 100mm o/a including 50mm mineral wool fibre |
| External leaf | – Clay brickwork 290 x 65 x 90 Hanson Desimpel Rosini bricks layed in stack bonded format with 7mm bed and perpend joints. |
| Wall ties | – sliding tie anchor provided by Ancon. |
| Wall ties spacing | – 900mm vertical and horizontal. |
| Mortar for outer leaf | – Ankerplast type B proprietary brand thin joint adhesive |
| External leaf | - layed using polyjet glue gun and mortar system |

An exposed decorative galvanised steel ring beam (channel section) located at first floor level was included to break up masonry continuity.

Total area of external cavity walls = 600m²

(ie 600m² of clay brick, 600m² aggregate block)

General laying rate for 2+1 gang = 700 bricks per day

Foundation type would not be affected by either conventional masonry or thin joint.

Figures 3.1(a) – (c) illustrate the building elevations and superstructure construction using the pump and gun thin joint process.

Figure 3.1(a) Main elevation showing stack bonded brickwork & full height glass panels. White Design 2003
Figure 3.1(a) – (c) Architectural elevations and superstructure construction

Figure 3.2(a) Polyjet pump and gun for application of the adhesive

Figure 3.2(b) Application of adhesive mortar from single bead dispenser. Mortar is placed centrally or slightly to the rear of the bed so that bricks are pressed from rear towards front and the mortar pushed forward

Figure 3.2(c) Adhesive delivered as 25kg pre bagged mix. Add water within mixer

Figure 3.2(a) – (c) Polyjet glue gun machine, pre bagged adhesive method of application in external brickwork. White design 2003

Figure 3.1(b) Gable end constructed with straw bale system. White Design 2003

Figure 3.1(c) Superstructure of structural steel work and traditional blockwork inner leaf

Figure 3.2(a) – (b) shows the thin joint brick laying process using the polyjet glue gun and pump. The specialist adhesive was supplied as a 25kg pre bagged mix to which only water is added. (Figure 3.2(c)). The water content is critical to the mix performance (Ref Chapter 8.3).
Figures 3.3(a) – (e) University of West of England. The completed superstructure and architectural detailing. External leaf 290mm long bricks x 65mm high x 90mm deep. Stack bonded thin joint masonry with bed and perpend joints = 7mm
This being the first thin layer mortar project of any significance there was an initial training period and the inevitable learning curve necessary for what is a radically different bricklaying technique.

### 3.2.1.4 Development objectives - Observations, results and conclusions.

a. First opportunity for Hanson in UK to evaluate use of thin joint high performance adhesive mortar when used with clay masonry.

The construction of the School of Architecture using the in-situ thin joint adhesive masonry process was only made possible due to the timely conclusions drawn from the Oxford Brooke PII study (Oxford Brooke 2004) and the fact that a member of the PII working group had encouraged the designers to put this process into practice on a live project.

Any new innovative systems, materials or processes presented to the construction industry are always met with an element of caution. It is critical for the proposer / provider of the system to be supportive of a client who may feel that they are being used as a guinea pig for someone else’s ideas. It is also important to ensure that at the very least a client who is prepared to take on a new idea will get what he would have expected.

An overall cost benefit from a thin layer masonry project must be realised if the idea is to progress further. This does not simply mean like for like comparisons of material or construction costs, but the overall conclusive cost must be advantageous.

b. Examination of logistics, of procurement processes, delivery, haulage and transportation of material.

Adhesive mortar is manufactured in Holland and is packaged in 25kg bags. Bags are packed onto timber pallets at 40 to a pallet. These need to be transported and stored. Transportation planning of material was critical in order to ensure no potential delays to the programme.

Material production time is not more than a few days. However one must add to this the transportation to docks, customs and admin time, shipping times, disembarkation
at UK port and transport to site. This can lead to a minimum delivery period of 14 days - subject to successful transport and shipping / ferry crossings which can be affected by inclement weather. Transportation problems could not be tolerated if a number of large scale projects run concurrently bearing in mind that there are no easy alternative suppliers.

To avoid potential delays material needed to be packaged in large volumes and stocked within the UK.

At some point in the future alternative adhesive materials should be developed and distributed from the UK.

c. Structural testing evaluation - compression, flexural and wall tie pull out

A series of tests had to be carried out to evaluate strength parameters which included lateral load, compressive load and wall tie pull out strength specifically for the brick type specified.

In 2002 the UK masonry code BS5628 part 1 included no design data for thin joint mortar so none of the standard design tables could be used for masonry calculations.

Instead tests were carried out in accordance with the procedures outlined in the relevant code appendices including wallette testing for both lateral load (characteristic flexural strength) and compressive load (characteristic compressive strength)

Wall tie pull out tests were carried out in conjunction with Ancon at CERAM laboratories.

Accurate evaluation of this data was particularly important as the wall was constructed of stack bonded brickwork which will manifest lower flexural strength in the continuous vertical joints perpendicular to the bed joints (normally referred to as the “strong direction” for the more familiar staggered stretcher bond)

The masonry performance also dictated the type and frequency of stainless steel ties and wind posts.
Wall ties were specified at 900mm both vertically and horizontally and the masonry performance was such that in terms of structural design there was no necessity to introduce wind posts. However in the event the design team considered it prudent to include them.

d. Establishment of a training programme for operatives of the system. This would include knowledge of materials and their behaviour, comparisons with standard mortars and laying techniques and adequate knowledge of the polyjet pump / gun.

In Belgium and Holland thin joint clay masonry systems have been well established and a number of approved training courses exist for new operatives and as refresher courses for those already conversant with the system. Standard training usually takes two to three days for beginners and it involves familiarity with both materials and the pump / gun machinery. Such courses are provided in conjunction with colleges and the material suppliers. The training is considered to be a formal part of the system and leads to operatives gaining recognised certification for levels of competency.

For the UWE project two bricklayers were sent to Belgium and underwent the training programme. However this happened some months prior to the start date on site (due to unconnected contractual issues) and as such a relearning exercise was necessary.

Prior to the masonry package starting, two polyjet machines were provided for the contractor. These were supplied by the adhesive mortar manufacturer and the normal process of plant hire being on a day rate was reduced due to this being the first project. Site commencement was a major anti-climax as the pump used for the demonstration would not work when initially set up! This scenario had taken place in front of the client, design team and contractor and as such did not provide a boost of confidence to the system in terms of first impressions.

Adaptation of polyjet glue guns for UK use – this presented one of the most complex issues albeit that it should have simply been a matter of conversion from one electrical supply voltage to another! All of Continental Europe employs a 210v electricity supply – not only in general and domestic use but also on building sites. On all UK sites a 110v supply is the only acceptable output. This necessitated using a step up transformer which whilst possible in practice does lead to a power supply which is sensitive to voltage pressure changes causing a cut out at the gun, the latter being supplied by only 12v.
e. Use of the project to identify the necessary skill level required for onsite bricklaying process.

Some of the claims made in continental Europe are somewhat overstated! Laying rates of 1000 bricks per man per day are said to be achievable by operatives who need only be semi-skilled.

It is stated in Belgium and Holland that the thin joint adhesive systems will both de-skill the bricklaying process and increase output – based on laying rates of up to 1000 units per day. This was not found to be the case. In order for the project to be a success it was found essential to employ the skills of high quality bricklayers who above all demonstrated a willingness to work with the system. Later in-situ projects were to endorse this aspect of the construction technique. Familiarisation with the pump and mortar process is not too difficult for operatives of all skill levels but setting out and achievement of plumb, lined and level masonry still requires high levels of tenacity in the setting out process.

The greatest stumbling block is the systems’ vulnerability to sabotage! All operatives be it bricklayers or labourers can very easily cause the pump and mortar system to break down or stop all together without too much effort. Similarly it is easy to demonstrate that the system is slow (bricklayers keeping the work output to a minimum) and to present finished masonry which looks unquestionably inferior to traditionally laid brickwork.

In the case of the UWE project, it was fortunate that from the outset two very experienced bricklayers and a conscientious labourer were employed from start to finish.

Alignment of ties between inner and outer leaf could potentially create difficulties unless special types of tie wire was used. These are a thin plate with a circular tube type tie across the cavity. Alternatively slotted channel ties which allow for easy alignment between inner and outer leaf bed joints could be used.

The quality of work was never in question and output was eventually in excess of traditional trowel methods.
Chapter 3 - Thin joint masonry – case study No 1

f. Workmanship, laying techniques and laying rate

It was noted from monitoring on site construction that the bricklaying output or daily rate of laying did increase with time and as bricklaying was drawing to completion the daily laying rate averaged 500 – 600 per man. An impressive result for stack bonded 290mm long bricks whose smooth regular finish and continuous vertical and horizontal joints were very unforgiving of imperfections.

Mortar volumes were closely monitored and this had a bearing on the overall cost of the materials and system when comparing with traditional masonry. (See section h below)

g. Monitoring system performance when working in varied climatic conditions including autumn, winter and spring.

Performance is affected by weather conditions in much the same way as for traditional bricklaying.

Water content of the mix must be adjusted to provide the right viscosity and this will be affected by air temperature.

A mix consistency must reflect not only the brick porosity (and water absorption / suction rate) but also air temperature and periods of prolonged exposure to direct sunshine / heat. As successive courses are laid masonry strength is enhanced by the weight of further courses. A mix which is too dry will crumble, not flow in a continuous bead and will not attain the desired adhesion level. Too wet and the mix will cause premature compression of the joints, noticeable by bulging and narrowing of the bed joints.

Mix consistency requires manual skill and judgement to avoid long term performance problems. Not only might the mortar be affected by climatic conditions in completed masonry, there is also a need to consider the glue gun, hose and pumping equipment. Extreme temperatures will affect the setting time of mixes and any machinery left with mortar within the workings may suffer irreparable damage. Examples include, blocked hose, gun or mixer paddles all of which will be beyond repair if left with hardened mortar on surfaces.
h. Comparative costs – conventional v thin joint masonry.

An accurate comparative cost analysis of a new system against a traditional conventional system or process is always extremely difficult to establish for a number of reasons. A number of areas need to be addressed including:-

- Materials
- Labour
- Transportation to site
- Specialist installation plant / tools
- Time taken offset against site management costs
- Prelims.

A simple and fairly basic exercise was carried out to compare the overall cost for the system as used with the cost of traditional construction but in both cases ensuring that as many parameters as possible are considered.

<table>
<thead>
<tr>
<th>Traditional system</th>
<th>£/m²</th>
<th>Thin joint</th>
<th>£/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bricks 30p each</td>
<td>45/m²=£13.50</td>
<td>Bricks 30p each</td>
<td>48/m²=£14.40</td>
</tr>
<tr>
<td>Mortar</td>
<td>£5.00</td>
<td>adhesive</td>
<td>£10.00</td>
</tr>
<tr>
<td>Labour</td>
<td>400/day x 1+1=£180=9m²</td>
<td>Labour</td>
<td>800/day 2+1=£300=16m²</td>
</tr>
<tr>
<td>(120 +60)</td>
<td>£20.00/m²</td>
<td>(120+120+60)</td>
<td>£18.75/m²</td>
</tr>
<tr>
<td>Machinery</td>
<td>=£50/day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixings</td>
<td>=£2/m²</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is important to use experienced bricklayers with an open mind and willingness to learn new methods. As with any new system there is a slow start. However, in spite of the initial concerns, all parties including the design and construction teams were very satisfied with the brickwork quality and appearance on the completed building.
3.2.1.5 Conclusions

The system provides new aesthetic style (thin joint), consistent quality, high level of accuracy, high bricklayer output and improved structural performance. This was demonstrated within the Case study and in subsequent case studies for in-situ projects. Added costs include pump hire, adhesive and high risk on reliability. Job worthwhile if money is available to give desired finish type. More likely to be specification led

Very important to have trained operatives and a backup maintenance service to prevent delays or down time.

Client was concerned that the party which brings the concept to the table should be able to support the whole package ie design, technical support and on site construction as a sub-contractor.

It was felt that an excellent idea had been sold to the client but that no one other than the system provider could give any expertise to its use.

Clients who allow an innovative project to go forward cannot do so “at their own risk”. They must be fully supported by the system provider.

Hanson subsidised the sub contract work ie all pumps etc provided free as was all repair and maintenance. This situation requires review and would not be cost effective on further projects.

It can be damaging in the early stages of innovative developments to be too ambitious as the project will fail to live up to expectations. Such a situation does not always readily allow for a second chance.
3.2.2 Case study no 2, Private development, Tuxford, Nottinghamshire
Two detached houses
April – June 2004

The intention of the client was to develop and construct two 3-bedroom detached houses which were built to a very conventional format on plan and incorporated standard traditional masonry wall construction, Jet Floor ground floor system, timber first floors and a truss rafter roof format.

3.2.2.1 Overview - Introduction

As is often the case with innovative construction projects, proposals and ideas often originate from someone already associated with the product development work. In this case the bricklayers who had become familiar with the thin joint adhesive brickwork system through both being trained and then becoming trainers were known to the house developer. This bricklaying team had also been responsible for building a number of masonry test panels for structural testing, durability trials and to evaluate the aesthetics of the format with a variety of UK bricks.

The developer having been suitably impressed with both the Hanson ideas and the bricklayers work suggested that he would be happy to consider building his properties using the thin layer masonry systems.

These two properties offered an excellent opportunity to build an environmentally friendly house using the thin joint masonry – both in clay brickwork and aggregate blockwork. Further this project was not so contractually demanding in terms of time scale or finance.

3.2.2.2 Development Objectives

1. Evaluation of a domestic project using masonry walls but using the thin joint mortar systems for cavity and single leaf internal brick and blockwork. Jet Floor prestressed ground beam and insulation block floor and Hollowcore pre cast concrete first floor. Traditional timber truss system was incorporated.

2. Asses the construction processes for in-situ thin joint adhesive masonry – clay brickwork and aggregate blockwork as appropriate. Evaluate the impact of whole wall thin joint masonry systems.
3. Because the house design was of standard construction and included traditional
details it allowed easy comparison with traditional construction techniques in terms
of time, quality, cost and ease of construction
4. Using the Hanson Jet Floor, an evaluation of the performance of the floor / wall
intersection was possible.
5. Houses were built under NHBC Certification. This ensures close scrutiny by third
party legislators / technologists which if successful ensures similar construction in
the future without legislative objections being raised. Comparisons to be made
between conventional detailing and the modified thin joint approach.

3.2.2.3 Structural Design
The overall structural stability of the houses presented no difficulties as overall
dimensions, wall arrangements and room layout complied with Building Control and
Regulation Approved Documents. Brickwork and blockwork flexural strengths,
compressive strength and bearing stress were evaluated and exceeded minimum criteria.

3.2.2.4 Architectural Detailing.
It was always anticipated from the outset that detailing and construction would be the
criteria which might present barriers to a successful build. Dimensional co-ordination
between bricks and blocks presented the most significant problem since 5mm bed and
perpend joints were selected for the facing brickwork outer leaf. This would not correspond
with the traditional sized blocks and a 3mm thin block adhesive joint.

3.2.2.5 Brickwork Properties (Hanson, 2004)

Hanson Calder reclaimed (Class B specification)
Standard format 215mm x 102mm x 65mm high
Mortar joints 5mm perpends, 5mm bed joints
Mortar type – Omnicol type B
Bricklaying was carried out using the pump and gun system previously trialled on the UWE
project in Bristol as well as for sample wall panels.

3.2.2.6 Blockwork Properties

To ensure dimensional co-ordination with the brickwork outer leaf, an aggregate block was
specified of a non-standard size ie 440mm long x 205mm high x 100mm thick. In any large
scale production a non-standard block would be fabricated – as for the house - as a one off batch.

The aggregate concrete block inner leaf also employs a thin joint adhesive mortar. The blocks were specially fabricated to be 205mm high to ensure coursing alignment with the 5mm bed joints of the brickwork ensuring correct placement of wall ties. The block adhesive differs from the clay brick adhesive being complimentary to cementitious products. It is applied using a gauge box (scoop) as opposed to the glue gun for brickwork and its main benefits are high strength and early setting time as well as the speed of blocklaying. (Figure 3.4a) compares the conventional and modified brick and block dimensions.

(a) Standard brick and block dimensions with 10mm bed and perpend joints

Bed joint thickness = 10mm, perpends = 10mm

(b) Standard brick and non standard block heights (205mm) for use with thin joint system

Bed joint thickness = 5mm, perpends =10mm

Figure 3.4 Dimensional variations of purpose made blocks for co ordination with thin joint brickwork.

The non standard dimensions using thin brickwork joints aligned to blocks with thin joints requires alteration of masonry sizes co-ordination (Figure 3.4b)
3.2.2.7 Cavity wall insulation and wall ties
Insulation was provided using 100mm thick Styrofoam rigid boards
Conventional ties could not be used as brick / block joints did not align vertically. Consequently Ancon sliding anchor proprietary ties were specified which involves drilling and fixing to the inner leaf.

In any large scale production a non-standard block would be factory manufactured in large volumes rather than the specific one off batch produced for this project.

3.2.2.8 Masonry construction process.
The bricks were layed using a glue gun and adhesive mortar pump in exchange for the traditional trowel methods. Good quality thin joint brickwork affords high compressive and flexural strength and an increased resistance to rain penetration. The high strength also allows for adventurous bond types since stretcher bond is not relied on for strength as is the case with traditional or conventional mortars. Pointing of thin joint masonry is not necessary (the glue gun lays continuous “beads” of mortar which are set back from the brick face) as a flush joint results after bead squeezing which compliments the reclaimed brick appearance of the Hanson Victorian Mixture. Another benefit of the glue gun is the neatness of the joints and the clean finish with very little mortar finding its way down into the cavity. Thin joints can create problems for bedding of lintels and dpcs. Figures 3.5(a) and (b) illustrate the brickwork laying process and use of a glue gun and adhesive mortar.
Mortar is applied to the perpends by standing a row of bricks on end and applying the mortar to those ends prior to laying on a pre laid mortar bed. (Figures 3.6(a) and (b))

The blockwork laying process employs a scoop and / or trowel (Figures 3.7(a) and (b)). The cavity wall construction is shown in figures 3.8(a) and (b).
Additional features to the masonry façade finish include prefabricated arch components and infill panels to gable features.

Another significantly innovative element is to be found in the ground floor system – Hanson Jet Floor precast beams with polystyrene block infill. This is used for speed of construction and for its thermal properties (Hanson 2004).
3.2.2.9 Conclusions and Lessons learnt

1. The overall quality of finish and appearance were to a very high standard. Aesthetically it was felt that the reclaimed brick with a thin traditional dark joint was most appealing. (Figure 3.10)

2. The structural performance of the masonry was better than required for domestic construction with resistance to lateral wind load and compressive loading being more than adequate.

3. Both the brickwork and the blockwork displayed standards of workmanship and quality which were significantly above average when compared with traditional construction.

4. Some of the detailing and dimensional coordination were difficult to establish and maintain when compared with traditional or conventional masonry construction. All details had to be redrawn in order to recalculate co-ordinating sizes for the brick with a thinner joint ie 5mm rather than 10mm,

5. Care was required when spacing wall ties – but fewer ties were required than in traditional build.

6. Thin joints can create problems for bedding of lintels and dpcs.

7. Use of the two different adhesive types can potentially cause error and confusion. Also there is a lack of flexibility as it is not possible to change quickly from one leaf type to another as a different mix needs to be prepared.

8. Use of the glue gun and pump system for brickwork on a small domestic site presents potential power problems. However since the machine runs as a matter of course on the standard 240v this is a particular benefit although it would not be allowed on larger sites where 110v is mandatory.

9. The thin joint mortar system for blocks is acceptable. It is fast, efficient and uses very low volumes of mortar.

10. The bricklaying system with pump and gun is vulnerable to weather conditions. Very wet weather can be hazardous when using the electric pump, bricklaying in cold weather must stop as the temperature falls to zero (as with conventional mortar systems)

11. Adjustment of water content for the brick adhesive mix is very important to avoid problems with workability and floating of units.

12. Overall bricklaying rates were faster than traditional trowel methods when comparing direct laying times. However the set up time and end of day cleaning for the adhesive system made overall output comparable rather than quicker.

13. Some brick laying was done by trowel rather than gun. A good quality finish was achieved but the system is slower due to the viscosity and “sticky” composition of the
adhesive which does not flow from the trowel. Instead it has to be treated like tile adhesive.

14. This being a small domestic site, dealing with waste mortar can present problems as all components of the pump and gun require thorough cleaning and power washing to ensure proper working order on the next use. The correct method, which was set up on site is to form a temporary sump area where mortar waste settles and is then removed as solid cement based waste when hard.

15. Gun maintenance is a potential problem, due to difficulty in carrying out repairs. Furthermore a fitter is often required, and also expensive parts are not available in the UK.

16. Adequate protection is necessary for unused bags of powder mortar, in a similar manner to conventional cement powder.

17. Adhesive consumption was approximately 50% that of conventional mortar as expected. However adhesive is more expensive than mortar.
3.2.3 Private individually designed house using structural masonry, Thaxted, Essex

3.2.3.1 Background / Design brief

The Client was the Chief Executive from Design For Homes, an organisation which addresses architecture in housing and is co funded by the RIBA. As such he was familiar with current product development and innovation within the industry and wanted to create a new home for 6 family members – plus an attached annex for single or two person occupancy.

**Design Brief - Floor space**

The house is built on a large plot of land originally the site of a 1950’s small bungalow positioned at one end of the plot and which was conveniently used as a temporary site office and was eventually demolished. The site sloped and had a stream running through the middle adjacent to the proposed location of the new structure and which was later used to feed a purpose built lake to the south east of the property. The land provided a habitat for great crested newts and some areas had to be "fenced" or cordoned off to prevent their access to the site area. Site access off a narrow minor road presented some limitations to size of vehicle entering the area.

A geothermal system was also included in the scheme. Construction in the soft buff coloured high quality clay facing blockwork has presented a striking addition to the Essex landscape which takes on many forms and images depending on the weather, time of day and on the seasons.

The design was developed around a number of innovative building products and systems which were under various stages of development at the time of project development. The specific area for the new construction was green field with heavy vegetation and undisturbed topsoil which presented extremely wet and muddy conditions in the winter months. This problem was compounded by the close proximity of the stream. This and the cold weather conditions proved to be a significant factor for the bricklaying process which was carried out predominately in the winter months and included long periods with on site temperatures recorded at or below freezing point.
Programme
The project was presented as a BBC type “Grand Designs” style project with a number of products being tested here for the first time. As a large self build project this inevitably led to the client experiencing many of the misgivings and co-ordination problems associated with such a building.

Although project managed by the client, there were difficulties in keeping to a disciplined programme and co-operation between trades, manufacturers of new and innovative techniques and the design team, was not always easily achieved. Cost and programme timescale were grossly underestimated and problems of project ownership became complicated as funding issues were not always clear. The author was directly involved in the supervision and management of the masonry wall part of the programme and can conclude that the overall construction programme was extended by approximately 9 months and the superstructure and sub structure build costs were increased by 30 %.

In spite of the many problems and a programme which over ran by 12 months, the end result has been a unique individually designed home which presents a very spacious and lofty structure of high thermal mass due largely to the massive masonry spine wall which creates the core structural component.

3.2.3.2 Groundworks, foundations and superstructure construction

Extensive areas of topsoil and natural vegetation had to be cleared as part of site preparation. This involved substantial trees. The area set aside for the eventual lake had to be excavated and soil from here was banked up a hill to a location in which it would eventually form part of the final landscape.

The Undisturbed vegetation overlying very soft ground led to a need for driven piles - 120 being required, many driven up to depths of 9m.

On top of the piles precast concrete ground beams were placed to form a raised foundation system to support the eventual masonry spine wall and internal buttressing walls.

The ground floor was constructed using the Hanson Jet Floor system ie prestressed beams with polystyrene in fill blocks spanning between, the whole composition being finished off with a structural screed.
**Superstructure**

The main structural element is a freestanding / cantilevered masonry diaphragm wall constructed in clay facing blocks for the external leaves with cross ribs being in dense concrete blocks. The wall is L shaped on plan, the longer 30m length forming part of the main house and the 15m return forming the central wall of the annex.

The wall is 9m high and is centrally located in the house with “lean-to" lightweight timber framed structures to either side forming the main house space. In the preliminary design, the spine wall was assumed to be a propped cantilever but the timber frame manufacturers would not allow their structure to take any load transfer from the spine wall, hence the assumption of a true cantilever.

The effective height of this cantilever was reduced locally by the introduction of some post tensioned buttress cross walls which formed internal walls to the ground and first floor space of the house (being approximately 4.8m high). These were built in dense concrete aggregate blockwork initially elected to be made as prefabricated panels. The build programme was such that on site construction was deemed more practical largely because the available bricklaying work force were committed to on site operations and the block panels if made off site would have been manufactured in Derbyshire some 120 miles away.

The external leaves of the spine wall were built in a stack bonded masonry format to give the desired finish of tiled, continuous joints both vertically and horizontally. However as with all masonry this would inevitably suggest that the flexural strength might be compromised by a lack of bond.

Using concrete blockwork for the diaphragm wall cross ribs lead to continuous vertical joints between the rib and inner and outer leaves. The use of the clay block work was the authors first choice for two reasons. Firstly to ensure homogeneous material within the wall structure, and also to try and bond ribs into the leaves even though this would lead to a bond pattern where the ribs were visible – a scenario not uncommon within diaphragm wall masonry. At one stage the use of standard clay brickwork was considered for the ribs in order to ensure some empathy in expansion properties (all clay having a tendency to expand whilst concrete blocks would inevitably shrink). However this would still require the use of clay brickwork adhesive rather than the cheaper blockwork adhesive material. Aesthetics and cost prevented this option. Since the ribs comprised some 15% of the masonry, use of the very expensive blocks would increase the wall cost accordingly.
The architect and client were from the outset very decidedly set on a stack bonded finish and this was the final choice. The result was to use concrete blockwork ribs which were tied into the external walls by means of stainless steel thin flat bar ties. (Figure 3.11)

Development objectives

a. Evaluate performance of the stack bonded larger format clay blocks using high performance adhesive.

b. Monitor performance of structural spine wall

c. Construct prefabricated post tensioned buttressing cross walls.

d. Establish structural properties of buttress walls and composite spine wall.

e. Monitor workmanship quality and buildability.
f. Site conditions and building processes throughout the construction programme which included a winter period.
g. Monitor performance of spine wall in respect of thermal mass.

Design information and construction sequence

A design model was made by the Consulting Engineer in order to demonstrate the structural system and overall stability (Figure 3.12 (a) to (d))

![Figure 3.12(a)](image1)
![Figure 3.12(b)](image2)
![Figure 3.12(c)](image3)
![Figure 3.12(d)](image4)

Figure 3.12 (a) – (d) Images of the model used to assist in understanding the design principals

The following sequence of images (Figure 3.13 (a) to (f)) show the construction processes for the foundations and groundworks

![Figure 3.13.(a)](image5)
![Figure 3.13.(b)](image6)
The main spine wall was constructed of continuous reinforced in-situ strip footing which bears onto piles.

Works up to ground floor level

The following (Figure 3.13 (a) to (f)) show the Jet Floor installation and the spine wall construction.
Completed in situ dense aggregate blockwork was post tensioned in order to provide an enhanced buttress wall effect. (Figure 3.15 (a) and (b))

The main living space or shell of the superstructure comprised a timber frame “lean to” arrangement of pitched timber joists. The external walls were made of triple glazed argon...
filled panels in conjunction with masonry. All internal finishes were solid plaster. The sloping roof finish was slate. (Figure 3.2.3.6 (a) to (d))

In spite of the many problems and a programme which overran by 12 months (due to various construction operations being delayed either by inclement weather, construction issues, defects and repair and maintenance issues on plant and machinery) the end result has been a unique individually designed home which presents a very spacious and lofty structure of high thermal mass due largely to the massive masonry spine wall which creates the core structural component. Figure 3.17(a) to (c).
Figure 3.17 (a) to (c) The completed house with lake in the foreground, Thaxted, Essex
3.2.3.3 Discussion

a. Performance evaluation of the stack bonded larger format clay blocks using high strength adhesive.

Large format clay facing blocks are not widely manufactured or used in the UK having only recently gained popularity with architects in the past 2 or 3 years. In Europe clay blocks are used extensively for internal walls and the inner leaf of cavity walls although their properties are different from clay facing blocks which have higher strength and superior durability for external use with a high quality exposed face. At the Thaxted project external clay facing blocks were required both for a high quality / low maintenance finish but also durability and structural performance.

Technical specification data is outlined below.
Testing ensured compliance with the appropriate masonry Codes.(BS EN 1999)
- Flexural strength of masonry
- Compressive strength
- Wall tie pull out strength
- Frost resistance.

b. Monitor performance of structural spine wall - movement

The objective was to evaluate potential movement and monitor actual movement of the masonry as opposed to any movement due to structural settlement. The diaphragm wall was constructed of external clay facing blocks for the inner and outer leaves while the internal cross ribs were built in concrete aggregate blocks. In such a detail the main concern was with differential movement as the clay material has a propensity to expand whilst the aggregate blocks will contract.

Movement properties

The overall wall dimensions based on the plan view of the L shape was 30m x 15m – a total of 45m of clay walling. In accordance with the relevant design information of the time basic guidance was given in BS5628 Part 3.
Common knowledge confirms that all clay masonry will tend to experience long term expansion unlike cement based materials which have a propensity to shrink. BS5628 Part 3 suggests as basic guidance that movement joints in clay bricks are spaced at approximately 10-12 metres. BS5628: Part 3 clause 5.4 states that in no case should joints exceed 15 metres and the spacing of the first joint from an internal or external angle should not exceed half of the general spacing. In long narrow runs of walling or panels, which have certain unrestrained edges, a spacing of half the general recommendations should again be incorporated. Movement joints should be continuous for the full height of brickwork.

Joints should be weather sealed on the external face and be filled with an easily compressible material such as Compriband, or any similar proprietary brand of filler. Materials, which cannot be readily compressed by hand, will not normally allow free masonry movement. BS 5628: Part 3 states that “the width of a joint in millimetres should be about 30% more than the distance between joints in metres”.

Cracking due to movement can often be induced from the corner of openings, i.e. windows and doors, but the prediction of such cracking is extremely difficult with many parameters to consider, including the interaction of various materials such as concrete and brickwork, and the structural behaviour of the building. The use of brick reinforcements such as "Murfor" or "Expamet" can provide some control over such cracking.

With respect to horizontal expansion joints for vertical movement, present construction techniques dictate that the outer leaf of a cavity wall should be supported in accordance with the guidance outlined in BS 5628 part 1 i.e. “The uninterrupted height and length of the outer leaf of external cavity walls should be limited so as to avoid undue loosening of the ties due to differential movements between the two leaves. The outer leaf should therefore be supported at intervals of not more than every third storey or every nine metres whichever is less. However for buildings not exceeding four storeys or twelve metres in height, whichever is less, the outer leaf may be uninterrupted for its full height”.

The spine wall of this structure presented no problems in respect of clay brickwork thermal expansion due to the restraint provided by the buttressing walls and the bed joint reinforcement placed in and around the vicinity of all openings.
Vertical expansion was readily accommodated (or rather resisted) by the diaphragm wall / cross rib structure in which the ribs and external leaves were built such as to move compositely.

Monitored for movement

c. Construction of prefabricated post tensioned buttressing cross walls.

Some prefabricated dense blockwork walls had been been built and tested at Kingston University (Kanyeto, 2006). This ensured that buttress walls of the desired dimensions would not present a problem. However due to programme difficulties these walls were eventually constructed as thin joint blockwork in-situ elements. Although prefabrication would have provided a much faster on site construction, access via a mobile crane would have presented logistics problems.

d. Establish structural properties of buttress walls and composite spine wall.

Compressive and flexural strength of dense aggregate blocks is required in their design. Kanyeto (2006) provided reliable data for design.

e. Monitoring workmanship quality and buildability.

One of the most critical parts of the construction was to set and maintain a suitably high standard of workmanship. This was always going to prove difficult with the smooth cream clay block which displays any mortar stains, chipping or blemishes. Further, joint consistency and uniformity is essential. Throughout the project workmanship was monitored and the end product was acceptable.

f. Site conditions and building processes throughout the construction programme which included a winter period.

The bricklaying team for Thaxted had already become familiar with the glue laying techniques from their previous involvement both in the construction of numerous test panels and of a previously completed project – 2 houses at Tuxford in North Nottinghamshire.
Brickwork for the Nottinghamshire project was to a very high standard with black 7mm joints to a standard size facing brick. Further, both the site conditions and the large format clay block caused difficulties in construction progress. Nevertheless adequate finishes were achieved.

It must be remembered that the spine wall when completed was to be fair faced on both sides and that both sides would present an internal wall to the building.

The heavy weight of the blocks also led to slow progress.

g. Monitoring performance of spine wall in respect of thermal mass.

The spine wall is 9m high and is L shaped in plan; the longer length being 27m, and the shorter length 12m. Being a structural wall, in a facing material that constitutes the internal finish for the entire length of the building presented concern regarding any potential expansion and subsequent cracking.

This phenomenon was allowed for by the inclusion of 2 vertical expansion joints which ran for the full height of the wall and were located through the complete wall thickness. Additionally bed joint reinforcement was included to provide restraint and interaction between brick leaves and blockwork ribs.

3.2.3.4 Lessons learnt

In terms of the elemental design, the wall and its strength properties lived up to expectations

1. Masonry spine wall solution was a success and demonstrated that a 9m high cantilever wall in stack bonded clay blocks is structurally possible.
2. Use of post tensioned buttress walls was successful in reducing effective height of spine wall
3. Openings were achieved without use of lintels, but by exploiting strength properties of the high performance adhesive.
4. On site work created problems due to poor site conditions, particularly in the winter months
Whereas design was successful, site management and construction works were problematic. However the end result was positive in spite of a number of major issues relating to ;-) 

1. Ownership of the project and on site responsibility were both issues which caused significant problems in keeping to programme.
2. Many construction materials and systems were being tried and tested virtually for the first time and when problems occurred their resolution was not easily attained.
3. Masonry – Working in cold weather presented all of the problems typically expected with traditional masonry i.e. freezing of materials such as mortar, difficulties in laying the larger format blocks due to floating and mortar workability.
4. Use of the glue laying pump was an item of significant concern. Problems with maintenance and reliability. Repair speeds were slow usually requiring the support of a specialist – time consuming and costly
5. Setting out issues – greater site control and accuracy are required due to the thinner joints. Particular attention must be given to the clay facing blocks, these being of a larger format than traditional bricks. The use of thin joints rather than conventional 10mm joints demands greater setting out accuracy.
6. Weather proofing the building was particularly problematic due to the design incorporating a “lean to” framed structure abutting the spine wall. The wall was constructed first and with its diaphragm format was exposed to the elements until such time that a coping detail was positioned.
3.2.3.5 Material properties and testing

As part of this project, material properties needed to be evaluated. This was included as a further objective. The investigations included the compressive strength of the mortar and the flexural strength of the masonry. Results follow.

Compressive strength of mortar – November 2004

ANKERFIX MORTAR CUBES FROM SITE AT THAXTED

A set of 8 cubes were cast on site and returned to the Hanson laboratory on Friday 05/11/04 – 2 cubes were made from each of 4 mixes:

1) From bag used 04/11/04 – Batch no. 10054001012819
2) From bag used 05/11/04 – Batch no. 10054001012819
3) From bag taken from new pallet – Batch no. 10054001012819
4) Black mortar – Batch no. 10055001012818

Cubes were demoulded and weighed on Monday 08/11/04 – 1 cube (ref. A) from each mix tested for compressive strength at 3 days old, 1 cube (ref. B) from each mix tested at 14 days. – The results are given in Table 3.2.3.1

<table>
<thead>
<tr>
<th>Cube Ref.</th>
<th>Weight G</th>
<th>Dimensions Mm</th>
<th>Approx. Density kg m(^{-3})</th>
<th>Ultimate Load kN</th>
<th>Compressive Strength N mm(^{-2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>2068</td>
<td>102x102x102</td>
<td>1949</td>
<td>79.4</td>
<td>7.63</td>
</tr>
<tr>
<td>1B</td>
<td>2090</td>
<td>102x102x102</td>
<td>1969</td>
<td>165.4</td>
<td>15.90</td>
</tr>
<tr>
<td>2A</td>
<td>2050</td>
<td>102x102x102</td>
<td>1932</td>
<td>77.2</td>
<td>7.42</td>
</tr>
<tr>
<td>2B</td>
<td>2051</td>
<td>101x101x102</td>
<td>1971</td>
<td>169.6</td>
<td>16.46</td>
</tr>
<tr>
<td>3A</td>
<td>2046</td>
<td>102x102x101</td>
<td>1947</td>
<td>72.4</td>
<td>7.03</td>
</tr>
<tr>
<td>3B</td>
<td>2063</td>
<td>102x102x102</td>
<td>1944</td>
<td>155.8</td>
<td>14.98</td>
</tr>
<tr>
<td>4A</td>
<td>2078</td>
<td>102x102x101</td>
<td>1978</td>
<td>93.6</td>
<td>9.09</td>
</tr>
<tr>
<td>4B</td>
<td>1986</td>
<td>100x100x100</td>
<td>1986</td>
<td>191.0</td>
<td>19.10</td>
</tr>
</tbody>
</table>

Mean 3 day strength: =7.8 N mm\(^{-2}\)
Mean 14 day strength: =16.6 N mm\(^{-2}\)

Table 3.2.3.1 Compressive strengths of mortar cubes – November 2004

Compressive strength of mortar – December 2004

ANKERFIX CUBES FROM SITE AT THAXTED

A set of 6 cube moulds were delivered to the Thaxted site on 25/11/04 – Made cubes were returned to the laboratory on the 17/12/04 – 2 cubes were manufactured from each of 3 mixes on 3 different days. The results are given in Table 3.2.3.2
Chapter 3 - Thin joint masonry – case study No 3

1 & 2) 01/12/04 – marked F
3 & 4) 05/12/04 – marked W
5 & 6) 07/12/04 – marked D

<table>
<thead>
<tr>
<th>Cube Ref.</th>
<th>Weight g</th>
<th>Dimensions mm</th>
<th>Approx. Density kg m⁻³</th>
<th>Ultimate Load kN</th>
<th>Compressive Strength N mm⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1905</td>
<td>101x102x102</td>
<td>1813</td>
<td>106.5</td>
<td>10.3</td>
</tr>
<tr>
<td>2</td>
<td>1920</td>
<td>101x102x102</td>
<td>1827</td>
<td>111</td>
<td>10.8</td>
</tr>
<tr>
<td>3</td>
<td>1854</td>
<td>97x102x102</td>
<td>1837</td>
<td>85.5</td>
<td>8.6</td>
</tr>
<tr>
<td>4</td>
<td>1890</td>
<td>101x102x102</td>
<td>1799</td>
<td>93</td>
<td>9.0</td>
</tr>
<tr>
<td>5</td>
<td>1987</td>
<td>102x102x102</td>
<td>1872</td>
<td>114.5</td>
<td>11.0</td>
</tr>
<tr>
<td>6</td>
<td>2005</td>
<td>102x102x102</td>
<td>1889</td>
<td>116.5</td>
<td>11.2</td>
</tr>
</tbody>
</table>

Mean strength “F”; \(=10.6 \text{ N mm}^{-2}\)
Mean strength “W”; \(=8.8 \text{ N mm}^{-2}\)
Mean strength “D”; \(=11.1 \text{ N mm}^{-2}\)

Table 3.2.3.2 Compressive strengths of mortar cubes – December 2004

Flexural strength of wallettes –

Gima Aversa clay blocks (nominally 327x215x90mm) were built into panels built with Ankerfix thin bed mortar. Load applied perpendicular to bed joints. Panels were 3 stretchers x 3 courses (nominally 989 x 653 mm) nominally constructed in stretcher bond with two beads of mortar.

Panels were numbered 150-155 and tested 05/08/04. Results are shown in Table 3.2.3.3

<table>
<thead>
<tr>
<th>Panel Ref.</th>
<th>(l_1 \text{ mm})</th>
<th>(l_2 \text{ mm})</th>
<th>(b \text{ mm})</th>
<th>(t_u \text{ mm})</th>
<th>(F_{\text{max}} \text{ kg})</th>
<th>(F_{\text{max}} \text{ N})</th>
<th>(f_{x} \text{ N mm}^{-2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aversa 150</td>
<td>795</td>
<td>470</td>
<td>647</td>
<td>88</td>
<td>1798</td>
<td>17640</td>
<td>1.716</td>
</tr>
<tr>
<td>Aversa 151</td>
<td>795</td>
<td>470</td>
<td>647</td>
<td>88</td>
<td>1771</td>
<td>17370</td>
<td>1.690</td>
</tr>
<tr>
<td>Aversa 152</td>
<td>795</td>
<td>470</td>
<td>646</td>
<td>88</td>
<td>1593</td>
<td>15630</td>
<td>1.523</td>
</tr>
<tr>
<td>Aversa 153</td>
<td>795</td>
<td>470</td>
<td>646</td>
<td>88</td>
<td>1791</td>
<td>17570</td>
<td>1.712</td>
</tr>
<tr>
<td>Aversa 154</td>
<td>795</td>
<td>470</td>
<td>645</td>
<td>88</td>
<td>2251</td>
<td>22080</td>
<td>2.155</td>
</tr>
<tr>
<td>Aversa 155</td>
<td>795</td>
<td>470</td>
<td>646</td>
<td>88</td>
<td>1769</td>
<td>17350</td>
<td>1.691</td>
</tr>
<tr>
<td><strong>Mean Values</strong></td>
<td><strong>795</strong></td>
<td><strong>470</strong></td>
<td><strong>646</strong></td>
<td><strong>88</strong></td>
<td><strong>1829</strong></td>
<td><strong>17940</strong></td>
<td><strong>1.748</strong></td>
</tr>
</tbody>
</table>

Table 3.2.3.3. Masonry Wallette strength about an axis perpendicular to the bed joints
The characteristic strength of the masonry is indicated in Table 3.2.3.4

<table>
<thead>
<tr>
<th>Panel Ref.</th>
<th>$f_x$</th>
<th>$y (\log_{10} f_x)$</th>
<th>$y^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aversa 150</td>
<td>1.716</td>
<td>0.23452</td>
<td>0.05500</td>
</tr>
<tr>
<td>Aversa 151</td>
<td>1.690</td>
<td>0.22789</td>
<td>0.05193</td>
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<td>Aversa 152</td>
<td>1.523</td>
<td>0.18270</td>
<td>0.03338</td>
</tr>
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<td>Aversa 153</td>
<td>1.712</td>
<td>0.23350</td>
<td>0.05452</td>
</tr>
<tr>
<td>Aversa 154</td>
<td>2.155</td>
<td>0.33345</td>
<td>0.11119</td>
</tr>
<tr>
<td>Aversa 155</td>
<td>1.691</td>
<td>0.22814</td>
<td>0.05205</td>
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<tr>
<td><strong>Mean Values</strong></td>
<td>1.748</td>
<td>0.24003</td>
<td>--</td>
</tr>
</tbody>
</table>

**Gima Aversa blocks** - Standard deviation of log values; 0.04974

$$y_c = 0.24003 - 2.18 \times 0.04974 = 0.1316$$

$$f_{kx} = \text{antilog}_{10} y_c = 1.35 \text{ N mm}^{-2}$$

**Table 3.2.3.4** Characteristic masonry wallette strength about an axis perpendicular to the bed joints

Gima Aversa clay blocks (nominally 327x215x90mm) were built into panels with Ankerfix thin bed mortar and tested with load applied parallel to bed joints. The panels were 2 stretchers high x 5 courses long (nominally 658 x 1091 mm). Wallettes were built in stretcher bond using two beads of mortar.

Panels were numbered 156-161 and tested on 06-10/08/04. Results are shown in Table 3.2.3.5

<table>
<thead>
<tr>
<th>Panel Ref.</th>
<th>$l_1$ – mm</th>
<th>$l_2$ – mm</th>
<th>$b$ – mm</th>
<th>$t_u$ – mm</th>
<th>$F_{\text{max}}$ – kg</th>
<th>$F_{\text{max}}$ – N</th>
<th>$f_x$ – N mm$^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aversa 156</td>
<td>930</td>
<td>390</td>
<td>652</td>
<td>87</td>
<td>594</td>
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<td>0.957</td>
</tr>
<tr>
<td>Aversa 157</td>
<td>930</td>
<td>390</td>
<td>655</td>
<td>88</td>
<td>535</td>
<td>5250</td>
<td>0.838</td>
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<td>Aversa 158</td>
<td>930</td>
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<td>653</td>
<td>87</td>
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<td>2740</td>
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<tr>
<td>Aversa 159</td>
<td>930</td>
<td>390</td>
<td>653</td>
<td>87</td>
<td>822</td>
<td>8060</td>
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<tr>
<td>Aversa 160</td>
<td>930</td>
<td>390</td>
<td>653</td>
<td>88</td>
<td>533</td>
<td>5230</td>
<td>0.838</td>
</tr>
<tr>
<td>Aversa 161</td>
<td>930</td>
<td>390</td>
<td>652</td>
<td>88</td>
<td>477</td>
<td>4680</td>
<td>0.751</td>
</tr>
<tr>
<td><strong>Mean Values</strong></td>
<td>930</td>
<td>390</td>
<td>653</td>
<td>88</td>
<td>540</td>
<td>5300</td>
<td>0.859</td>
</tr>
</tbody>
</table>
### Table 3.2.3.5 Mean and characteristic masonry wallette strength about an axis parallel to the bed joints

<table>
<thead>
<tr>
<th>Panel Ref.</th>
<th>$f_x$</th>
<th>$y \ (\log_{10} f_x)$</th>
<th>$y^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aversa 156</td>
<td>0.957</td>
<td>-0.01909</td>
<td>0.00036</td>
</tr>
<tr>
<td>Aversa 157</td>
<td>0.838</td>
<td>-0.07676</td>
<td>0.00589</td>
</tr>
<tr>
<td>Aversa 158</td>
<td>0.449</td>
<td>-0.34775</td>
<td>0.12093</td>
</tr>
<tr>
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<td>0.12090</td>
<td>0.01462</td>
</tr>
<tr>
<td>Aversa 160</td>
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<td>0.00589</td>
</tr>
<tr>
<td>Aversa 161</td>
<td>0.751</td>
<td>-0.12436</td>
<td>0.01547</td>
</tr>
<tr>
<td>Mean Values</td>
<td>0.859</td>
<td>-0.08730</td>
<td>--</td>
</tr>
</tbody>
</table>

**Gima Aversa blocks** - Standard deviation of log values; 0.15325

$$y_c = -0.08730 - 2.18 \times 0.15325 = -0.4214$$

$$f_{kx} = \text{antilog}_{10} y_c = 0.38 \text{ N mm}^2$$

In comparison with code values, these strengths are acceptable. It is nevertheless disappointing that the orthogonal ratio is so low as in other tests values have been much higher, in some instances approaching unity.
3.2.4. Case study no 4 - University of Hertfordshire, Digital Laboratory, Hatfield.

Architect – RMJM, Contractor – Bluestone Construction  
Standard UK format LBC Melford Yellow brick with 5mm thin joint  
All masonry laid insitu using the pump/gun system  
55000 bricks used overall  
Concrete blockwork inner leaf laid with standard mortar. Part of an RC Frame structure

3.2.4.1 Introduction  
This project included the most extensive area of thin joint clay brickwork to date on any UK building. It was particularly interesting to note that the walls comprised conventional brick / insulation / block cavity walls combined with a reinforced concrete superstructure. The only difference in design was for conventional masonry the use of a 5mm adhesive joint for the outer leaf brickwork which was laid using the polyjet pump and gun system.

The brick laying sub contractors had some experience of constructing thin joint aircrete masonry but this project was their first attempt at gun laid clay brickwork. There were inevitable initial teething troubles in terms of familiarity with and the correct care and maintenance of the glue gun. However as the work proceeded so did the daily output.

Quality was never an issue and both the materials and workmanship were considered to be exceptional, particularly when one considers that the facing brick is one which is normally perceived as a standard “house builders” brick; the Hanson London Brick Melford Yellow facing.

Project Name : Digital Laboratories  
Commenced November 06 - Completed May 07  
Address : University of Hertfordshire  
College Lane  
Hatfield  
AL10 9AB

Architect : RMJM, The Old Rectory, Church Lane, Fulbourn, Cambridge CB1 5EP  
Main Contractor : Bluestone, Harrier House, St Albans Road East, Hatfield, Hertfordshire  
AL10 0HE

The overall technique gives a clean cut finish to the brickwork.
The University of Hertfordshire’s new Digital Laboratory designed by RMJM and constructed by Bluestone, comprises a reinforced concrete frame superstructure with cavity walls constructed in what at first appears to be traditional brick and block masonry.

However when inspected from close quarters it is apparent that the external clay facing brickwork has been built using the Dutch thin joint clay masonry adhesive system. Some 70,000 Melford Yellow facing bricks with 5mm joints in grey adhesive mortar have been built in a traditional stretcher bond format.

The finished masonry illustrates a good example of standard format masonry which manifests dimensional accuracy and excellent consistency of colour.

The key difference in construction to traditional techniques was in the building process. Trowels were replaced by a polyjet pump and glue gun which delivers a continuous bead of adhesive mortar to the bed ensuring a standard of workmanship which does not vary. Mortar quality is closely controlled being delivered pre-bagged with only water being added on site.

The bricklaying contractor was Intrepid Limited and after a rapid learning curve all parties were agreed that the system enabled a quality of masonry which compares favourably with traditional techniques.

In addition to the outer leaf of the cavity walls, a number of freestanding walls were also constructed using the process.

Apart from quality, other benefits of thin joint adhesive brickwork include enhanced strength which enables a reduction in the number of wall ties per square metre from 900mm x 450mm up to 900mm x 900mm frequency, a greater resistance of the outer leaf to rain penetration and a much lower risk of efflorescence due to the chemical composition of the adhesive. Brickwork details are illustrated in figures 3.18(a) – (d).
3.2.4.2 Lessons learnt

Design and detailing

1. This project illustrated the additional design and detailing input that is required by the system supplier when recommendations are made over the use of a new and alternative system for which the project design team has little or no experience.

2. As a result of (1) above brickwork setting out had to be detailed by the brick manufacturer in order to address the 5mm bed and perpend joints which replaced the conventional 10mm joint so changing co ordinating sizes for brickwork.

3. Blockwork was laid with conventional 10mm joints hence a slotted stainless steel tie system was required to cater for the non-alignment of brick / block joints.
4. The above issues can only be completely overcome in a project if addressed early enough (preferably pre detailing stage) to avoid duplication of design work and subsequent cost.

3.2.4.3 Site issues

1. The bricklaying contractor was very enthusiastic to try the thin joint system in the hope that it would provide a faster more economical solution in conjunction with high quality. Had the contractor not been of this frame of mind it would have not been possible to use it on this project.

2. A period of tuition and training was recommended by the brick and polyjet pump suppliers prior to commencement of the works. This was delayed right up until the start of the project and was not carried out to an acceptable standard with many issues arising related to the machinery, electricity supply and disposal of waste from cleaning and working in poor weather.

3. Hanson provided an instructor to give demonstration of the pump workings.

4. Ongoing cleaning, repair and maintenance of the pump caused the greatest hindrance to the project

5. Machine reliability was always an issue and problems usually related to improper cleaning at the end of a working day.

6. Obtaining spare parts for the machine and hiring a mechanical / electrical plant specialist was problematic, i.e. costly and difficult to get at short notice.

7. It soon became necessary to establish a list of common spare parts which could be kept in stock to ensure continuous ongoing site work without delays or stoppages

8. Working in cold weather caused problems in a similar fashion to the problems experienced with conventional brickwork i.e. working in falling temperatures below 2°C was not advisable as it impaired the mortar workability and the setting process.

9. Mortar mix design and water content were difficult to control in respect of mix viscosity and ease of laying.

10. On site electricity supply is a major problem due to the polyjet pump and gun mortar application system being set up to run off 220 – 240 volts in Europe whilst all UK sites have power supplies of 110volt. To enable the pump to work it was necessary to build in a step up transformer (taking the voltage from supply at 110v up to 240v). This arrangement makes electrical supply very sensitive and any surges in power on site due to sudden use of other machinery such as tower cranes can often cause the polyjet plant to cut out.
3.2.4.4 Contractual issues

1. Since the system had been introduced to the design team and contractor as one developed for the UK by Hanson, this puts an obvious pressure on Hanson to provide machinery and a method of maintenance in order to avoid contractual delays.
2. For all issues to be resolved immediately this would require Hanson site supervision at all times.
3. It is not possible to rely on the bricklaying subcontractor as his own pressure to keep on programme will naturally cause diversion of problems back to the system supplier.
4. Without the suppliers own site supervision it is not possible to control work output and quality
5. In a number of cases when machine breakdowns were reported and specialist engineers checked out the problem, it was invariably human error ie negligence in use rather than machine parts which caused the problem. (This fact is endorsed when Hanson operatives worked with machines for extensive periods without any problems)

3.2.4.5 Conclusion

This was the first significant example which used thin layer masonry highlighting that large externally sourced subcontractors cannot be responsible for the system. It is uneconomic, vulnerable to abuse and can be at the centre of contractual delays.
3.2.5 Case Study No 5  
Carnival Arts Centre, 3 St Mary’s Road, Luton LU1 3JA Luton  
Architects – Ash Sakula,  
Contractor – Apollo Construction

3.2.5.1 Introduction  
The Carnival Arts Centre in Luton was constructed with in-situ thin joint clay brickwork commencing in 2007 with final completion / handover in mid 2009. The decision to try a thin joint in situ adhesive masonry process was taken by the architect following a visit to the Hanson Prefabricated Eco House constructed at the BRE’s innovation park in 2007.

With its complex brick bonding and curved external elevations it was thought impractical to construct the walls in a prefabricated form although this option had been a strong consideration. By the time that the thin joint option was chosen a number of projects had already been completed in situ with some success.

Architecturally this was a challenging construction in terms of the required masonry finish and the anticipated quality. The appointed brickwork sub contractors had already worked on three other projects with Hanson and the author and as such the Architect’s expectations were for a very high level of quality and workmanship particularly in the quality of mortar joints in terms of consistent thickness, colour and profile. (Figure 3.19)

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**Fig 3.19 rendered image of building layout (Ash Sakula 2007)**
Contrasting dark blue and cream engineering bricks were chosen with a blue black mortar. Masonry was largely curved in plan form and the colours were used to form a complicated sound wave pattern demanding attention to the placement of every clay unit. Typical construction details are shown in figure 3.20(a) – (b).

3.2.5.2 Construction and work on site
Site access was both restricted and with limited room available for locating the polyjet pumps.

As the programme went into the winter months low productivity resulted which caused frustration added to that brought about by the frequent stoppages due to pump related problems. The sub contracted bricklayers were quick to lay blame squarely onto pump and gun unreliability although it was often found during the subsequent repair sessions that the issues were frequently operative driven.

Stoppages were caused when mortar containing solid lumps passed into the mixing part of the pump and then through into the hose and the finer gun nozzle which became blocked. 

Figure 3.20(a) – (b) typical construction details are shown (Ash Sakula 2008)
and then required cleaning. The correct procedure with lumpy mortar is to report back to the suppliers as this is a quality issue. In such cases the resulting outcome is either to condemn the affected batch or to sieve the material prior to use. The decision on suitability would rest with mortar specialists and their assessment as to the structural performance of the material if used. Invariably where inspections did take place it was reported that the mortar site storage was inadequate and in some cases material was not fully protected from the weather and in particular rain and frost. At times the mixer paddle was not turning, the gun jammed and if the hose was not cleaned properly at the end of a working period non operation resulted the next day.

This project, more than any previous one, led to the conclusion that the application of a glue gun, polyjet pump and pre bagged mortar process will cause site disruption, delays, maintenance issues and slow progress with bricklaying. This scenario was contrary to initial expectations. The outcome of all this was a bad feeling between the sub contractor and Hanson, and problems with site supervision as the system became the scape goat for any masonry related delays. All too frequently the main contractors site agent would inform the author that the bricklayers had stopped working and recorded “down time” even before problems occurred. With this scenario there had been a complete breakdown in trust towards the bricklayers and for their part a lack of confidence and subsequently no willingness to see any success in the process. In such circumstances there was no chance that the system would stack up financially.

3.2.5.3 Architectural appraisal
In spite of the practical and contractual set backs, the Architect, Cany Ash, Principle of Ash Sakula, was very supportive of the system. Her own words describe her view on the creative styles of the masonry. “ the new Carnival Arts Centre in downtown Luton is strange, shambolic and magnificent. It consists of two new buildings astride a large courtyard with a continuous enclosing perimeter, part brickwork, part screen, both 4.5m high. Two large gates, one gold, one stainless steel mesh, break the enclosure at either end of the courtyard, a courtyard which is transformed into a street as part of the carnival route.

The larger volume campus building houses performance spaces, a state of the art workshop, teaching spaces and café. The smaller building hosts administrative offices, the national carnival archive, incubator units and a crèche. The courtyard is an all-both-and space: a green conversational lung, a spillover space for workshop and performance and a new street for carnival.
The brief asked for a building that reflects ‘the spirit of carnival’. To us that meant capturing some of the kinetic energy and materiality of carnival. Our choice of materials was led by this ambition, for the building to engender a sense of making and experimentation and a tactile, textural quality. And yet, while the façade craved attention it didn’t want to be an essay in tricksy bling. Like architects, carnival artists have a deep interest in materials. They work at the edge of possibility, designing kinetic structures the size of houses light enough to be carried all day on someone’s back. They are not a lay audience: they know when a junction is fudged. To win their respect the construction had to be well done, to be tough and robust and have some serious logic behind its playfulness.

For the brickwork we chose two bricks, one a smooth blue-grey engineering brick by Hanson, the other a white brick by Roben, with a thin 5mm glued joint. The glued brickwork forms a continuous wrap round the volume camp building, broken only by the full height display windows in place of expansion joints. Ikat patterns in white brick, based on samba acoustic rhythms, are stitched into the blue-grey brick either side of these breaks, creating a tautness stretching and leading round the building.

Minimising the joint thickness was important for this textile quality and to achieve this we used an Omnifix glue mortar pioneered in the UK by Hanson. The other benefit of this glue was that longer lengths of unbroken brickwork could be achieved than with conventional mortar.

The smaller, office and crèche building faces the courtyard with white brick to reflect a lightness back into the courtyard. The brickwork is punctuated by pop-up windows, breaking the parapet line, and steps in and out at each office or incubator unit, giving an individuality and importance to each of the spaces, the stepping also eliminating the need for expansion joints.”

Figure 3.21(a) – (c) serves to illustrate the brickwork of the completed building.
3.2.5.4 Lessons learnt

1. The bricklaying contractor was familiar with the in-situ glued system, the brick laying process and the characteristics of the polyjet pump. The prime objective for this exercise was to evaluate output and to try and establish competitive costs for materials and labour.

2. For this project a weekly hire charge was made for the polyjet pumps.

3. Reliability of the polyjet pump was a significant problem in the context of the brickwork subcontract.
4. Additional polyjet pumps were purchased so that a spare was always available. This was essential to avoid slow turn round time for repairs even though the maintenance mechanics were at close proximity to site. Call out responses need to be at least same day, and were anything up to 3 days.

5. A set of regularly required spare part components for the pump and gun were established and simple maintenance was agreed to be carried out by sub contractors.

6. Many of the day to day problems were caused by mismanagement of the polyjet – typically blocked hose, misuse in cold weather, inadequate cleaning at end of day. glue gun not cleaned.

7. The sub-contractor tried to recoup money based on allegations of programme delay which were not always validated by the main contractor.

8. Brick quality, colour and dimensional tolerance presented no problem for the system.

9. Winter weather conditions played a significant part in causing programme delay

3.2.5.5 Conclusions

The outcome of this project was to terminate the working relationship with the bricklaying subcontractor who discredited the system with the design team in an effort to make it unpopular.

The most viable solution for the thin joint adhesive brickwork system in the UK is to establish a design supply and installation team under one banner i.e. a supply and fix company. Such an organisation must also have complete control of the maintenance processes in order to eliminate site stoppage time.
Chapter 3 - Thin Joint Masonry

3.3 Summary and appraisal of thin joint adhesive masonry in-situ techniques in the UK based upon the overall conclusions relating to performance of the process in the Case Studies

As a result of the 5 in-situ case studies which included a variety of building types, locations, contractors and materials types the following conclusions were drawn

3.3.1 Appearance and performance. Thin joint masonry provides both architects and engineers with an opportunity to produce visually diverse concepts to traditional masonry in addition to superior overall wall performance in terms of structural properties and durability.

1. The concept of thin joint masonry using clay bricks of standard and non standard format is appealing to architects aesthetically. The reduction in percentage area of mortar (from approximately 20 to 10% or less) is desirable in bringing out a rich uniform clay colour.

2. The mortar's superior performance improves the bonding capabilities of the masonry which enables many bonding patterns to be included in a wall design giving greater versatility to the masonry appearance. Unlike traditional mortars, use of the thin joint mortar materials increases flexural strength in joints perpendicular to the bed joints ie improves the orthogonal ratio (typically valued at approximately 0.35) such that with some brick / mortar combinations the ratio is nearer to 1.0. This increases masonry design opportunities.

3. The improved overall structural performance of masonry built with high performance mortars allows for reduction in wall ties, fixings and lintels.

4. When thin joint mortar is correctly constructed with continuous bed and perpend joints (a characteristic which is not difficult to achieve with the use of the gun and pump system) there is an improved quality of workmanship and an increased resistance to water ingress or rain penetration through the outer leaf of a clay wall.

3.3.2 Thin joint masonry – work on site

The in-situ thin joint masonry adhesive system was expected to radically change the traditional bricklaying methods by introducing a pre mixed bagged high performance
cement based adhesive which is mixed with water in a poyjet mixing pump. The electrically
driven pump then delivers mortar via a flexible hose to a glue gun which includes a mix
speed regulator to control output. The hose simply supplies a bead – or in some cases
several beads – of mortar directly to the brickwork bed.

Such a system ensures that mortar is delivered in a consistent volume and located
accurately to the brick beds thereby improving workmanship consistency and quality.

The range of joint thicknesses for thin joint masonry vary from 3mm minimum up to
approximately 7mm maximum. Thicker joints may be laid although beyond 7mm the
masonry strength is reduced and the mortar consumption – and cost - increase to a level
which is uneconomic.

In Holland the thin joint system is often used with the perpends being left unfilled and the
bed joints being as thin as is possible to achieve. This is considered desirable by some
architects as it presents a more prominent clay finish – and a strong clay colour – than will
be achieved with standard 10mm joints where there may be up to 20% of the elevation
made up of cement grey joints.

With regards to the filling of vertical perpends, when this is necessary (as is the case in all
UK construction) it is achieved by laying a dry stack of units as soldiers or as brick on end
and then applying the glue gun to the exposed headers. By slicing through the continuous
mortar bead, each brick can be placed in the brickwork bed row with mortar already placed
on its header ready to receive the next brick.

With correct initial training of operatives and familiarity with the glue gun equipment it is
possible to achieve a brick laying output in excess of the traditional trowel methods whilst
also maintaining high overall quality of workmanship, consistency, appearance and
structural performance.

All this should lead to an increased use of the technique within the UK. However this is not
the case and there are a number of fundamental reasons why attaining success is marred
by a number of difficulties.

1. One of the most significant issues relates to a culture change. Bricklayers have carried
out the masonry laying process virtually unchanged for decades, if not several hundred
years. Proposed change will lead to some resistance and perhaps a little suspicion.
Bricklaying is a craft and promoting thin joint brickwork on the basis that “we can do without bricklayers” or that we can deskill the process is not something that will be well received.

2. Experience in the UK has shown that the thin joint system with its glue still requires skill especially for 3-7mm bed and perp ends joints. The joint application may be consistent but setting out, alignment and levelling depend on the skills that a bricklayer has learnt. It is not necessary to use gauged bricks or bricks of tolerances greater than the standard deviation according to EN771. But this in itself will require good bricklaying skills to ensure consistency in the brick / joint spacing. Use of gauged bricks would add to the already inflated cost of the glue mortar.

3. The polyjet gun works extremely well if it is used and maintained in accordance with the instructions and if a short tuition course is followed. Training is usually given by the adhesive or masonry manufacturers and two days is the recommended minimum. Training includes not only practical bricklaying using the gun but also correct mixes and care and maintenance procedures to ensure that equipment runs unhindered by either weather conditions or by human error.

It is an all too familiar scenario that contractors who are new to the system, having priced favourably and won a contract to supply thin joint masonry are then reluctant to spend any time on preparation or familiarisation before starting on site.

Some of the common problems that have been experienced are highlighted below

The European manufactured polyjet pump and gun run off a 220volt supply and as such cannot be used directly on UK sites which are supplied only with110voltage. This necessitates the installation of a step up transformer which is attached to the pump and requires all necessary safety checks and trip switches. The electrical supply from the pump to the hose and gun is only 12volts and should therefore present no hazard.

Setting up the gun and pump – the equipment is designed to run virtually continuous from start up to end of day completion which is followed by appropriate cleaning of the components. It is not advisable to leave the pump in a static position whilst still containing glue mortar which is designed to set rapidly, particularly in hot weather. One of the biggest problems will be if mortar remains in the hose for any length of time. It will set and render the hose useless. Similarly, mortar solidifying around the mixing paddle will be impossible to remove.
Mixes should be tried and tested, particularly the correct water content for ease of flowing from the gun and also compatibility for the general temperature and the brick properties such as suction rate and water absorption.

Hose lengths can vary to suit given circumstances. The shorter the hose the better as it reduces the load on the pump motor as it tries to push material through the hose and gun. Long hose lengths may be necessary where it is necessary to carry out work at a first floor lift whilst retaining the pump at ground level.

Bad housekeeping and machine maintenance inevitably lead to break downs and the need for repair. Inevitably this will lead to contractual issues relating to programme delays and cost.

Correct procedures
The issues which bring about potential claims for delay tend to occur because the system is developed by a material producer and endorsed by the architect. However in pioneering projects there is no clarification as to who has specific responsibility for the thin joint brickwork process. The system is designed and specified by the material producer who also supplies the mortar. Apportionment of risk needs to be clear to all parties.

**3.3.3 Construction and workmanship and the in-situ process.**
The pump and gun concept which has proved to be relatively successful in Europe has not been well received in the UK for a number of fundamental reasons.

1. Components and spare parts for the pump and gun are not readily available and are very costly. Furthermore, incorrect use, lack of care and poor maintenance of the equipment lead to costly damage and repairs
2. A culture change is needed when using the pump and gun system as compared with traditional trowel techniques and if not embraced by the operatives the process will not enable successful construction of masonry.
3. UK sites use 110volt power whereas in Europe all sites use 220volts. This fundamental difference had one of the most adverse effects on the process as it is necessary to use a step up transformer to run the machinery. The step up transformer is very sensitive to power surges from other on site plant such as overhead cranes and will often lead to frequent cut outs in power supply. A pump based on UK power demands needs to be
developed. This, however, is unlikely to happen until the demand for the product and system improves.

4. The thin joint system uses mortar joints that are less than 10mm and this will create design and detailing issues as the coordinating size of masonry is generally in keeping with other manufactured products such including doors and windows. Any deviation away from traditional coordinating sizes involves greater attention to detailing and possible requests to change from standard sized products to non-standard – which will increase costs.

5. When a building process is new there is a high risk of problems due to lack of familiarity even, as in the case of thin joint masonry, where the method is tried and tested albeit not in the UK. Consequently there is an understandable reluctance within the construction industry to expose a client to any new and innovative ideas particularly if there are any issues relating to quality or cost. This scenario was seen to be the case with all of the buildings constructed using thin joint adhesive. Each project was considered a success but the cost of attaining that success did not leave major clients wanting more until there was more confidence in the technique.

Without modifications or further development to plant and equipment and without a willingness by operatives to retrain for the new processes, it is difficult to see how the thin joint in-situ system can successfully progress in the UK. However, as the problems are related to construction, training and correct application rather than design related, it is believed that promoting the use of this material requires development in the pre manufactured processes and the use of prefabricated single and double skin cavity walls offers better opportunities. In other words, the risks must be removed from the construction process and taken by the manufacturer of wall panel systems.
Chapter 4 Market for Prefabricated masonry

4.1 Introduction
The need to improve the popularity of masonry construction processes was based on the steady and continued decline in the UK demand for clay bricks. A government drive to promote “modern methods of construction” (MMC, 2005) which followed on from Latham’s “Constructing the Team” and Egan’s “Rethinking Construction” brought about an opportunity to develop building systems that would be embraced by designers and builders alike. Specifically the modern methods of construction ideology was assumed to be focused primarily on lightweight construction such as timber framed buildings, lightweight cold formed steel framed buildings, SIPS panels and volumetric structures. All of these were perceived as being processes which would involve assembly, primarily in a factory environment, they were lightweight to transport and easily erected on site. Consistent high quality, high standards of performance and speed of construction were the principle design objectives.

Masonry was not automatically on the agenda of a designer interested in prefabricated building systems for several reasons. It is a relatively heavy material, built by manual labour relying on skill in craftsmanship. It is a labour intensive process where speed of construction is not a primary objective. It is not perceived as a process which would lend itself to high levels of repetition or repetitive component fabrication.

The objective of the following chapters is to consider the development of prefabricated masonry processes and techniques and to identify their potential for consideration as an alternative to the more established prefabricated materials. If successful prefabricated masonry provides a structural material which is highly durable and in the case of clay brickwork, aesthetically desirable. However success requires that such a process will be economically competitive.

4.2 Market statistics for walling and cladding materials
Including facing bricks, rendered block and insulated render systems, it is estimated that the total installed wall cladding area declined from over 45 million m² in 2008 to 39 million m², before showing gradual improvement to 48million m² in 2012 and 2013, as illustrated (Figure 4.1). The growth forecast predicts steady continuous increases up to and including 2018 with a figure of 68million m². The 48million m² of 2013 has a value of £1.8billion for materials.
Since a significant part of the UK cladding information and marketing data has been derived by AMA Research, their key findings and summary of their latest report for 2014 - 2018 are outlined below. This summarises the market and economic climate during the past few years, i.e. prior to, during and post-recession:

- The overall value of the market is difficult to estimate due to the fact that some elements are system based and the product and material is integral with the installation, but keeping this in mind it is estimated that product and material value at trade purchase price is £1.8 billion for 2013.

- The 2009-2011 downturn in the housebuilding, industrial and commercial new work markets impacted on demand for most cladding products and materials, in particular the largest groups - facing bricks, profiled metal panels, artificial stone, metal panels and curtain wall.

- Since 2011 there has been some improvement in output for private house building, social housing refurbishment, waste management infrastructure and the Central London office market.

- Driven largely by the Help to Buy schemes, and a shift back from flats to houses, demand for facing bricks has outpaced supply, with imports needed to make up the
shortfalls. This has been due to the time taken to restart ‘mothballed’ brick plants combined with a marked shortage of bricklayers.

- Energy efficiency legislation and requirements of Part L of the Building Regulations have driven up demand for insulated external walls, in particular render coated external wall insulation systems and composite panels.

- Over the short to medium term, reasonable volume growth is expected, largely driven by private housebuilding activity and the government’s Help To Buy and other affordable homes programmes.

- Other end-use sectors likely to show increased demand are commercial offices, waste management and leisure, reflecting expected recovery in the commercial new build sector as well as commitments to further expansion in sectors such as waste.

- There are a number of large-scale, high-end residential / mixed-use high-rise schemes in and around Greater London scheduled for development over the next few years. However, demand for cladding will possibly be limited to infill panels.

- Clay, and to a much lesser extent concrete, facing bricks still constitute the largest product group. The other main types of cladding used on private housebuilding developments are rendered systems and artificial stone. Standard rendering such as roughcasting and external wall insulation systems are used extensively on social housing newbuild and refurbishment and in particular in areas exposed to higher than average rainfall and strong winds e.g. Scotland and West Wales.

- By value the largest sector is the curtain walling and structural glazing sector, while the share taken by facing brick is considerably lower by value.

- Other higher value sub-sectors include the high specification zinc, copper and aluminium metal cladding systems, natural stone cladding and pre-cast concrete cladding systems.

- After brickwork, steel and aluminium profiled and composite wall panels comprise the second largest product group, the key areas of demand being: warehousing, out-of-town retail ‘sheds’, waste management and utilities facilities and industrial units. The impact of the recession on the retail and industrial sectors reduced demand for metal cladding, but demand is recovering with the need for more online retail warehousing and waste management facilities.
Over the 2008-2012 period, lower levels of construction activity in the commercial sector have fed through to reduced demand for up-market cladding, particularly unitised curtain wall and other architectural products. Since 2012, there has been renewed demand in Central London office projects and a growing trend among architects for copper and zinc rainscreen systems and roofing.

With so many different types of cladding products on the market, the supply base is highly fragmented, although there is a high degree of market concentration in some sub-sectors. (AMA 2013)

In the clay bricks industry, the top three producers account for around 80% of the market, i.e. Ibstock, Hanson and Wienerberger. (BDA 2013). These companies are also leading suppliers of other types of 'niche' clay cladding material such as brick slips and terracotta rainscreens. However, imports account for the majority of terracotta rainscreen systems installed in the UK.

The metal cladding panel market is a little more fragmented although Kingspan Insulated Panels is by far the largest manufacturer of composite panels. The profiled panel market is less concentrated (ONS 2013, AMA 2013)

Systems companies and their approved fabricators / installers mostly account for the lower-middle sectors of the curtain wall market. Leading systems suppliers in this sector are Kawneer, Technal, Schueco, Reynaers and Metal Technology. The largest installers tend to be general building envelope contractors including Prater, Lakesmere, Red Architectural and Baris Façades. The upper-middle to top end of the market is mostly accounted for by European turnkey contractors using bespoke solutions. In 2012-2013, the most successful in the UK were Permasteelisa UK, Lindner Façades, Seele UK and Yuanda UK. (AMA 2013).

In the renders and external wall insulation systems sector, there are around 20 or so key suppliers – key suppliers are Saint Gobain Weber, Sto, Alumasc Façades and Wetherby Building Systems.

The remainder of the wall cladding market is highly fragmented in terms of material types and in each sub-sector there are relatively few suppliers. For example Techcrete is the dominant supplier of precast concrete panels; Marley Eternit is the UK’s only manufacturer of fibre cement panels (their nearest competitor is Cembrit); Formica is the UK’s only producer of external grade high pressure laminate sheets, although there
are several major European brands supplied to the UK, chief among these being Trespa and Prodema.

Market research for cladding is not easily obtained and it has been noted that certain information provided by AMA has been contrary to current trends. In particular the suggestion that certain sectors are not yet realizing full growth potential is contrary to recent findings. Specifically MoD work, healthcare, hospitals, schools and universities are now increasing more than was predicted by the report.

The decline in brick sales (always measured as a quantitative value) went from 8 billion in the 1940’s to 4 billion in the ‘80s and then below 2 billion with continued decline due to economic issues. (Brick Development Association 2013) (Construction Products Association 2014). The current UK brick manufacturing output capacity was in the region of 1.7 billion for 2013 but it is unlikely that there will be a return to the 1980 levels of output due to a number of manufacturing plants having been closed and dismantled. Figure 4.2 shows brick production, sales, deliveries and national stock levels by volume from 2005 – 2010. (AMA Research, 2013)

<table>
<thead>
<tr>
<th>Year</th>
<th>UK Production</th>
<th>% change</th>
<th>Deliveries/sales</th>
<th>% Change</th>
<th>Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>2,748</td>
<td>-</td>
<td>2,570</td>
<td>-</td>
<td>791</td>
</tr>
<tr>
<td>2006</td>
<td>2,510</td>
<td>- 9</td>
<td>2,399</td>
<td>- 7</td>
<td>906</td>
</tr>
<tr>
<td>2007</td>
<td>2,471</td>
<td>- 1.5</td>
<td>2,409</td>
<td>+ 0.4</td>
<td>965</td>
</tr>
<tr>
<td>2008</td>
<td>1,926</td>
<td>- 22</td>
<td>1,796</td>
<td>- 25</td>
<td>1,105</td>
</tr>
<tr>
<td>2009</td>
<td>1,216</td>
<td>- 57</td>
<td>1,388</td>
<td>- 23</td>
<td>921</td>
</tr>
<tr>
<td>2010</td>
<td>1,351</td>
<td>+ 11</td>
<td>1,484</td>
<td>+ 7</td>
<td>778</td>
</tr>
</tbody>
</table>

Source: BIS/AMA Research

Figure 4.2 Brick and Block Market (AMA Research 2013)
Figures for national UK brick sales from 2011 to 2014 are as follows (Brick Development Association statistics 2014)

<table>
<thead>
<tr>
<th>YEAR</th>
<th>SALES (MILLIONS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>1,553</td>
</tr>
<tr>
<td>2012</td>
<td>1,456</td>
</tr>
<tr>
<td>2013</td>
<td>1,651</td>
</tr>
<tr>
<td>2014 (to Aug)</td>
<td>1.717</td>
</tr>
</tbody>
</table>

Percentage changes in brick and block sales over the past 3 years from 2010 to 2013 are shown in figure 4.3 (Office of National Statistics 2014)

Figure 4.3 Delivery changes month by month from 2010 to 2013. (ONS 2014)

4.3 Market for prefabrication – proposals for prefabricated masonry manufacture

The drive towards a change and improvement in construction techniques and specifically off site construction came with the promotion of Modern Methods of Construction (MMC 2005) which encouraged the development of materials and construction processes towards improving the overall output and efficiency and quality of the construction industry.

One of the key areas of focus was prefabrication.

The total offsite manufacturing sector was valued at £2.2bn in 2004, with prefabricated buildings having an estimated value at £640m. (ODPM 2006). The key potential area for
development of prefabricated panels was the social housing sector particularly in apartments and flats due to the repetitive nature of construction and these sectors represented strong continued growth. There were circa 23,000 social housing completions in 2005 of which MMC represented over 50%, with masonry solutions lagging behind those of timber and steel frame. As far as it is possible to deduce from the sample surveys (AMA Research 2007) the current situation has changed significantly in terms of the proportion of MMC houses built in prefabricated systems. The market share for timber framed buildings compared with traditional cavity walls has recently decreased. The graph shown in figure 4.4 (BDA 2013) highlights the market share for the key wall cladding systems.

![Market Percentage share of Wall Cladding Materials](image)

**Figure 4.4 Wall cladding market share (BDA 2013)**

Whilst this chart gives an overview of the market share for cladding it does not specifically indicate prefabricated processes. However it does illustrate “panels” as being just over 23% of the market. In addition figures are presented for curtain walling, metal sheet, concrete, fibre cement sheets, timber, tiles and cladding weatherboards. These systems are in essence prefabricated structural or non structural finishes as opposed to brick and stone which are generally deemed to be constructed in a traditional manor by hand using skilled craftsmen.
Until recently timber frame had seen a steady increase in market share compared to traditional masonry due in part to the ability of timber frame producers to offer complete build solutions utilising offsite manufacturing with an accompanying installation package (Structural Timber Association, 2012), (Stewart Milne Timber 2014, www.stewartmilne.com) and similar).

At one time the timber market share was as high as 10% in the UK and specifically 15% in Scotland. As is observed in graph 4.4 the market share in 2013 was 4.1%. To date the masonry industry has not been able to provide a competitive prefabrication offer other than the traditional supply of components direct to the builder or through appointed Sub-Contractors.

A clear opportunity was identified to offer offsite masonry manufacturing with a supply and fit solution of a product that has all the benefits of a traditional build.

The following information (Figure 4.5) is extracted from the document AMA Research, September 2014. The chart illustrates estimates of cladding products by area installed in 2013. (AMA Research, 2013). However, it should be noted that product definition, a lack of robust data and fragmented market structure means that estimates should only be treated as broad indications of relative market position. The product mix tends to fluctuate from year to year, as very large projects with large areas and/or high value cladding installations can distort the market. For example, high value curtain wall installations worth up to c £30m are a feature of that sub-sector, directly influencing the share achieved, according to the quantity of these larger projects completed during a given year. (Figure 4.6)
Key factors to note are:

- The overall share taken by facing bricks has increased marginally since 2009, mainly due to an increase in the volume of houses being completed, coupled with a decline in the number of flats built.
- To 2009, metal profiled and composite panels accounted for around 20% of the total wall cladding market by area installed, underpinned by their use on warehousing and out-of-town stores. However, a marked downturn in these key markets has since impacted on demand.
- Metal composite panels have taken share from built-up systems and single sheet panels, due to factors such as requirements for faster turnaround times.
- Rendered concrete facing blocks account for around 10% of total external wall finishing, although demand is largely limited to residential new build. Conversely, however, insulated render systems are mostly used on high-rise mixed-use and apartment block developments, hotels, schools and other non-domestic applications where they are becoming increasingly specified in conjunction with volumetric and panellised building system. Key factors to note are:
  - The share taken by facing brick is considerably lower by value.
  - The share taken by curtain walling systems and structural glazing is 24% by value, but by volume, closer to 5%.
• The value in the others category is driven by high specification metal cladding systems, natural stone and pre-cast concrete.

![Chart 13: UK Wall Cladding Market by Product Type by Value (Bricks, Metal Panels, Render Systems, Curtain Wall, etc)](image)

Figure 4.6 Product type – market share by value (£) (AMA Research 2014)

• Bricks are 40% by volume and 23% by value (Figures 4.5 and 4.6). This shows the potential for increasing masonry value by developing a prefabricated walling system where the profitability will be in both the masonry materials and installation.

Focus on the provision of new homes has increasingly moved up the government’s agenda over the past few years as housing demand continues to exceed supply (House Builders Federation 2013) together with an increasing need for more affordable housing. Sustainable solutions are now demanded in response to increased regulation and the anticipated consequences of global-warming. (Latham, 1994) (Egan, 1998, 2001, 2002) (ODPM, 2006)

Prefabricated cavity wall systems provide a stand alone masonry solution whilst single leaf prefabricated masonry can be used with lightweight steel and timber framed structures. These processes fitted well with the MMC construction solutions across the main end user market sectors; housing, apartments/high density residential and public/commercial.

Since its introduction, although the government of the day has changed and the economy has experienced the most dramatic downturn in living memory (CPA figures) the need for efficient construction processes coupled with the requirement for sustainable solutions has not altered and in the latter part of 2013 and 2014 provide continuity.
and moving forward there is a clear increase in infrastructure work and in the number of homes being constructed. This in turn leads to greater demand for all building materials.

This thesis represents a proposed strategic plan towards the development of prefabricated masonry solutions in all sectors including the commercial, retail, industrial, health, education and MOD construction.

4.4 Sustainability

During 2006 / 2007 the Government had sustainability at the forefront of its construction policies particularly in the field of social housing. This was first exemplified by the introduction of the Code for Sustainable Homes (CSH) in 2007. Accreditation to a high code level was required for publicly funded developments or those on public or formerly public land. This included social housing.

Prefabrication processes enable the environmental benefits of traditional masonry such as durability, low maintenance and thermal mass to be exploited, whilst enabling improvements during the on-site build process which will reduce the construction site impacts. These would include reduced waste as well as lower site energy and water use, and a reduced risk of pollution incidents. Transportation of complete panels rather than all of the component parts will reduce transportation costs even if only on the basis of reduced numbers of delivery loads.

The systems should be sufficiently flexible to allow the design of panels to meet the anticipated demands for more sustainable buildings, such as those that were being built to a high CSH level. Ironically the Code which was the invention of the Building Research Establishment is now being replaced by an alternative procedure which will form part of the UK Building Regulations. This means that the information therein and the regulatory requirements will be statutory law. Where prefabricated masonry processes can be adopted successfully this means that it will be possible to meet high standards in terms of energy, acoustics, air permeability performance and more recently thermal mass. The use of environmentally friendly materials and products, such as those with a high recycled content or low energy use in manufacturing, can be chosen where this is important as design criteria. Responsible sourcing of material also became an important parameter and recognition given to materials that are sourced locally rather than being imported from other continents. (BES 6001 2014)
During 2013 the organization known as Zero Carbon Hub produced a document which considers the “design v as built” solution. (ZCH 2013). This work considers the actual building performance based on measurements of parameters that are subjected to real build conditions which include variable temperature, wind and driving rain. The design v as built process highlights that good building construction practice, thermal mass, insulation and natural ventilation are the key elements of ensuring high building performance at a minimal cost.

The Code for Sustainable Homes will now be superseded by a supplement to the Building Regulations.

4.5 Target Market and Sales Projection
The affordable housing programme was the main driver for MMC within housing with government having originally set targets for social housing to be at least 20% conforming to MMC. These were surpassed and completions in 2005 were 23,398, with around 56% (13,185) of the properties in this sector being MMC. It was anticipated that this trend would continue to increase as government investment was dependent on greater use of MMC.

Geographically the majority of MMC construction is situated within London and the South East, which is understandable as the main growth area for new builds is here and the limited space and need for less disruption suits MMC products.

Initially focusing the MMC development (either through client partnership or ad-hoc projects) on this market segment was seen as a way to give a degree of confidence (lower the risk) in the context of market growth opportunities and to build on already established key client partnerships, where key account / project management communication channels are well established. This was endorsed by the potential housing number starts that were predicted and the repetition on units to be constructed.

However it was also established at this time that a sound market existed for prefabricated masonry panels in the non housing sector where repetition in panel types (eg spandrel panels, piers and smaller single skin walls) presented potential for less complex structural components.

The CPA 2014 half year review states “Output in the largest construction sector, private commercial, fell 33.1% between 2008 and 2012. In 2013, however, major office projects in
London have proved sizeable enough to start a recovery in the sector. The sector is expected to grow 2.7% in 2014 following growth of 2.4% in 2013. From 2015, wider economic recovery and a rise in demand for prime office and retail space outside of London and the South East should also boost the sector. The largest constraint to industry recovery continues to be public sector construction. Public non-housing output fell 27.2% between 2010 and 2012 and the sector is not anticipated to recover until the impacts of capital investment growth feed through in 2015."

4.6 Hanson Eco House BRE Offsite 2007
Prefabricated single skin glued blockwork was successfully used at the Building Research Establishment exhibition, Offsite 2005, where the author developed for Hanson Building Products the Hanson House (HH1), (Chapter 5.2.1 of this document, Case study no 6)

The site is part of the Building Research Establishment's (BRE) Centre of Excellence for housing with the purpose of showcasing MMC and innovative products within housing construction. OFFSITE 2005 projects acclaimed good accreditation throughout the industry and helped to raise product profiles. A second masonry structure, Hanson House 2 (now referred to as the Hanson EcoHouse™) was developed and erected at the BRE for Offsite 2007 using prefabricated cavity walls. Chapter 5.2.2 Case study No 7. Offsite 2007 showed how modern construction and advanced technologies are coming together to deliver higher performing, more sustainable and smarter buildings. This provided an opportunity to not only showcase this system but also to obtain a measured response from industry visitors to the show on the prefabrication process with what was a full scale example of a house.

4.7 Competition Overview
From the time of the Hanson House development starting in 2004 until the present day there is no direct competition within the UK market for a masonry cavity wall panel which has all of the performance criteria of traditional masonry embodied into a prefabricated solution. The development gave an opportunity to be at the forefront of MMC innovation within the UK. Other manufacturing plants for prefabricated housing solutions do exist in continental Europe but none follow as closely to a UK standard design, material specification and construction as does the Hanson EcoHouse™ along with its prefabricated masonry walls known by the trade marked name Hanson QuickBuild™. Manufacturing plants currently operating in Europe including Danilith and Rimatem. Danilith in Belgium is capable of producing approximately 250 bespoke houses per annum
since it was first set up some 60 years ago. Dutch manufactures Bergahoff and Verbo had similar operations in Holland but both are no longer trading. Currently Rimatem are the most active company in the true robotic masonry production process and their system includes continental bricks and clay blocks. (Rimatem 2014)

Competitive alternatives to masonry in prefabricated buildings within UK come from:-

Timber Frame (Inner Leaf) – This type of housing grew from around 11% to a peak of 17% of the total UK housing starts but currently the market share is approximately 8%. Over the past 6 years estimates suggest around 50% of UK social housing is now being made with timber frame. It is the largest sector in the prefabricated building market with a value of approximately £220m in 2005, accounting for a 45% share. This value has now been reduced to around £150m in 2014

Steel (both cold-formed and hot rolled) – is experiencing moderate growth across all the principle market sectors but tends to be strongest within low to medium high rise structures. Within the prefabricated semi-finished building market it had a value of around £123m in 2005 (25%).

Concrete – Had a value of £89m in 2005 (18%) within the market and covers pre-cast walls, floor panels and has a wide application in a range of end user sectors. It has significant high rise capability and is often used in apartments, public/commercial and all “party wall” sectors.

Structural Insulated Panels (SIP) – These are rigid foam insulation sandwiched between oriented strand boards. SIPS are experiencing good growth and had a value of £49m (10%) in 2005. These panels are generally used within walls, roofs, foundations, extensions up to 4 storeys high.

Panelised Modular Building Systems - Timber, steel and concrete. The UK market for panelised modular building systems was estimated to be worth some £440 million in 2013. Forecasts for growth are relatively optimistic, but dependent on recovery in the new housebuilding and other key construction markets.

The market comprises factory manufactured, 2-dimensional frames or panels for constructing walls, partitions, roofs and floors, typically supplied to site as systems in flat-
pack format. The main material used is timber, with other competing materials being light gauge steel, precast concrete and panels made from insulated oriented strand boards (SIPS).

The market has remained subdued following a period of significant decline between 2008 and 2010, primarily due to the downturn in housebuilding activity, cuts in public sector capital expenditure, the completion of major public sector construction projects and falling investment in private sector newbuild.

From 2013 onwards the tentative recovery in the economy, driven by the recovery in the UK housing and London office construction sectors have fed through to increased demand for MMC, partly due to temporary shortages of aircrete blocks and bricks. However, from 2015 the market is likely to experience more modest growth rates as this situation changes. Figure 4.7 summarises market trends.

The timber frame sector is by far the largest under review, with trends here largely underpinning those at the overall level. By value, the timber frame market was worth over £300m. The three other sub-sectors are much smaller, accounting collectively for around £110m.

Key end use sectors for panellised modular building systems are houses, apartment blocks, schools, budget hotels, smaller healthcare and care facilities and purpose built student accommodation. However, demand across the public sector has been impacted upon by cuts at central departmental, agency and local authority levels.

The industry has undergone some restructuring in recent years, with the exit of a number of major suppliers, particularly in the timber frame sector. Market supply is fairly fragmented, with no suppliers having dominant market shares - there are only three
relatively large manufacturers of timber frame systems that regularly report annual sales over £20m.

There could be a sustained recovery in demand for panellised modular systems in the short to medium term provided that key construction sectors, such as the private house building sector, continue to recover. The government’s pledge to support the development of up to 30,000 affordable homes in England and the need to accommodate thousands of armed forces personnel relocating from Germany should mean that affordable housing will provide a key sector for growth.

Another potential key driver should be the government’s Modular Building Systems Framework, which should encourage the increasing specification of steel frame and timber frame modular building systems on public sector projects. Other factors that should help overcome barriers to specification include the mandatory implementation of BIM across the public sector and the introduction of a quality assurance scheme by Build Offsite.

Taking these factors into account, forecasts for the short to medium term are for steady growth within the range of 3-5% per annum.

Volumetric construction
Between 2008 and 2010, market values declined primarily due to cuts in public sector capital expenditure, the completion of major public sector construction projects and falling investment in private sector new build. Since then there has been some improvement in the market, underpinned partly by demand for site accommodation on major infrastructure projects and the Olympic Games construction programme.

Key end use sectors for volumetric buildings for temporary applications are site accommodation, event hire schools, healthcare and commercial offices. Over the last 10 years the main areas of demand have been the MoD, healthcare, schools, budget hotels and purpose built student accommodation.
built by private developers. However demand across the public sector has been impacted upon by cuts at central departmental, agency and local authority levels. (Figure 4.8)

The sector has undergone some major restructuring in recent years, with the industry contracting and consolidating, a reflection of the cumulative impact of challenging trading conditions, restructuring and the exit of major players including; Tata Steel Living Solutions, Britspace Modular Buildings, Unite Modular Systems, Adroit Modular Buildings, Stackright Building Systems, Spaceover Group, Verbus Systems, Terrapin International and Vision Modular Structures.

There are tentative indications that from 2014 there could be a sustained recovery in the sector key drivers including; the government’s pledge to support the development of up to 30,000 affordable homes in England and the need to accommodate thousands of troops and their families relocating from Germany. By 2019, it will be necessary to build single living accommodation for some 8,000 junior ranks, equivalent to the size of junior ranks accommodation built under Project Allenby / Connaught.

4.8 Risks

Whilst the Government of the day originally set up and encouraged the use of MMC for house building, research is still ongoing to assess its benefits and due to the innovative nature of the building method within the UK certain issues remain a risk for successful market penetration. The formation of the Zero Carbon Hub by the NHBC are strong advocates of prefabrication and are involved in a design v as built exercise to look at the accuracy of physical properties of onsite work compared with laboratory evaluated tests. The Code for Sustainable Homes may be redefined with greater emphasis being placed on workmanship of in-situ construction such that traditional techniques are being promoted again. More recently thermal mass has also been quantified / evaluated within a building and masonry can now be identified as a viable and competitive alternative to light framed structures for overall energy efficiency

4.8.1 Technical

Although the automated / robotic wall manufacturing machine has been used within Europe, it has only produced single skin panels. A modified version of this would be the first of its kind to build brick / insulation / block cavity walls in this way and therefore ongoing development during commissioning will be essential. Any such plant would
require formal contractual technical support to minimise this risk bearing in mind the high capital outlay.

### 4.8.2 Cost
There are industry sources that suggest MMC has increased costs of around 7-10% over traditional methods. Although estimated costs of the prefabricated cavity wall are comparable, with supply and fix prices of circa £80m² it would be essential to work closely with its customers to ensure that the total benefits of providing this type of solution can be realised.

### 4.8.3 Volumetric Construction and Imports
Timber and steel product types are supplying most social housing MMC needs at present and this could continue to grow as they are better suited to volumetric construction due to their lightness in weight. There is however a continued risk as more and more competitors enter into the MMC market offering a greater choice, but current options do not offer the benefits of thermal mass, noise reduction and suitability for extensions that masonry provide.

### 4.8.4 Public and Specifier Attitudes
There are industry concerns about the public acceptability of MMC housing. Negative attitudes towards MMC may stem from highly publicised problems with historical use of prefabricated housing. However by using and selling the benefits of masonry albeit in panelised form, these concerns should be eliminated.

Specifier attitudes are often against prefabrication due to reduced design flexibility. The system is fairly flexible in the designing of the walling systems and for added convenience manual processes can be incorporated where necessary.

The author’s findings regarding transportation of prefabricated masonry demonstrate clear benefits in terms of environmental impact on local areas surrounding construction sites. Whereas materials for an on site built wall need to be transported by several vehicles for each of the component parts (bricks, blocks, insulation, wall ties and bed joint reinforcement, mortar, dpc materials, cavity trays and lintels) with a prefabricated solution the complete element is delivered in one consignment. A flat bed lorry will be capable of transporting five cavity wall elements, each one being up to 9m long x 2.5m high. This is equal to 22.5 m² per panel and 110m² per load. In terms of materials 110m² of cavity wall
includes 6600 bricks, 660 concrete blocks, 22.5m² of cavity wall insulation, the appropriate amounts of mortar, wall ties, dpc and lintels. Frequency of transport visits and the accompanying impact this has on the local area will be significantly reduced.

4.8.5 Skills, quality and quality control
MMC can require highly skilled labour for precise on-site assembly of factory-made house parts and there is current uncertainty about the availability of such skills. These risks combined with quality control issues would be greatly reduced by offering a supply and fix solution, which is considered essential. Hence the wall manufacturer will need to provide the installation service. The level of quality delivered on projects can be perceived as a critical success factor and there is generally a greater need for accuracy compared to traditional forms of housing construction. These risks are considerably reduced as only approved experienced installers should be appointed.

4.8.6 Accreditation
It was initially thought that any new manufactured process would be required to have a British Board of Agrément (BBA) and BRE Certification accreditation. Further, acceptance from the new standards for innovative dwelling construction (LPS2020, standing for Loss Prevention System) would need to be sought. The process could take over a year and could cost up to £100,000. However current thinking demonstrates that the prefabricated processes described in Chapter 5 may be designed in accordance with the standard construction legislative documents e.g the BS EN codes for masonry and the Building Regulations. This is because the assembled components behave as traditional masonry. The only additional design criteria relates to the loading during transportation, handling and installation. Load tests to determine performance and safety under this criteria are straightforward but will require simplified testing methods which are quick and easy quality checks (Chapter 8). If houses are built using unaccredited methods then it can be difficult to gain buildings insurance, and hence a mortgage. Hanson believe there is less risk than other forms of prefabrication as this system is using traditional masonry so accreditation is likely to be swift.

4.8.7 Change of Government
Many of the drivers for change towards MMC have been from government initiatives so any change in government may mean MMC slips down the agenda and loses focus and funding. The need for affordable homes and the housing shortage is unlikely to go away in the medium term and due to this system using traditional materials it shouldn’t be affected by MMC slipping on political agendas.
Research into prefabrication types has identified a number of key points necessary if prefabricated masonry is to increase in popularity.

When the Modern Methods of Construction (MMC) campaign was launched by the government in the mid 2000’s this prompted a renewed interest in prefabrication, rapid construction and a key focus on affordable housing since there was a distinct shortfall in the number of available homes. The interest level in prefabrication processes has come in cycles, in particular the massive build programmes of the 50’s and 60’s to produce multi storey tower blocks in framed structures with panelised cladding of various material formats. As time passed, however, it became clear that the quality and long term durability of such structures was questionable and either demolition or major refurbishment necessary.

In terms of the development of a prefabricated masonry system for the housing market this must be of simple design and composition and comparable with traditional construction. During extensive discussion with major housebuilders and developers some of the key drivers for successful prefabricated “heavy” materials such as masonry were identified:

- Cost must be comparable with traditionally built dwellings
- Design must allow for simplicity in architectural detailing with no requirement to alter other building components such as doors and windows

4.9. The potential for manufactured masonry processes

It is clear from previous data that in recent years brick sales reached a peak in 2007 of 2.4 billion bricks pa and then declined to an all-time low of 1.4 – 1.5 billion from 2008 – 2012 which coincided with the national (and worldwide recession). (ONS 2014). During that time the construction manufacturing industry experienced severe cut backs culminating in factory closures and redundancies so that any investment in product development in building innovation was minimal.

As things have now started to improve and the economy is experiencing growth there will be a need to increase manufacturing output. However any increases in clay brick production will be based on modifying and extending existing brick factories and improving output so that a steady increase will happen over several years in line with the trends in construction demands, economy and output. This increase is seen as preferable to an investment in new brick plants which have a typical capital outlay in excess of £30 million.
and the return on this investment is not always easy to realise with uncertainty in the economic climate.

The reduction in brick sales over the years is not only influenced by trends and changes in the economy but also to continued loss of market share to other materials and building processes such as use of alternative lightweight cladding systems and rendered finishes either replacing or supplementing brickwork facades. These changes result from perceived benefits of the alternative materials such as speed of construction, cost, performance or the appeal to architects due to aesthetic reasons.

Bearing in mind the aforementioned there is a need to improve the market share of masonry by increasing desirability for brick as opposed to alternative systems and materials such as timber, steel, concrete, glass or render.

4.10 Opportunities
Although the social housing sector has been used as the target for market penetration for prefabricated masonry panels there are many other opportunities for such a product both within housing and non housing sectors, particularly commercial buildings and infrastructure where speed of construction and repetition in panel design are critical.

4.10.1 Other Housing
The panels could be used within the private sector, of which there were over 845,000 apartment completions alone during 2004/05. A conservative estimate would mean around 42.2 million m² (est. 50m² per apartment) to target. (AMA 2013)

4.10.2 Single Skin
For builds where timber or steel frame are used this system could potentially provide either single skin prefabricated brick or block work outer skin cladding. With timber frame houses now accounting for around 20,000 house starts in the UK alone translating into 1.6m million m². HBP could provide the internal block walls for all types of housing, enabling a complete walling solution to house builders.

4.10.3 Other Sectors
In addition to housing there are also opportunities within all other end user sectors where traditional brick and block are considered. Research undertaken by AMA suggests the
residential sector only constitutes around 60% of the total pre-fabricated market, with healthcare, education and defence sectors all estimated to be worth £75m each by 2009.

A number of promotional techniques have been considered over the years to counter the declining interest in brickwork some of which are listed below:

- Potential for brick as a structural material. (BDA 1984), (Curtin et al 2008 latest ed) eg fin and diaphragm walls, off the frame cladding and reinforced / post tensioned brickwork.
- Improvement in the brick portfolio such as shape, size colour and texture. (Hanson, Ibstock, Weinerberger web site and literature, 2014)
- New laying techniques
- New prefabrication processes.

Members of construction teams will have specific requirements and expectations from materials:

- Architects – aesthetics, performance and low maintenance
- Engineers – structural performance, use of new construction techniques, design guidance
- Contractors – ease of build and cost.
- End user – durability, cost, performance and appearance

All of the above will be expecting a benefit from the material in terms of sustainability.

In all cases the key driver will ultimately be cost and confidence that a system is reliable. Most clients will be reluctant to be the first one to try a new material or construction method.

4.11 Case studies - Summary of thin joint adhesive masonry in-situ techniques as a background to prefabrication.

As a result of the 5 in-situ case studies which included a variety of building types, locations, contractors and materials types, conclusions were drawn and highlighted in Chapter 3. In short it was clear for the reasons documented that the UK construction industry would not embrace the concept of thin joint masonry even though the completed buildings were in themselves successful projects, in some cases winning awards for architecture, structural solutions and innovation. The fact that thin joint systems have been seen as an acceptable technique in Europe also demonstrates that national attitudes, building cultures and approaches to construction do vary depending on the attitudes of the
construction team. A good example of this is the use of thin joint adhesive brickwork in Europe where only the bed joints are filled and the vertical perpend joints left unfilled. The reason for this lies in the speed of construction (not filling bed joints increases bricklaying output by up to 50%) and the fact that the Europeans are comfortable to build with open vertical joints – a detail which would never be endorsed in the UK. This issue alone immediately removed a build time benefit of thin joint masonry.

The author has spent extensive time in Holland, Belgium and Germany investigating both the construction processes for cladding and the approach to cladding by architects and structural engineers. The findings can be summarized very simply. There is a clear willingness to embrace innovation and not the same risk averse attitude as is demonstrated in the UK. Consequently any new ideas appear to be more readily adopted in Europe than in the UK. The reservations to new ideas typically come from builders and contractors, less so from architects and structural engineers.

4.12 Background to prefabricated masonry

In order to examine an alternative option of providing a fast high quality cost effective masonry construction procedure consideration is given to prefabricated masonry. This technique is not new and although the concept is met with enthusiasm in practice it has not found popularity with the construction team including designers, contractors and bricklayers.

The reasons for this are many but principally the industry requires rapid construction, competitive costs when compared with traditional build and high levels of quality and appearance which match traditionally built brickwork. If these criteria are not met then an alternative masonry solution will not be accepted. The industry also embraces familiar techniques and there is a reluctance to take on any methodology which is new and where the cost is not easily controlled. In short no one wants to be the first to try what is deemed a new idea!

It is important to differentiate between true prefabricated masonry construction and composite concrete panels which comprise reinforced concrete cast onto pre cut brick slips in horizontal beds. Whilst the precast brick / concrete techniques are successful, they are considerably more expensive and are usually incorporated into longer spanning
structural members. The process of prefabricated masonry as documented in this thesis does not use composite brick / concrete but only mortar filled joints of masonry.

### 4.13 Prefabrication processes to consider

(Fisher 1992) has provided a report on the prefabrication types and processes that have been developed and in some cases used successfully although for a limited number of projects. The subject was further addressed (Edgell 2004) as an update to Fisher’s earlier work. Edgell’s report concluded that little had changed in either market size, prefabricated output or attitude to prefabrication. The basic processes include :-

1. Traditionally built masonry panels in a factory environment using conventional bricklaying techniques
2. Mechanised vertically manufactured panels using robotic techniques
3. Flat bed “cast” panels of masonry

Comparisons by the construction team will invariably start and finish with a cost of the panel (which includes manufacture, supply and fixing) against cost of in-situ brick laying.

If manufactured panels are to be competitive, until such time that it can be shown what savings are made when a true and fair comparison is carried out, the prefabricated panel development is driven primarily by a need to demonstrate that its cost is favorable with or even lower than traditional conventional masonry.

Adaptation of the three processes highlighted above will be dependent upon capital investment for each of the three processes, market demand and manufacturing output..

**Method 1 – traditionally built panels in a factory environment**

- Lowest capital outlay
- Slowest construction output but this can be varied depending on available labour
- Greatest versatility – due to use of skilled labour ie corners, openings, panel shape

**Method 2 –fully automated / robotic panel assembly**

- Highest capital outlay for machinery and a bespoke factory building
- Low labour costs - minimal labour force required, unskilled operatives with skilled supervision
• Implementation of CAD CAM processes to maximize design and fabrication output.
• High volume orders required and continuity of manufacture to optimise costs and maintain labour force.

Method 3 – flat assembly of panels in formwork
• Moderate capital outlay which may vary dependent on product demand
• Process will produce lowest cost panels due to simplicity of the process and the low capital outlay / payback.
• Not as versatile as method 1 but is suitable for inclusion of openings and short returns.
• Low labour levels and unskilled labour with skilled supervisors
• Design process based on provision of conventional detailing / drawings

Interaction between the three processes is possible and as a minimal risk operation, consideration can be given to the procedures in a strict order. The ideal manufacturing process will be a fully automated technique which includes robotic methods. The simplest and most economical manufacturing development will be the manually made panels in a large storage area or at least a large factory space. The former requires high initial capital outlay and a pay back period in excess of 5 years. However the volume output will be high (the highest of the three proposals)

The manually manufactured technique clearly demonstrates minimal capital outlay for the set up of the system and hence a short return on capital. This is a very versatile system and its output is improved by increasing the factory labour force.

The flat bed fabrication process provides some of the benefit of both techniques although the capital expenditure will be modest.

Almost all prefabricated systems are perceived as being more expensive than traditional masonry as they are generally compared on a material rate per square metre of the finished wall without taking into consideration the reduction in on site time, reduced site management or speed of installation. There is less prefabricated masonry in the UK than in other European countries, the USA or Australia although the technique has never been dominant anywhere in the masonry market. The most popular type of prefabrication in the UK is the composite concrete / brick slip format where either purpose made slips or cut bricks are placed in a mould, the joints sealed and concrete poured over the panel. This is a relatively expensive technique which is used primarily on very high quality specification.
work as in large commercial structures, the panels being of a structural reinforced concrete format.

In all 3 process types it is the mortar properties which are critical to the success of prefabricated systems and production of a structurally sound masonry element.

Some of Fisher’s findings in 1992 concur with those from recent market research by Hanson (Hanson – prefabrication development) (2008) and were as follows:

1. None of the companies fabricating masonry only systems developed in the 1960’s and 1970’s have survived commercially. This is also the case for certain companies still trading into the 1990’s who have now also ceased to exist.

2. Early prefabricated systems were based on horizontal casting techniques although the vertically constructed panels built by robotic processes have also developed.

3. Some manual processes of fabrication have been successful whereby bricklayers built vertical masonry panels in a factory environment. This process is successful but it is labour intensive and prohibitive of high volume output.

4. According to Fisher no prefabrication processes existed within a brick manufacturing company as the technique was considered to be inappropriate in the brick making environment. This is not now considered to be the case as is demonstrated by work documented in the following chapters of this research.

5. The building design process should incorporate prefabricated panels from the early stages as part of the conceptual process. Where prefabrication is considered as an afterthought (perhaps as a potentially more economical solution) invariably there are greater difficulties in achieving the required competitive costs as well as additional detailing matters.

6. Detailed commercial studies are essential to identify that market sector for which prefabricated panels are suitable. This should be done and conclusions reached on the viability of the project prior to investment in development time and production equipment.

7. In association with the commercial study a decision should be made as to whether the market identified is of a sufficient guaranteed size and of sufficient profitability to justify the capital funding for setting up a prefabrication operation.

8. Fisher’s final recommendation suggested that “It is not recommended that other methods currently described as being in use for horizontal casting should be adopted.” As will be reviewed in Chapter 7, it is precisely the flat bed panel
assembly albeit different from those described in the literature, which has realized the best potential for an economic prefabrication process.

9. Transportation of pre assembled panels has a particular advantage over traditional construction techniques as the panels contain the entire component parts i.e. mortar, bricks, ties and fixings. In conventional construction these component materials must be delivered separately.

Prefabricated masonry once installed will be subjected to the same loading conditions as conventional masonry. However an additional consideration is the loads and stresses of removal from the manufacturing plant, handling for storage, lifting, transportation, further lifting and installation. These design issues are readily dealt with in precast concrete panels due to the ease with which reinforcement can be accommodated to resist whatever loads may occur.

With masonry construction bed joint reinforcement may be implemented with little additional complication and relatively low additional cost and this will increase a panel flexural strength perpendicular to the bed joints only. Further reinforcement in the vertical direction (which would improve flexural strength parallel to the bed joints) requires considerably higher labour input, accuracy and skill to ensure adequate cover to the steel which in standard single skin leaf can only be threaded through the perforations of standard clay units. In such cases the perforations must be large enough to accommodate an appropriate bar diameter plus adequate cover. Additionally the brick perforation arrangement must be such as to enable alignment from one course to the next. This is readily achieved with a stack bonded format but difficult with stretcher bond brickwork which is the most common masonry used.

The construction process to build reinforced masonry with vertical reinforcement is slow as bricks need to be “threaded” onto the bars and this process is restricted by the height of the masonry being constructed. Use of reinforcement adds a significant cost to masonry both in terms of the material and labour. In addition the reinforcement of prefabricated panels is generally incorporated to provide strength when handling a panel and this is only for a short period of time. This is impractical if manufacturing conventional cladding panels which will seldom require reinforcement.

Accordingly any increased strength requirements during manufacture need to be of the lowest additional cost. Minimising reinforcement can only be achieved if a mortar is
implemented with improved properties (enabling flexural and tensile strength improvement of the brickwork). In addition a manufacturing, handling, transportation and lifting technique should be developed which minimises the loads and stresses during this procedure. These issues are discussed in greater detail for manual, robotic and flat panel manufacture in chapters 5, 6 and 7 respectively.

4.14 Conclusions
There is a steady and continuous increase in construction output in all building sectors including housing, commercial, industrial, retail, leisure, health, MoD and civil engineering.

The increased growth is seeing an increase in the use of masonry including clay facing bricks in all sectors.

Whilst annual brick sales are increasing they are not likely to return to the peak national sales figures of thirty years ago which were in the region of 4 billion bricks per annum.

Lightweight structural materials including steel and timber frame, composite panellised systems and volumetric buildings are looked upon as being the natural choice for prefabricated wall and building processes due to speed of construction and lightweight materials.

Masonry is popular for its aesthetic appeal, durability and low maintenance and it is generally perceived as a product that is constructed in-situ.

Designers would choose to use prefabricated masonry but to date there have been no systems developed which are considered to be viable alternatives if speed of construction coupled with building performance are the key criteria.

When the MMC campaign was launched in 2005 there was a strong belief that prefabricated masonry would find its best market and highest production requirements in the social housing sector. With this in mind it was assumed that a robotic factory manufactured process would provide the greatest potential volume output. Such a factory would be designed to produce some 50,000 m² of walling per annum. Flats and private housing were also perceived as having potential for high volume wall production. Current thinking indicates that whilst housing is still a significant building sector, the best potential
for prefabricated masonry lies in either civil engineering such as flood defence schemes, retaining walls and parapet walls or buildings which incorporate repetitious panel details. This latter sector is likely to be commercial, industrial or retail.

Three masonry prefabricated processes are considered in greater detail in the following chapters of this thesis with emphasis being given to capital outlay, potential production capacities, finished wall costs and simplicity in the fabrication methodology.
Chapter 5 - Manually manufactured prefabricated masonry panels

5.1 Introduction

In 2003 as part of Hanson Building Products product development and also for the Partners In Innovation project (Oxford Brookes, 2004) sample panels of thin joint masonry using high performance adhesive and clay bricks were constructed by bricklayers. These were made as test panels in order to evaluate performance with respect to aesthetic properties, frost resistance and durability, resistance to rain penetration and strength.

There was some uncertainty as to what brick types might be compatible with the mortar in terms of ease of laying and also finished appearance (Ankerplast 1992) although many varieties have been used in continental Europe (Figures 5.1 and 5.2) to compare thin layer and conventional masonry aesthetically.

Figure 5.1 Dutch thin joint brickwork (Ankerplast 1992)

Figure 5.2 Conventional brickwork with 10mm joints (Ankerplast 1992)

The initial driver for development of thin layer clay brickwork was the desire by architects to obtain a clay façade which had less appearance of mortar and more of clay. Traditional brickwork comprises approximately 17% mortar surface when 10mm joints are employed. Thin joint masonry gives approximately 8% mortar surface for 5mm joints. Figures 5.3 (a) – (d) illustrate some of the various brick types with joints thinner than the traditional 10mm.
Sample thin joint panels:

![Figure 5.3(a) Standard UK format cream engineering bricks with thin 5mm joints](image)

![Figure 5.3(b) UK pavers laid on edge with 3mm joints](image)

![Figure 5.3(c) Stock bricks with 3mm joints](image)

![Figure 5.3(d) Rough stock bricks with 3mm maximum joints](image)

**Figure 5.3 (a) – (d) Sample panels of various bricks laid with thin joint adhesive**
*(Trials at Hanson Waingroves Brickworks - 2003)*

All preliminary panels were of a size typically used for testing and were no more than 1m square or standard wallette dimensions as used in flexural and compressive strength tests (BS EN 1053 Methods of test for masonry). Manual inspection demonstrates that such panels were extremely robust, readily handled and transportable without sign of fracture or cracking after no more than 24 hours setting and hardening, a characteristic not found in masonry made using conventional cement : sand mortars.

In the period following the Oxford Brookes work other tests were carried out in the UK. Larger panels of clay brickwork were made (Figures 5.4 and 5.5) and transported to Kingston University for full scale structural testing. (Kingston University, Hanson report, 2005). Additionally, aggregate blockwork panels were made, transported and utilised in Kingston research work (Kanyeto 2006). This exercise provided the opportunity to evaluate how well such panels would travel – having a journey of some 150 miles strapped upright onto a flatbed lorry trailer.
Prior to construction of the Kingston test panels, two single skin brick panels were constructed which were 4m long x 1.2m high. These were lifted by using undershot sling straps and moved by a fork lift around the factory yard (Figure 5.6). No structural information was formally recorded although the panel was visually inspected during and after lifting and handling.

Two visual observations were noted from the panel handling and transportation exercise at the Hanson Waingroves brickworks:

- The panels did not break nor show any signs of cracking to bricks or mortar joints even under the effects of transport over a very rough road surface
- The panels visibly demonstrated deformation / flexibility under loading to a greater magnitude than would typically be expected with traditional cement sand mortar built brickwork where deformation is negligible before cracking is observed.
The method of handling was somewhat “rough and ready”. Panels were lifted using simple lorry straps as slings. These have a tensile load capacity of 5 tonnes each. The sample panel self-weight was approximately 1.7 tonnes. However the stresses and localised loading on specific points of sling support were high. In some cases the action of lifting a panel caused a high proportion of panel self-weight to be concentrated on one sling due to the inaccurate spacing of slings. Handling in this manner did potentially cause unseen damage in terms of localised concentrated load and localised stress.

When a sample panel was first lifted, a visible deformation was observed of up to 6 mm. Although this deflection occurred it was not accompanied by any cracking in either the bricks or mortar. This characteristic was noted and given further consideration in a number of test regimes where some panels were made flat and the deformation due to both self-weight and a controlled load application were recorded for given time periods. Additionally deflection was recorded under a sustained load over a given time period. Finally the deformation (or more specifically reduction in deformation) was recorded as the applied load was removed. A measure was also made of any permanent deformation of the panel after removal of load over a continued time period.

Further tests were carried out on single brick stack bonded samples laid horizontally, supported at each end and loaded with weights in incremental amounts. When a stack failure did occur it was noted that such a failure was never instantaneous at the point of maximum load application but always after a time delay of anything from 5 seconds up to 4 – 5 minutes. Further investigation into this creep phenomenon is required.

### 5.1.1 Factory built panel process – plant and equipment

The technique for factory clay brickwork panel construction included the use of a polyjet mortar pump and gun (described in chapter 3) by a process which mirrored the on-site thin joint brickwork technique. The immediate benefits of this method were:

The procedure was carried out by bricklayers trained at Hanson’s laboratory who were already familiar with both the laying methods for brickwork using the pump and gun system as well as the scoop technique which is used for thin joint aircrete blockwork.

The standard power supply in the factory is 440 volts and this was easily stepped down to 240 volts which was then compatible with the pump power supply. Voltage “step down” is easier to achieve than “step up” (required for the UK site supply of 110volts) as the feed is not as sensitive to cutting out during any power drops or surges.
Pump use, repairs and general day to day maintenance were easier to deal with in a factory environment than an open building site. Break downs, repair and maintenance and parts replacement were dealt with more readily in a factory. On site electricians or mechanics were available and if necessary a specialist could be called to carry out non-standard repairs. Control of stock items i.e. spare parts and replacement components was easier to manage and to monitor as was component storage and protection from theft.

5.1.2 Factory built process – working environment

There are a number of distinct benefits of the factory environment for masonry fabrication. Control over the pump maintenance in the factory eliminates the risk of contractual delays which can occur with on site use.

1. End of day cleaning is easier and disposal of mortar and cement waste are more readily contained than on site with settlement bunds being set up to contain water and material residue. Pollution effects are minimized or even eliminated.
2. The factory environment is significantly easier to work in with controlled climate and temperature and comfortable working conditions allowing for regular working hours and comfort breaks.
3. Health and safety issues are greatly improved with a comfortable consistent workplace, working temperature, localised work position with minimal hazards. The work place can be managed with much tighter control than on site.
4. All operatives are known by the Company and are either directly employed or employed as specialist sub contract labour. Only those personnel who are up to the required standard are employed. The duty of care of the employer to the employees is more controlled.
5. The general working environment enables consistency in production output, control of the masonry quality and careful temperature controlled curing.
6. There are no delays incurred due to weather related issues, no wet or down time.
7. Work does not have to cease due to falling temperatures.
8. Work output in the conditions and environment described will be increased by at least 20% which will be reflected in the cost analysis model. This is demonstrated by the daily m² output per man for factory made panels when compared with in-situ panels.
9. Lighting in the factory is artificial rather than a natural daylight but will be of a controlled and consistent level and favourably positioned to ensure maximum visual aid to the bricklayers.
5.1.3 Factory location and suitability

Out of necessity (and economy) much of the product development described in this thesis was undertaken in an old steel framed factory building which had been the former site of a brick kiln at Hanson Waingroves. The building had no overhead crane facility as these are not a requirement of a brick kiln factory and although it provided a large clear open floor work space the height to eaves of the portal framed structure was relatively low (approximately 5m). This would prove to be an issue when trying to manoeuvre a number of panels when using a heavy duty mobile crane which requires height in order for the jib to be able to handle the loads being dealt with. Additionally the concrete floor of the building although relatively sound, was of a low grade finish, uneven and not level.

These points added to the design and manufacturing problems and to the solution process since the floor surface on which panels are constructed is required to be flat and level and allow for masonry to be built plumb and vertical in such a manner that the panel is easily removed from the place of fabrication to the storage area.

In terms of masonry panel development, three types were considered, single leaf clay brickwork, single leaf aggregate concrete blockwork and partially insulated brick / block cavity walls. Prior to this development, prefabricated cavity walls had not been constructed in the UK with UK materials and a performance specification which would comply with the UK Building Regulation requirements both at the time of construction and for predicted future wall designs. This approach referred to as “future proof” design, involved the development of a manufacturing process which could be readily revised or altered to meet any future design, construction or legislative demands without significant alterations to processes or additional costs. (Rogatzki 2009)

A number of procedures were considered in order to achieve this effectively.

5.1.4 Moveable working platform - steel trolley on rollers

An alternative solution for vertical panel manufacture was the consideration of constructing panels on flat bed trolleys. A trial trolley was obtained from a precast concrete manufacturing facility. This comprised of a steel universal beam structure with steel checker plate flooring. The whole structure is supported off two batteries of small solid steel wheels (somewhat in the format of a railway wagon) which allow the trolley to be moved by towing either with a fork lift or a heavy duty vehicle. The benefit of this method is that it provides a solid flat elevated platform upon which masonry panels could be fabricated. It eliminates any height restriction problems during construction, movement and transportation. Panels do not require lifting in the factory and can be simply rolled out into
the relevant storage area where they are placed into storage racking using a heavy duty fork lift truck which has a load carrying capacity of up to 15 tonnes i.e. in excess of the heaviest proposed panels which do not exceed 10 tonnes based on the heaviest materials and the largest dimensions constructed.

The height of the trolley working platform is approximately 500mm above ground level and it is designed to provide a working platform with access to either side of the area in which the wall will be constructed. A single trolley was employed for initial trials and used for the construction of 5 cavity walls. The method was considered favourable both for ease of construction and for panel movement to storage. However in the early stages of prefabrication development there were some disadvantages to the method.

A single trolley would allow for only one panel to be fabricated at any one time. Consequently to achieve high volume manufacturing output it would be necessary to provide several trolleys (the number would be determined by the manufacturing output required)

Panel lengths under consideration were in the region of 9m – 10m. This length was deemed as the optimum for weight limits and transportation by either a flatbed lorry or a low loader transporter. Accordingly the trolleys would be required to be up to 12m long (allowing a clear working space at either end)

The use of many trolleys would create issues with overall factory floor space and complicated manoeuvres in moving them from the factory to the storage area.

During the preliminary trials, however, the key problem was a more fundamental one; the existing factory floor was of poor quality and the trolleys could not be easily moved on steel wheels without suspension resulting in damage to the panels and causing a potential safety hazard during movement due to instability.

The technique was addressed later in the manufacturing development process but in the initial trials where panel structural integrity, cost, quality and accuracy were the prime concerns it was concluded that construction would be carried out using temporary masonry plinths.

5.1.5 Panel development using masonry plinth bases – preparation of the working area

Due to the poor quality of the factory concrete slab floor preparation to receive panels entailed the laying of dense concrete aggregate blocks laid on flat ie on their sides, in
traditional mortar of such thickness that would ensure the formation of a plinth with a level top surface upon which the brick panels would be constructed. Figures 5.7(a) to (c) show the base plinth details.

![Figure 5.7(a)](image)

**Figure 5.7(a)**

![Figure 5.7(b)](image)

**Figure 5.7(b)**

![Figure 5.7(c)](image)

**Figure 5.7(c)**

**Figure 5.7(a) – (c) Base plinths set up for panel construction showing single leaf and cavity walls (Hanson Waingroves)**

The standard mortar mix used to build the plinths was 1 : 9 cement : sand which was of sufficient compressive strength to support the plinth and the heaviest predicted walls and also weak enough to be easily removed when no longer required.

Using this method plinths could be constructed to any length and in any position to suit the size of panels being fabricated. This enabled optimum use of floor space and the preparation time for plinth construction was typically between 1 and 3 days. This process was included in the panel cost and eventual commercial price.

The plinth process could be used for all wall combinations i.e. single or double leaf and from any material be it brick or block. Although it was developed out of necessity due to the poor quality and uneven surface of the factory floor it does provide a versatile and relatively economical way of setting up a base on which to construct wall panels. Other plinths of lean mix concrete and clay bricks were also trialled although blockwork provides the quickest and cheapest build solution. (Rogatzki 2009)
5.1.6 Manufacture / construction of panels – working access

Manual panel production closely follows the procedures used for in-situ traditional brickwork when consideration is given to working access. Masonry can be constructed from ground level up to a height of approximately 1.2 m without the need for working platforms. Above this height it is necessary to introduce a temporary scaffold. The most practical and cost effective solution involves the use of standard temporary lightweight steel / aluminium working platforms which are set on caster wheels and could be readily moved as required. (HSE 2005)

Static semi-permanent scaffold would only be beneficial if erected in a permanent position from which all walls are constructed and then moved to storage.

5.1.7 Health and safety – good working practice

Although one of the perceived benefits of factory manufactured panels is to minimize health and safety issues, since the process is still a manual one it is imperative that all legislative safety documentation, risk assessments and good working practice are adhered to (www.hse.gov.uk/risk). This includes risk assessments for all working operations, use of protective clothing and full training and competence assessment in any of the relevant construction operations. These not only relate to the masonry laying process but to correct handling of all materials and full competence training in use of the appropriate masonry laying systems. In particular training in handling of and working on scaffolding is required and all working platforms require guard rails and access ladders set within the working platform area. (HSE 2005)

When full panel production is in operation the factory space is busy with both people traffic and plant and machinery. This environment is potentially hazardous and requires strict control.

When lifting and removing panels it is imperative that no nearby masonry construction operations are taking place. Indeed the panel movement has been assessed as the highest risk level operation. (HSE 1998)

During and after completion of the panel production it is important to ensure that temporary propping of the construction is present at all times. As panels are built off temporary plinths of relatively low mortar strength, these possess low flexural strength. Prefabricated panels cannot automatically be assumed to be stable under self-weight without any restraint or propping. In the case of a cavity wall where the inner and outer leaf are of masonry of
different densities and consequently weight, the structure may in fact be unable to support its own weight and would topple over without being propped.

Early trials utilised timber propping systems with a simplified A frame structure composed of diagonal struts placed at either side of the wall and at 90 degrees to it. These are connected at the base of the wall by a cross member at floor level. The A frames sit at the ends of the walls.

5.1.8 Lifting and removal of panels from the factory floor to the storage area

Removal of panels was achieved by using a crane and strap / slings and in order to allow slings to be wrapped around or to be positioned underneath the completed panel, consideration was given to the plinth being constructed with correctly positioned open gaps to accept the straps / slings. As the strap width was no more than 100mm this gap did not compromise the brickwork panel construction as the localised brick to this area simply bridged over the plinth space. However the problem with this approach was that it requires a similar base arrangement where the panels are to come to their final resting place within a building otherwise there is no way of removing the slings after placement. Figures 5.8 and 5.9 show completed cavity walls and single leaf block walls stored and ready for removal.

An alternative approach to panel lifting involved leaving out specific single bricks from the first course of the panel to receive the slings. In the prefabricated cavity walls recesses were cut into the inner leaf base course of blockwork to receive the slings. This was...
Chapter 5 – Manually manufactured prefabricated masonry

straightforward to construct but required an additional on-site operation of fitting the missing brick units. It was however demonstrated (Hanson Eco House, BRE, Offsite 2007) that refitting of bricks after panel installation did not compromise either the panel integrity or its appearance as the operation was carried out with the same mortar. The main criticism of this approach was the added on site time, the need for a skilled operative to carry out the work and the fact that a newly developed fast construction process is hampered by localised remedial work to complete the structure.

The location of lifting slings depends on the shape and length of a panel and also the position of any doors and windows. As a general rule for rectangular panels slings would be located uniformly along the panel length using two, three or four slings depending on the overall length as shown in Figures 5.10 to 5.13. Slings are generally positioned to either side of doors and large windows to avoid high localised loading which might potentially cause cracking in the panels. Figures 5.10 to 5.13 show the procedure for
locating lifting straps, fixing to the lifting beam and lifting the panel free of the plinth. (HSE 1998)

5.1.9 Setting out and set up of panel construction – factory layout

Once a suitable plinth base has been prepared the setting out of factory made panels is achieved by use of vertical profiles, preferably of square timber or rectangular hollow section steel which are movable and set at either end of the panel to be constructed. A taut plumb line and builder’s line assist in vertical and horizontal setting out. The profiles are marked with brickwork coursing of co-ordinating dimensions so that vertical setting out is easily achieved without the need to carry out constant checks with a line.

Accuracy of brickwork will be at least to the standard that may be set in site construction but will usually be superior to it. Dimensional accuracy of the masonry will be dictated by location and verticality of the uprights. Initial trial panels in single leaf brick, aggregate block, aircrafted block and cavity walls of brick and block were built to a tolerance of +/- 2mm over a 9m length. This is a tighter tolerance than required by BS 8000-3, 2001 Table 2. Such accuracy was not only a good achievement in terms of general masonry quality – being of closer dimensional tolerances than are required – but it was considered necessary to ensure accurate on site assembly / installation for sitting one panel on top of another and at connections / corners. Brick finished panels must marry up accurately as any discrepancies will be highlighted in the brick bonding. It was also noted that dimensional accuracy was achieved for three different material types and for three quite different methods of panel construction i.e. use of gun and pump for clay brickwork, the purpose made scoop for aircrafted blockwork and thin joint mortar and a trowel process with an alternative thin joint adhesive for the aggregate blocks.

This demonstrates that workmanship quality is governed as much as anything by the working environment and the correct preparation of setting out jigs and frames.

For clay brickwork overall panel construction accuracy is approached in a manner similar to on-site work in that the specific bricks to be used are set out dry in order to establish size variation. It is unlikely that dimensional variation will be significant between individual bricks within one brick consignment although care is needed if any feature brickwork or banded details are included as an alternative brick may be of a different clay type and be of consistently different dimensions to the main brick. A good example of this is demonstrated with stock type products which are machine thrown as opposed to extruded wire cut products. Although both types may be within the dimensional tolerance range for the requirements of BS EN771 – 1 (BSI, 2003) the stock bricks will be to the lower end of
the range and the extruded bricks to the higher end. This problem is no different to that experienced with traditional on site brick laying.

In all of the panels constructed brick dimensional tolerance did not cause any issues as the mortar joints accommodated variations as with standard construction. However it is necessary to consider that the thin joint brickwork process with joint thicknesses from 3mm up to 7mm will be less tolerant of dimensional variations than with 10mm conventional masonry and brick selection may need to take this into account.

Factory made masonry does have the advantage that material selection is completely controlled by the manufacturer through their quality control system and this ensures that all materials used would be to a required or set quality standard. In small projects the masonry material will always come from the same production batch and should therefore be of consistent properties. In larger projects there is a chance that material may be supplied from different production batches as this is something which is controlled by material demand and the need to fulfil a concurrent number of sales orders and deliveries. It is this issue which can lead to traditional site based problems of colour or size variation in materials that might end up being built in the same structure. Such a problem can readily be avoided with internal supply of material as there is tighter control over despatches. There is also less likelihood of materials coming from different production batches. (PAS 70)

This scenario is also the case for aircrete and aggregate blocks although colour variation is not critical (as blocks are generally not manufactured with a faced finish). Cracking and surface defects would be a more common problem here. (Hanson Aggregate Concrete Blocks, 2009)

5.1.10 Maximising factory output of manually produced panels.

With traditional on site masonry construction it is usually the case that a 2+1 gang will operate i.e. two bricklayers and a labourer. The labourer prepares and ensures an adequate supply of materials in order to maximise the bricklayers time and laying rate. Producing a single panel in a large open spaced building presents little problem in terms of material storage and movement of operatives. However the key drivers for opting to use a prefabricated masonry solution are cost and output. Where panels are made by manual labour the most critical parameter in driving down cost will be panel production time.
Factory manufacturing for high volume projects requires a large open space protected from the elements. If panels are to be constructed in any quantity it is critical both from the point of view of health and safety and also ensuring optimum output that all materials, plant and equipment and construction layout areas are carefully controlled.

The maximum output of panels is completely dependent on the available labour and the amount of labour required will be based on the size of a particular job and the construction programme.

**Example:** to construct a single clay brick work panel it is sufficient to employ a bricklayer working unaided. The bricklayer would prepare the pump and gun, set up mortar mixes and construct the masonry. At the end of a working period – and in any case at the end of a working day – the equipment is washed and cleaned ready for the next session.

In this scenario a single operative will have a reduced available build time as there will be a setting up period at the beginning and a cleaning down period at the end of a working session. Use of a bricklaying labourer to carry out these tasks will maximise the build time. The following simple examples serve to illustrate comparative work output. The brick laying rate is assumed to be 1 brick per minute.

**Example 1 :- 1 bricklayer only (no labourer)**

- Assume total available work time excluding breaks = 7 hours
- Set up time = 30 min = -½ hour
- Clean up time = 30 min = -½ hour
- Mortar mixing during the work day = -1 hour
- Available laying time = 5 hours
- Typical laying rate = 1 brick per minute
- **Total bricks laid = 5 hours x 60 per hour = 300 bricks**

**Example 2 :- 1 bricklayer plus labourer**

- Assume total work time excluding breaks = 7 hours
- Set up time (not required by bricklayer) = 0 hour
- Clean up time (not required by bricklayer) = 0 hour
- Mortar mixing during the work day = 0 hour
- Available laying time = 7 hours
- Typical laying rate = 1 brick per minute
  - (assuming all materials set up)
- **Total bricks laid 7hrs x 60 per hour = 420 bricks**
Example 3: 4 bricklayer plus 1 labourer

- Assume total work time excluding breaks = 7 hours
- Set up time (not required by bricklayer) = 0 hour
- Clean up time (not required by bricklayer) = 0 hour
- Mortar mixing during the work day = 0 hour
- Available laying time = 7 hours
- Typical laying rate = 1 brick per minute
- (assuming all materials set up)
- Total bricks laid 7hrs x 60 / hour x 4 brick layers = 1680 bricks

<table>
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<th>Labour</th>
<th>Cost per day (£)</th>
<th>Bricks laid No per day</th>
<th>Bricks laid (m²)</th>
<th>Cost £ per brick</th>
<th>Cost £ per m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 bricklayer</td>
<td>£140.00</td>
<td>300</td>
<td>4.615</td>
<td>0.46</td>
<td>£30.33/m²</td>
</tr>
<tr>
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<td>420</td>
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<td></td>
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<tr>
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<td></td>
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</tr>
<tr>
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<td>1680</td>
<td>25.86</td>
<td></td>
<td>£25.52/m²</td>
</tr>
<tr>
<td>1 labourer</td>
<td>£100.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>£660.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes
1. Labour rates for illustrative purposes and typical of small building firm
2. Bricks assumed to be 215mm long x 65mm high
3. Mortar joints assumed to be 5mm thick (bed and perpend)
4. Number of bricks per sq meter = 65 with 5mm joints

Table 5.1 Comparative costs for bricklayers / labourers and brickwork output

Other parameters would have to be considered in a more comprehensive costing analysis but the above serves to demonstrate that for the manual production of a high number of panels there is an optimum labour set up which enables the maximum output for masonry laying.

A single labourer will not be effective when supporting more than 4 bricklayers as is illustrated in the working layout plan in Figure 5.14. Four bricklayers can use one polyjet pump and glue gun from working positions effectively. The labourer can clearly support one gun set up as this keeps his working area to a minimum.
Figure 5.14  Typical plan layout of a brick wall panel production for four walls using 4 bricklayers, 1 labourer and 1 pump

The glue mortar pump and gun are a high capital outlay (approx. £5000 each based on 2007 costs) and in order to maximise their effectiveness they should be fully employed to ensure maximum output. This necessitates the pump and gun dispensing the optimum amount of mortar and this can be best achieved if more than one panel is being manufactured at any given time.
The bricklaying operation requires the gun to deploy a run of mortar along a bed joint (usually for the full panel length which is up to approximately 9m). Following this all of the bricks laid to form the first course on that bed joint need to have mortar placed on one perpend. Placing a mortar bed joint and preparing the perpends might take approximately 5 minutes and is virtually the same as the operation employed on site described in the earlier case studies of Chapter 3.2. Laying bricks on the bed joint will then take at least 20 minutes and during that time the pump is steadily rotating to keep the mortar to the right consistency. If more than one bricklayer can use the same pump this maximises its output. Careful planning and layout ensures that up to 4 bricklayers and one labourer can work off one pump building 4 separate panels. This ensures maximum use of the pump.

The labourers’ role in this situation is a busy one and requires more responsibility (and potentially more money) than is necessary for the traditional on-site labourer. It involves setting up the pump, feeding with dry mortar, adding a controlled amount of water and ensuring correct mixing speed to maintain the right mortar consistency.

The labourer also needs to assist in feeding bricks to the bricklayers in the correct locations such that they are readily accessible with minimum travel distance.

This consideration of wall building layout and location of building materials within the factory space was identified as the key parameter to ensure maximum production and to drive manufacturing costs down. In addition to this the bricklayer’s laying rate per day also influences the final cost.

The aforementioned procedure describes single leaf clay brick walls. When cavity walls are to be fabricated this will include a clay brickwork outer leaf, a concrete blockwork inner leaf (of either aggregate or aircrete blocks) and a cavity with an insulation material included such that the wall thermal performance criteria are met. The two leaves are tied together using wall ties and any openings for windows and doors are also formed in the panel.

The completed construction will then provide a prefabricated cavity wall which is manufactured off site, removed from the assembly area to a storage area and delivered by lorry to be installed by a competent installation team, a banksman and a suitable crane.

The considerations discussed previously for single wall construction within a factory (ie the location of materials from which the wall is built and movement of the walls to a place of storage prior to transportation to site) are compounded by the amounts of material needed for a cavity wall.
This includes clay bricks, mortar for the brick wall, concrete blocks, mortar for the block wall (which will be of a different specification than for the clay brick wall), wall ties, cavity stops, bed joint reinforcement, insulation and formwork to form any openings.

**Example - the construction of a square single storey cavity wall building of 9m x 9m overall dimensions including 2 windows and a door**

Material requirements

- 90m$^2$ of bricks = 5400 bricks = 10 packs.
- 70 bags of brickwork mortar.
- 900 blocks = 10 packs. 10 bags of block mortar, 
- 150m of bed joint reinforcement, 
- 270 wall ties
- dpc material,
- timber for formwork.

For maximum construction output and to build the 4 cavity wall panels simultaneously will require at least 4 bricklayers and 1 labourer working with 1 strategically positioned pump. It would also be possible to have 2 bricklayers working on one panel ie one on the brickwork leaf and the other on the blockwork leaf. In these circumstances the build time is reduced further although the labour cost increases.

**5.1.11 Factory layout**

**Benefits of manually built factory panels**

Inside a factory material quality can be controlled to a higher standard than is achieved on site with improved storage facilities and no exposure to weather conditions. Workmanship will be to a quality which is consistently superior to that achieved on site.

Bricklaying rates will be higher for factory made panels achieving up to 25% improvement over site work based on an improved working environment, working conditions and a bricklaying process which is quicker than traditional trowel methods.

Workmanship is not affected by daily or seasonal variations in weather conditions. Additionally site winter working hours will be curtailed by available light and acceptable working temperatures whereas the factory working environment and temperature are controlled for human comfort
Chapter 5 – Manually manufactured prefabricated masonry

Factory temperature will be set to ensure optimum workability of materials and faster curing times.

Hand fabricated masonry provides significant flexibility for panel design and may include walls with openings, non-rectangular (including gable), curved walls and walls with complex relief brickwork.

Wall panels may be single skin or two leaf cavity constructions in a variety of masonry materials including clay brick, aircrte block, aggregate block and stone. The thickness of each leaf is not limited in terms of construction and it is possible to build 215mm as well as the single 102mm thick walls.

Bond patterns are not limited.

The cost of manually built panels is very competitive, transparent and easily evaluated in terms of materials and labour.

Panel layouts and the building process as described above serve to illustrate one working technique which aims to achieve maximum output.

During the construction of various wall types and dimensions it became apparent that different teams adapt different build procedures. For example as an alternative to 4 men working on four panels, in some cases two men worked together on the same panel, this approach works well for panels that are in the 9m length category. The consistency of the thin joint mortar mix is such that colour / texture variations in workamanship seldom occur when mortar is used from the same batch and mixed in the poly jet pump.

In Europe the process is such that perpends are left unmortared and the finished brickwork has very thin joints that are not pointed. In the UK this technique was frowned upon by architects concerned about rain penetration through the open perpends and structural engineers who believed that the strength might be compromised with no vertical joints. Additionally it was generally the case that all joints are pointed after the adhesive process is completed and have a tooled finish.

Further development of the prefabricated process included the trials and eventual adaptation of 10mm thick joints i.e. conventional UK brickwork dimensions. Having established that a “thin” joint has been aesthetically desirable architecturally the development of conventional size UK joints i.e. 10mm was simply to ensure that dimensional coordination was maintained particularly with the UK sized bricks making brick setting out easier, better correlation with the inner leaf when including conventional
wall ties and an ability to use standard sized doors and windows. Embracing 10mm joints significantly improved the interest in the system which benefits from being a modern construction process that is able to replicate traditional and conventional construction.

Using 10mm joints does add cost as the adhesive mortar is considerably more expensive than standard cement sand mixes and an initial investment is required for the polyjet pumps.

Although some successful case studies demonstrate the benefits of the manually prefabricated system, it became clear that based on cost and high volume output it was necessary to consider further manufacturing developments.

5.1.12 Design and detailing of prefabricated panels

In addition to the development of the factory manufactured process there was a necessity to evaluate the structural characteristics of single skin panels and cavity wall panels.

Early development testing both as part of the Oxford Brookes PII and at the Hanson Laboratories was progressed in order to establish standard structural properties such as compressive, flexural and shear strength as well as pull out, tensile and shear values for wall ties in the various mortar types.

Further single storey height panels were built and transported to Kingston University for lateral load testing to expand the knowledge base (Kingston University, 2005)

Approach to evaluation of panel strength and structural integrity

Apart from the fact that the masonry has been manufactured off site and in a factory environment the basic construction format is virtually the same as for traditional in-situ masonry. Once installed, the prefabricated walls were expected to have performance characteristics that are at least to the standard of traditionally built panels which are designed to resist vertical compressive loading and lateral (wind) loads. Only the mortar specification enhances the structural properties.

In addition to the normal design load checks, prefabricated masonry is subjected to loading from being lifted, moved into storage racking, placed onto a lorry for transport, removed from the lorry and lifted into place as part of the final installation. In traditional masonry it is simple to detail a building such that the location of any joints can be controlled to ensure that continuity and fixity can be achieved as and where required. With prefabricated panels one is introducing a series of rigid plates with joints at top and bottom and at each end. The shape of the panel will dictate its strength parameters as will the
location of openings and any projections. Further consideration must be given to lifting of
double leaf walls and the interaction of the two leaves and the wall ties.

Wall panels built in a factory must be designed to withstand the same loading conditions
as those built in-situ including self weight, imposed and wind load. Additionally
consideration must be given to loading due to lifting, handling and transportation to enable
the walls to be moved and stored in the factory, transported to site, lifted and fitted into
position, connected to and supporting adjacent panels.

Hence the design criteria to be considered are :-

1. The structural properties of the panel based on materials and structural tests.
2. The fixing / restraint details of panels and their interaction ensuring that the building
   maintains overall structural stability.
3. Wall ties and their interaction between inner and outer leaf during transportation.
4. Cavity wall panels are staggered ie the outer leaf does not align with the inner leaf.
   This ensures that there is a connection between adjacent panels inducing stresses
   which need to be considered. Figure 5.15 plan views illustrates the lap or stagger
   of the inner and outer leaves
5. Masonry detailing. – as with any prefabrication drawings it is the manufacturers’
   responsibility to ensure that there is continued alignment and bonding between
   adjacent brickwork panels. Where, for example, stretcher bond brickwork is used
   on a two storey building it is important to ensure that the bond pattern continues
   through from ground floor into first floor. This must be maintained during panel
   manufacture.
Cavity Wall Settingout - Plan View

Figure 5.15 Plan view of cavity wall setting out details and layout plan

Figure 5.15 illustrates a typical floor plan of a domestic dwelling that could be constructed using a combination of prefabricated single skin and cavity walls. Details of the prefabricated cavity walls are also indicated in the figure.

General Finished Panels Criteria
In the construction of these prefabricated panels, high tolerance standards were set. These tolerances are based on products manufactured to the following British Standards: BS EN 771-1:2003; BS EN 771-3:2003 & BS EN 771-4: 2003

Dimensions

<table>
<thead>
<tr>
<th>Permissible deviation mm</th>
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</thead>
<tbody>
<tr>
<td>Straightness in any 9 metre length</td>
</tr>
<tr>
<td>Verticality up to 3 metre height</td>
</tr>
<tr>
<td>Verticality up to 7 metre height</td>
</tr>
<tr>
<td>Overall thickness of cavity wall</td>
</tr>
<tr>
<td>Deviation of bed joints up to 5 metre length</td>
</tr>
<tr>
<td>Deviation of bed joints up to 9 metre length</td>
</tr>
<tr>
<td>Overall panel finished length</td>
</tr>
<tr>
<td>Overall panel finished height</td>
</tr>
<tr>
<td>Parallelism of finished panel (measured across panel diagonal)</td>
</tr>
<tr>
<td>Joint thickness of bed joint and perp end joint for 5mm joints</td>
</tr>
<tr>
<td>Joint thickness of bed joint and perp end joint for 10mm joints</td>
</tr>
</tbody>
</table>

Aesthetic Appearance
The finished aesthetic panel appearance shall be in accordance with (BS EN771, 2003) and (PAS 70, 2003)
5.2 Prefabricated masonry panels – Case studies

Four case study projects were constructed using panels manufactured by the manual or traditional bricklaying processes, but in a covered factory environment. These included two demonstration houses constructed at the BRE in Watford, a flood defence system in Carlisle and a private house in Leicestershire which was based on the principles of the Hanson Eco House built at the BRE.

The first BRE house was part funded by the The Concrete Centre and it incorporated prefabricated insulated cavity walls for the ground floor with both leaves made of aggregate blocks. This specification was requested as there was a desire to demonstrate as much cement based material as possible (hence the omission of clay brick). The first floor was built in Thermalite thin joint aircrete masonry. Wall finishes included part render and a proprietary lightweight insulated brick composite cladding system. (Hanson Wonderwall™, 2005). The Hanson EcoHouse™ 2007 was then developed and two years later a prototype was constructed and erected at the BRE site for the Offsite 2007 exhibition. Subsequently a flood defence system was erected in Carlisle which incorporated single leaf prefabricated brickwork walls and in Leicestershire a private house was constructed based on the EcoHouse™ model and achieving a Code for Sustainable Homes level 6 status.

All of these projects were developed by the author.

5.2.1 Case study no 6 – Development of Hanson House for the BRE Offsite 2005 Exhibition

5.2.1.1 Introduction A timely opportunity to develop a prefabricated masonry solution for a domestic dwelling presented itself when a proposal was put forward (and accepted) to construct a masonry demonstration project for the BRE Offsite 2005 exhibition at Watford. The purpose of the exhibition was to provide a selection of houses embracing innovative prefabrication design and construction which was eventually documented in the Government publication, MMC Modern Methods of Construction (MMC, Office of Deputy Prime Minister 2006). This highlighted prefabrication as a preferred construction technique. At this time the design of the Hanson House was based on a development idea in which Hanson would demonstrate a typical building that could be constructed using its products. This included walling systems, flooring systems, hard landscaping, box culverts and basements. The services, roof structure and finishes were not produced by Hanson. Most of the demonstration houses for Offsite 2005 were manufactured of lightweight framed or modular buildings as the perception was that this form of construction afforded the fastest build time and most efficient end product in terms of energy and quality. The
house developed by Hanson comprised concrete and masonry materials. Figure 5.16 illustrates all elevations and Figure 5.17 shows a full cross section through the structure.

Another criteria of the MMC brief was to develop a £60,000 house (Modern Methods of Construction, 2006) – something that proved to be an unrealistic target as such a stringent cost could not be met in practice.

![Figure 5.16 Elevational details of proposed Hanson house. (The Concrete Centre, 2006)](image)

Offsite 2005 was a 4 day exhibition with the erected buildings remaining on semi-permanent display thereafter for invited guests to view. This enabled the long term viewing, inspection and performance monitoring of a diverse selection of innovative dwellings for visitors from all professions and sectors of the industry to appraise the construction methods. The prefabricated masonry house was developed in partnership with The Concrete Centre, (the trade association for concrete and cement manufacturers) and the design comprised a two story 3 bedroomed house with a basement. It is because of the support and part funding by the Concrete Centre that the house was built with cavity walls of two leaves of blockwork (as the remit required use of as many cement based products as possible). Clearly a brick / block cavity wall would have provided a favourable option as this would have demonstrated a prefabricated solution based on an established standardised, well understood construction method. In the event the external cavity walls comprised of two leaves of aggregate blockwork 100mm thick with a partial cavity fill of phenolic foam insulation. (Figures 5.18).
The cavity walls were constructed at the large empty steel portal framed factory at the Hanson Waingroves Brickworks, Derbyshire on the basis of the previous development work which had been carried out there. The labour was provided by a large masonry contractor with trainee bricklayers and an experienced bricklaying supervisor.

Use of the trainees minimised labour costs and demonstrated the standard that could be achieved with inexperienced operatives. The completed walls presented a concrete aggregate block face finish both internally and externally which was not in itself aesthetically suitable for the completed house. Proposals were considered to apply a wet plaster finish internally and a lightweight composite brick cladding externally in the factory. This option was subsequently rejected as the key objective was to evaluate the integrity of the walls from completed construction to site installation with any desired finishes being applied on site.
A total of eleven panels were constructed including external cavity (Figure 5.18 & 19) and internal single leaf walls for the ground floor only. The first floor was built in-situ using the already accredited Thermalite thin joint aircrete masonry system encompassing a 215mm single leaf thick trench block. A number of panels were L shaped corner panels to ensure robustness of the finished superstructure and one internal panel was a T shape.

Care was necessary when lifting corner panels to maintain a vertical attitude which was achieved by determining the panel centre of gravity and using that as a lifting focal point.

The thin joint adhesive used in the panels was of the type already established in Europe with thin joint aggregate blockwork and wall construction was done by use of a scoop rather than the pump and gun process used with brickwork.

Figure 5.20 illustrates a CAD rendered image of the completed house.
The construction programme and cost restraints were such that panels were constructed within one working week by an eleven strong labour force. Whilst the desired output was achieved there was some compromise on finished quality. The high number of operatives in the factory presented a hazardous working environment the likes of which would not now be acceptable if planning further prefabricated panel projects.

5.2.1.2. Wall construction

- A purpose made mortar was used of equivalent compressive strength to a 1:3 cement : sand which had an early high strength gain (Omnicol Con Fix literature, 2005). Both bed and perpend joints were approximately 3mm thick.
- Aggregate blocks of 7N/mm² strength, 100mm thick, standard face size 440 x 215 for both inner and outer leaves of the cavity walls were used.
- Helifix 250mm long 4mm diameter twist wall ties were utilised
- 50mm Phenolic foam cavity insulation in a 100mm cavity was applied.
- Openings included Catnic cavity wall lintels
- Single leaf walls comprised of 7N/mm² 140mm thick aggregate concrete blocks

Figure 5.21 shows the visual and structural concept. As previously described the cavity walls were built off a pre constructed concrete blockwork plinth with blocks laid 440mm wide to accept the 300mm overall thickness of the cavity wall.

Although the factory became crowded with panels under construction,(Figures 5.22 & 23) it was decided due to time constraints to minimise wall movements and not to move them to a storage area but after construction to lift and place them directly onto the flat bed lorries in one operation for transportation on the 140 mile journey from Derbyshire to Watford. (Figure 5.24)
Whilst the very tight construction programme was maintained (there was no room for delays as the purpose of these panels was to construct an exhibition house to be completed for a specific opening day) there was still a learning curve for many of the brickwork apprentices some of whom had never laid thin joint masonry before.

As stated previously finishes were not applied to the walls in the factory. Once the structure was erected an external vertical lightweight clay brick slip insulated cladding was applied to the external face. Internal blockwork finishes were left exposed. Additionally the straps and ties used to connect adjacent wall panels required internal blockwork to be left exposed for fixing of such ties. As an exhibition house the structure was left internally with no finishes which enabled visitors to see the fixings, straps and ties and the mortar type.

Key criteria which had to be maintained were :-

- Panels to be plumb, line and level with no twisting or distortion.
- Verticality and accuracy in overall dimensions to ensure a good fit at installation stage.
- Both bed and perpend joints to be fully filled to maximise block mortar contact area for flexural strength.

Recesses were cut into two locations in the blockwork base course to receive lifting straps. In the case of the L shaped panels three recesses were formed in the base course to accommodate straps for the lifting beams and ensuring that the panels remained vertically upright during lifting (Figure 5.25 (a) and (b)). During the first lifting operations for the L shaped panels it became apparent that 2 point lifting was acceptable for maintaining the panel in a vertical attitude due to the short length of the return.

As is apparent from Figures 5.25 (a) and (b) the panel aesthetic qualities left a lot to be desired, in particular the edge details were often rough and uneven. When panels were assembled, although the use of the straps and ties ensured structural integrity when lifting, it was still considered necessary to grout the joint details to ensure reasonable air tightness to the structure.

Summary of key features :-

Architecturally the house was designed to have a fairly conventional appearance externally with a clay brickwork finish. The structure was two storeys plus a basement and prefabricated garage unit. However, internally the building formed open plan spaces with
minimal finishes purposely exposing the construction types. The construction was as follows:-

Basement. Twin wall – a cavity wall with inner and outer leaves of concrete with partial fill polystyrene insulation in the void. Once in place the remainder of the void was filled with concrete (pumped mix) which was cast monolithically into the ground floor slab. Inclusion of a basement structure was at that time thought to be a potential construction feature which would enable maximum use of space within a given footprint and this followed the guidelines of the Property Planning Guidance (PPG3, 2000) which suggested a specific maximum number of dwellings on a minimal hectareage of land. Basements and a third floor / attic or roof space were two methods of maximising space.

The basement has always been a popular structural component to housing in Europe but it has not been well received in the UK - at least not since the Victorian period when all brick terraced houses included a basement as an area of storage. Such basements were constructed in brickwork. Modern basements are invariably designed in reinforced concrete or insulated concrete formwork (ICF). Further development work has been ongoing in the masonry industry to consider basement design and the use of prefabricated masonry. Aggregate concrete block structures appear from this development work to have good potential in terms of structural properties, the flexural strength being considerably enhanced with thin joints. (Tovey, 2004)

Ground floor – This was formed using Omnia RC decking (Hanson 2004) comprising pre cast slab units 1200mm wide which incorporate an exposed reinforcement / lattice truss. Concrete was poured on top of this to connect integrally to the basement twin walls.

Whilst Omnia decking was used over the basement area, the remainder of the ground floor (set out as a kitchen area) was constructed with the Hanson Jet Floor system. This is a lightweight pre cast beam and insulation construction with a concrete screed finish.

First floor comprised conventional pre cast concrete hollow core floor units. The first floor was designed to give a complete open space with no internal walls – particularly appropriate to accommodate high numbers of visitors at the exhibition.

Ground floor walls – These comprised prefabricated cavity walls with both inner and outer leaves constructed in aggregate concrete blocks as previously described.
Chapter 5 - Thin joint masonry – case study No 6

Walls from first floor to eaves level were constructed in Thermalite thin joint glued blockwork using 215mm trench blocks. (Thermalite 2003)

The exterior of the building was clad in the Hanson Wonderwall brick slip lightweight composite cladding system. (Figure 5.26) (Hanson TiS 2003). On completion this presents an appearance of traditional brickwork.

Figure 5.26 Installation of the lightweight cladding panel system Hanson Wonderwall.

5.2.1.3 Movement, lifting and handling

The masonry panels for this project were constructed in a factory shed which although more than adequate in floor area, lacked the headroom necessary for a large crane to manoeuvre and lift panels. Crane lifting capacity reduces with reach and pitch of the jig. Hence the heavier the panel, the higher the crane arm needed to rise above the actual panel for lifting capacity. (HSE, 2005)

At the Hanson Waingroves factory shed with this headroom problem, all panels were moved using 2 heavy duty fork lift trucks which operated in tandem - a skill not easily learnt as two driver operators manoeuvred in harmony! Panels were taken from the shed to be lifted onto a flat bed lorry. Support and fixing during transportation was provided by slings racheted or tensioned up to 5 tonnes over the panels down to the lorry bed. Cavity wall panels had been fabricated with rigid Styrofoam insulation in place.

Transportation – 3 loads were taken from Hanson Waingroves, Derbyshire to BRE at Watford. One lorry was a traditional rigid flat bed vehicle and the second was a similar flat bed vehicle with a flat bed trailer. Although panels were securely held down, the transportation mechanism was very basic. If the system was to be used for transporting of high volumes it would be necessary to develop steel rigid stillages.

Whilst the current method was acceptable it relied on crude temporary timber propping with some polystyrene packaging to prevent movement during travel. When panels arrived at the BRE site there was clear evidence of some movement during transportation.
underpinning the fact that timber propping on the lorries was adequate for one journey only and could not be reused.

5.2.1.4 Conclusions / lessons learnt:-

a. Panel Fabrication

This exercise offered a first attempt at offsite manufacturing evaluation. The key parameters which are all interlinked include labour force skill, laying output and panel manufacturing cost. In the eventual cost analysis labour is some 30% of the total output which makes its rationalisation very important. (Hanson House, 2006)

b. Lifting and handling

Panels for this project were lifted by use of heavy duty straps / slings with a load carrying capacity of 5t each. Although acceptable for this preliminary exercise such a system is far from suitable for high volume construction. The technique meant that parts of the base course of blockwork had to be removed by cutting from the wall to accommodate the slings. Once panels were site located the slings were removed and the recesses filled in. This exercise involved two additional operations which penalised both cost and time ie removal of blockwork to form the recess and making good upon completion.

c. On Site construction

Taking into account the fact that this was the first time a number of large prefabricated cavity walls had been moved, the whole exercise was completed without any major problems. All panels were successfully delivered in the correct sequence to ensure easy installation on site with the furthest panel from the crane being placed first. A 100 ton capacity telescopic crane was used for the installation process.

All panels required push / pull steel props to support them during the whole installation process. Full wall stability and removal of props only occurred when all ground floors were in place and the first floor pre cast units were located to add restraint to the top of walls.

The detail at the top of the wall was straightforward and mirrored what would be constructed traditionally ie the inner leaf was lower than the outer leaf by an amount
equivalent to the thickness of a pre cast floor beam unit. Once the floor beams were placed on top of the inner leaf, masonry construction continued – in this case with the 215mm trench block which was aligned to the face of the ground floor outer leaf wall.

d. Areas for improvement :-

   Manufacturing process
   Appearance
   Panel handling
   Transportation

Positive points so far

   Structural performance excellent
   Speed of block laying using the thin joint mortar (notwithstanding that
   workmanship must be improved and this could have been achieved with
   improved skill level)
   Speed of installation of the ground floor prefabricated panels
   Simplicity of installation

Figures 5.27 (a) to (e) illustrates the lifting and installation process. Figures 5.28 and 5.29 show the completed Hanson House as fabricated and installed at the BRE for the 2005 Offsite exhibition.
Figure 5.27 (a) to (e) lifting and installation procedure for the installation of prefabricated cavity walls at the BRE site, Watford (Offsite 2005)
Chapter 5 - Thin joint masonry – case study No 6

Figure 5.28 Architects conceptual CAD image

Figure 5.29 Completed house, Hanson House at the BRE Offsite 2005 Exhibition
5.2.2 Case study No 7. The Hanson EcoHouse™ and Hanson QuickBuild™ walling system

5.2.2.1 – Introduction

The Hanson EcoHouse™ was constructed for the BRE Offsite 2007 exhibition in order to demonstrate the latest developments in off-site masonry construction, thermal mass and natural ventilation in the context of what at the time was the Governments voluntary Code for Sustainable Homes (2007). The code enabled developers to demonstrate a dwelling’s environmental performance by means of star ratings, the ultimate objective being to obtain a zero carbon rating by 2016. This is no longer applicable and as outlined in the literature search in Chapter 2, the Code (or a version of it) is being absorbed into the Building Regulations.

The Hanson EcoHouse™ was designed as a three-bed detached dwelling, displaying all the benefits of off-site fabrication, that together with thermal mass and natural ventilation assist in the development of a building system targeting the zero carbon houses of the future. In addition, it showed how quickly and easily a liveable and saleable property can be constructed. (Figure 5.30 shows the completed house)

The house was constructed using masonry panels manufactured off site in a controlled factory environment based on the process first employed in the Hanson blockwork cavity wall house constructed for the BRE Offsite 2005 event and as described in the previous case study (Chapter 5, Case study No 6). It demonstrated the benefits of high quality and speed of construction with virtually no site wastage. The process was also less susceptible to weather delays compared to on-site construction.

Designed to meet the combined challenges of off-site construction and the impact of climate change, this concept house was constructed using the unique prefabricated brick / block insulated cavity walls now known as the Hanson QuickBuild™ walling system.
5.2.2.2 The Hanson EcoHouse™ – Development ideas

Architects for the the EcoHouse™ were TP Bennetts and the design concept was based on the shape and format of a traditional bottle kiln. Consideration was given to three key areas, namely:-

**Thermal mass.** Masonry construction has high thermal mass. This inherent feature enables the dwelling to store heat and remain cooler for longer than lightweight structures meeting the needs of climate change and keeping buildings cool in an energy efficient environment.

**Natural ventilation.** The design of the EcoHouse™ was based on a brick kiln (Figure 5.31(a)) which was appropriate to one of the largest clay facing brick manufacturers). A ventilating roof lantern is used to give light and to enhance the natural air currents, so maximising the energy conservation potential.(Figure 5.31(b) and (c))

**Flexible design.** Masonry panels manufactured off site in a controlled factory environment provide total flexibility in the design of dwellings. The system was designed initially to meet the needs of housbuilders applicable across a wide range of housing options.

![5.31(a) Design concept for the Eco House™](image)

![Figure 5.31(b) Sketches – the brick kiln “chimney” concept](image)

![Figure 5.31(c) Principles of thermal mass and natural ventilation (TP Bennett Architects 2006)](image)
5.2.2.3 Hanson QuickBuild™ walling system

The project is particularly important as it provides the first example of prefabricated masonry cavity walls comprising 102mm clay facing brickwork outer leaf, 100mm aircrete Thermalite blockwork inner leaf and a partial fill cavity comprising 100mm Kingspan rigid insulation and a 50mm air space. (Figure 5.32)

Clay brickwork was constructed using the polyjet pump and gun technique as previously used in in-situ brickwork processes described in case studies no 1 to 5, Chapter 3. The blockwork inner leaves and internal blockwork walls were built by use of the thin joint scoop process. All three masonry types were laid using the appropriate glue mortar for the masonry in question

The two storey dwelling comprises walls that are 2.4m in height by up to 9m in length. Panels were both plain and with openings (both doors and windows) and on site installation time approximated to one storey per day. The ground floor also included a number of internal walls which were constructed in prefabricated aggregate concrete blockwork.

This was the first time that prefabricated masonry cavity walls have been constructed using the brick / aircrete combination. There were some concerns relating to the use of aircrete blocks which although adequate for in-situ construction had not been extensively tried and tested in a live prefabrication project. The stack bonded brickwork (deemed to be weaker than a stretcher bond configuration) although desirable as an architectural requirement, also demonstrated the strength properties of the wall particularly the residual strength during transportation and handling by crane. (Figure 5.33 and 5.34)
The key properties of the finished walls include higher flexural strength for both brick and block (up to twice the strength of traditional masonry), increased vertical strength, and an increase in resistance to rain penetration of the outer leaf due to the continuous consistent mortar jointing.

The thin, fully adhered joints also ensure an airtightness which is superior to that achieved with traditional masonry (4.9 m$^3$/m$^2$/hr as compared with the allowed figure of 10 m$^3$/m$^2$/hr).

In addition, the wall construction quality is very high, waste is minimal and restricted to the factory environment and the system does allow for any combination of bricks / blocks and for any brickwork bond pattern without a loss of flexural strength.

One particular benefit which became apparent during the transportation and erection process was the flexibility of the panels. Normally masonry is regarded as being brittle and it is somewhat unforgiving of even minor deformation which are manifested as cracking. In the EcoHouse™ walls vertical deflections of up to 40mm were recorded without signs of cracking. This was due in part to the inclusion of bed joint reinforcement (flat bars equivalent to 4mm diameter) which was used to minimise transportation damage.

Although both leaves of the cavity wall were connected by Helifix spiral wall ties, there was notable movement of one leaf relative to the other during lifting. This differential movement was actually beneficial during the location and placement on site.

Accuracy in construction was also a significant plus point with dimensional tolerances not exceeding $\pm 5$mm on the diagonal of a 9m long x 2.4m high panel. Typical deviations in length and height were 2-3mm. This accuracy was expected since all masonry was set out with metal profiles ensuring that, as with any standard masonry, key dimensions were adhered to even if some variation within joints occurred.

The strength, versatility and ease of buildability of the thin joint adhesive masonry system certainly allowed for the continued use of traditional materials in a variety of building types, albeit with radical departure from traditional methods of construction.
5.2.2.4 Design concept – superstructure

The overall structural design concept relied on masonry test data and calculations based on guidance provided in BS5628 Part 1. Design for the structure, as built, presented no problems other than for consideration of the lack of wall continuity where panels were abutting each other. The most demanding loading conditions relate to wall panels being lifted and manoeuvred into position.

The house was constructed as an “upside down” house ie. three bedrooms and a bathroom down stairs with a large open plan space on the first floor which provides kitchen, dining and living areas. The roof provides a lofty space for natural ventilation through an opening light at the top. (Figure 5.35 & 36). Both the wall and roof construction are such that heat loss is not an issue as the U values are lower than specified in Part L of the then current Building Regulations.

Further details of the house are given in Figures 5.37 and 5.38.
The ground floor is constructed using the Jetfloor beam and insulation block system whilst the first floor incorporates prestressed hollowcore units.

In terms of structural design of the masonry, procedures as outlined in BS5628 Parts 1 and 2 were followed wherever possible. Masonry characteristic strength values used in calculations were based on wallette tests carried out in accordance with Appendix 3 of the code. Structural stability of the ground floor walls presented no problem due to the arrangement of internal masonry. However at first floor level, since there were no internal walls, all panels had to span vertically between the steel framed roof structure ring beam and the first floor. To work successfully as a masonry solution as far as wind loading was
concerned this required the increased strength properties of the thin joint adhesive system, self weight of the roof structure and appropriate restraint at the eaves and floor level.

All materials were manufactured to an approved quality system, regular material testing was carried out throughout the fabrication and building process and construction was carried out under regular supervision. Consequently a partial safety factor $\delta_m = 2.5$ (i.e. special / special category as outlined in BS EN 1996 was employed in design calculations.

The wide cavity (150mm) coupled with thin bed joints presented a challenge when ensuring an appropriate strength of wall tie which would be accommodated in the construction format. Joints in brickwork were 6mm and in blockwork approximately 2mm

The superior strength facilitated by the use of thin joint mortars enabled the wall tie spacing to be limited to 900mm c/c both vertically and horizontally even with the use of stack bonded brickwork.

As a safety measure all openings were braced with a timber framework and diagonals for handling / transportation.

The ground floor / first floor detail was dealt with by the introduction of a steel channel (edge beam) which although desired by the architect for visual purposes, allowed for a break in continuity of the external masonry and again ensured that any manufacturing inaccuracies could be dealt with by the detail.

The stack bonded brickwork enabled corner details to be aesthetically pleasing by use of a standard vertical movement joint comprising readily compressible filler and a mastic finish. Joint thicknesses were detailed as 20mm to allow for dimensional variation of panels. In the event these were more than adequate for the construction accuracy that was achieved. (Figure 5.39)
5.2.2.5 Designing to the Code For Sustainable Homes.

When the original Eco House concept was being put together, the Code For Sustainable Homes was not yet in existence and this proved to be somewhat challenging when carrying out a code assessment.

Initial design requirements in terms of environmental comfort were based on the thermal mass concept which exploits the density of the construction materials (i.e. concrete and brick) to provide a cool structure on hot days as the building materials absorb the heat. This heat is then slowly released during cooler conditions. In simple terms the peaks and troughs in temperature changes over a day/night cycle are not as severe as for other structures which do not possess high thermal mass. (Farag PhD 2012), (Figure 5.40)

![Temperature variations for buildings of low and high thermal mass](image)

*Figure 5.40 Temperature variations for buildings of low and high thermal mass (The concrete Centre 2007)*

Temperature recordings were made for the EcoHouse™ on all elevations, both internally and externally in order to evaluate long term building performance.

Results are shown in Figure 5.41 (a & b) for both month long temperature variations and also for a particular day over a 24 hour period. This was done in 2007

Figure 5.41 (a) and (b) show the effect of thermal mass characteristics illustrated by the high peaks and troughs of the external temperatures when compared with the steady and consistent temperatures monitored inside the building. This result was expected and it
demonstrates the comfortable internal environment achieved with solid dense masonry materials.

The walls of the house achieved a U value = 0.18W/m²K
Windows were triple glazed krypton gas filled units
Water harvesting and geothermal heating systems were installed as was a solar collector system used for water heating.

An assessment of the building “as built” led to a Code Level 4 being achieved and further work resulted in attaining Code Level 5 by the BRE 2009 Exhibition.

5.2.2.6 Conclusions
With the Hanson EcoHouse™ and the Hanson QuickBuild™ walling system it was demonstrated that it is possible to provide a wide variety of construction solutions which embrace traditional tried and tested materials with the use of new construction and design techniques. In addition such solutions will embrace the progressive requirements of the Code for Sustainable Homes.
A brief summary of benefits of the Hanson EcoHouse and QuickBuild™ walling system are outlined below.

- Speed of build
- Tried and tested products
- Safer on-site erection
- Reduced site waste
- Easily extended
- Enhanced air tightness
- Reduced need for scaffolding
- Accommodates precast concrete floors
- (larger spans with greater flexibility)
- Reduced need for lintels, ties and fixings
- Masonry is durable and resistant to extreme weather conditions
- Better sound insulation
- Better fire insulation
- Not susceptible to rot or infestation
- Dries out more quickly after a flood with little or no residual damage
- Has the benefit of thermal mass - particularly useful as weather gets hotter
- More secure – walls more resistant to penetration
- The glued masonry walling acts as both structure and external full brick finish.
- Pre installed wiring loops and outlets can be incorporated into the walls prior to erection
- Exposed elements are not susceptible to damage from inclement weather conditions during construction
- All the benefits of traditional brick and block plus a fast method of building.
- Factory produced masonry, hence quality assured, durable, secure with thermal mass at a price consistent with current practice.
- The system inherently addresses the more exacting needs of the new Code for Sustainable Homes - airtightness, insulation, sustainability, durability, sound & fire insulation required for future high performance dwellings.
- The latest in 'Smart' building solutions technology with remote operation of heating, lighting, energy monitoring, security and interactive web-based hub link to community services for healthcare, education, welfare & leisure.
The manufacturing process used for the construction of the Eco House is not practical when a high volume of components are required as may be the case for the development of large scale housing. In such cases the time taken for panel manufacture, although still ensuring a greater comparative daily output than achieved by traditional on site processes will not be sufficient to provide mass housing.

Increased manufacturing output will only be achieved by the employment of increased manpower services and in a very large open spaced factory structure.

Since the Code for Sustainable Homes is no longer used as the benchmark document for energy and construction efficiency (this now being absorbed into the UK Building Regulations) it is not necessary in any further developments to carry out a Code evaluation. However the design criteria ie good building construction practice, thermal insulation and controlled natural ventilation will still form a key part of modern efficient construction. These parameters will need to be embraced into a high volume / high capacity manufacturing system; one which is competitive with traditional processes.

5.2.2.7 Further development work and construction details

In addition to developing a manufacturing process which is cost effective with a relatively low capital outlay, there is a clear need to drive costs down by ensuring that the completed prefabricated components include as much of the services and finishes as is possible, to reduce on-site additional labour and time.

Initial trials for such improvements within a cavity wall were undertaken in 2009 at the Hanson open factory shed where manual prefabricated panels have been developed (Figure 5.42). Innovations include :-

- Installing window frames and the glazed windows within the factory.
- Build in the services such as electric wiring within the prefabricated panel.
- Provide a wet plaster finish to the inner leaf of the cavity walls.
- Maintain structural / construction details which are simple, in accordance with the Building Regulations and incorporate only standard proprietary fixing components such that costs are again kept to a minimum (Figure 5.43 (a) and (b)). Figure 5.44 illustrates typical foundation details and figure 5.45 highlights the fabrication drawings for masonry panels.
Constructing prefabricated walls which include plaster finishes, completed doors and windows and built in services will provide a clear cost benefit when comparing with traditional on site construction reducing trades and saving on site time. Further work is required to develop this cost benefit.

Typical construction details for the Hanson House are illustrated in figures 5.43 – 45.
Figure 5.43 (a) and (b) External cavity wall connection – straps are used to tie internal leaves of the connecting panels. Wall ties connect the inner and outer leaves of each prefabricated panel. A compressible movement joint is used at the external brickwork junction. (Hanson Design Services 2007)

Figure 5.44 Foundation details for the QuickBuild™ system. (Hanson Design Services 2007)
Figure 5.45 Construction/fabrication details as prepared for a typical cavity wall showing location of wall ties, brick bonding pattern and bed joint reinforcement. (Hanson Design Services 2007)
5.2.3. Case study No 8, Lawn House, Private domestic dwelling, Burbage Leicestershire

Architect - Penny Shankar, Contract manager – Fred Badowski
Contractor - Hanson Irvine Whitlock, Project completed - November 2011

5.2.3.1 Introduction. Having visited the BRE Offsite 2007 and Insite 2009 exhibitions, Architect Penny Shankar elected to construct a private house incorporating the Hanson EcoHouse construction techniques including the prefabricated masonry walling solution, precast concrete floor units for the first floor and Jet Floor concrete beam and polystyrene for the ground floor system. Additionally there was a desire to construct this house in such a manner as to achieve a Code for Sustainable homes rating of 6 through incorporating a cavity wall which ensured the lowest U value achievable along with the inclusion of renewable energy systems. This was the first private development to be constructed using prefabricated brick and block cavity walls. Lawn House clearly demonstrated the sustainable benefits of using traditional materials in a new and alternative offsite manufactured format although the bespoke design did highlight certain drawbacks in terms of cost and construction efficiency. Figure 5.46 show the preliminary scheme details.

Lawn House, a Code Level 6 eco-house built in Burbage, Leicestershire was the first private development in the UK to be constructed using prefabricated brick and block cavity walls. The designer, Penny Shankar of Nelemor Projects, wanted to build a zero carbon brick and block house and approached the author and the brick manufacturer, Hanson Building Products to discuss whether prefabricated cavity wall panels and the benefits of offsite manufacturing could deliver a Code 6 building. Although prefabricated panels and composite panels have been used for many years, prefabricated cavity walls, where
the two leaves are tied together in the factory, were and in 2015 still are - a fairly new concept which has not been repeated. Figures 5.47(a) – (d) show plans and elevations of the structure.

Figure 5.47(a) South Elevation. (Penny Shankar Architect 2010)

Figure 5.47(b) West Elevation. (Penny Shankar Architect 2010)
Figure 5.47 (c) Ground Floor Plan. (Penny Shankar Architect 2010)

Figure 5.47 (d) First Floor Plan. (Penny Shankar Architect 2010)
5.2.3.2 Prefabricated wall panel manufacture, Hanson Stewartby Workshop.

The process of wall fabrication for Lawn House followed the same practice that had previously been employed for the Hanson EcoHouse™ that was erected at the BRE Offsite 2007 Exhibition. A different factory location, Hanson Stewartby in Bedfordshire, was selected for the build work, and the contractor was Hanson’s own team, Irvine Whitlock, who have extensive experience in various forms of masonry construction.

Irvine Whitlock are contractors of considerable size and have completed many large and prestigious projects which include difficult masonry detailing. There is a practical advantage about using an in-house team since the costs could be closely and accurately monitored and one of the key issues ie health and safety in the work place was treated with more diligence than might be the case with small subcontractors. The key benefits of an in house contractor for the prefabrication exercise are :-

- Health and safety supervision in particular :-
  - Documentation relating to the work place,
  - Use and handling of equipment, tools and machinery
  - Lifting and moving of large masonry panels,
  - Risk assessment monitoring
  - Supervision in relation to PPE equipment.
- Organisation, skills and programme
  - Strict work programme and schedule of works
  - Policing of the working area and traffic, plant and equipment
- Liaison with designer and R and D team over panel fabrication issues and problems.
- Cost control and monitoring of work progress
- An understanding of the product innovation working environment where there is often uncertainty and unpredictability over construction matters.

The number of walls to be fabricated (twenty in total) was not dissimilar to the number required on the EcoHouse™. However there were some fundamental differences which are highlighted below. The series of photographs, Figures 5.48 (a) to (f) show the typical factory construction process and panel removal via crane.
Figure 5.48 (a) Views of factory with panels under construction

Figure 5.48 (b) Blockwork inner leaf complete with brickwork under construction. Openings with concrete lintels shown

Figure 5.48 (c) and (d) Panel being removed with brick and blockwork the latter where the garage is positioned

Figure 5.48 (e) – (f) Panel being removed from plinth on which it was constructed. The vertical recess in brickwork to accommodate the square rainwater downpipe can be seen at mid point.
• The external walls were constructed of stretcher bond brickwork external leaf with a wider cavity and greater insulation thickness than is normally required in standard construction to UK Building Regulations.

• There was no detail incorporated at the first floor level which might hide any inaccuracies, in the brickwork setting out (such as the edge beam used on the Hanson EcoHouse™ at the BRE). Consequently high accuracy and good workmanship were required to ensure that when a first floor wall sat on top of a ground floor wall the stretcher bond pattern was continuous and the mortar joints matched such that brickwork appeared to be continuous from ground level up to eaves. This also involved ensuring that the stretcher bond detailing was clear and accurate to ensure continuity from ground to first floor (i.e. to ensure that half brick lap was maintained).

• Architectural details to accommodate the rain water down pipes had to be constructed with a very high level of accuracy to ensure that the square down pipe fitted snuggly into the open corner. In this case when the cavity walls were brought together on site the tie detail was between the block work inner leaves. The external leaves were arranged such that a vertical line / space was required at the corner point of contact.

• In certain wall panels a vertical square down pipe was located (or buried into the outer leaf at a position at or near the mid span. In such cases additional wall ties were needed to ensure continuity of lateral strength which was otherwise significantly reduced with a lack of continuity in the outer leaf. (Figure 5.49(a) and (b).

• Unlike the Eco House a number of panels were constructed to have a sloping top edge. Additionally some panels were constructed of clay facing brick and aircrete blocks. This occurred where some walls became part of the internal structure.
5.2.3.3 On-site installation of masonry panels and construction details

Onsite installation, although not restricted, did involve a 100 tonne crane having to operate from the road immediately adjacent to the site where panels had to be moved over a line of tall trees. (Figure 5.50 and 5.51). This operation was acceptable and successful although it did involve notifying local police and the local authorities’ highways department in order to gain permission. As such the offloading times for the crane were critical and limited to either a specific number of hours per day or to half or full days. Such access must be paid for and this cost needs to be allowed for in comparative cost calculations of traditional versus prefabricated processes. Although the general installation costs had already been identified for the Hanson EcoHouse, having a project with a fee paying client brought home the reality of prefabrication economy when comparing with traditional costs. Installation costs included road closures, crane hire and an installation team. These are additional costs that are not necessary with traditional build.

The only direct counter cost saving to these issues was speed of construction which had to be maximised at every opportunity. One example of this was in the setting out and location of panels during construction. Internal panels were located in position using a cold formed galvanised steel channel which was temporarily bolted to the concrete floor. This assisted and increased the setting out and installation process. This can be seen in figure 5.52 as can the temporary push /
pull prop supports. The supports were temporarily bolted to the floor screed for the duration of the installation work.

Panels were positioned directly onto a traditional flexible dpc which was located immediately on top of the in-situ built blue engineering brickwork that sat directly onto the foundations. Figure 5.53 and 5.54 shows the dpc in position on top of the blue bricks specifically at a corner detail where one of the inset downpipes is to be placed.

Figure 5.53 Panel located on brickwork above dpc

Figure 5.54 DPC on top of blue engineering bricks.

Figure 5.55 illustrates the overall thickness of the cavity wall which includes 100mm of phenolic foam insulation and an outside face air cavity of 50mm. This does decrease the internal footprint of the living area when compared with standard cavity wall construction, a situation which is not critical for a private development where land area is not an issue. However in smaller private development plots where space is a premium and certainly on large construction sites where the dwelling size / footprint must be such that a maximum number of plots per hectare is achieved excessively wide cavities (albeit thermally efficient) may not be desirable.

The panel erection sequence is critical to minimising installation time. This starts at the factory where as has already been discussed space is at a premium such that panel production must follow a strict procedure to enable their removal from the factory. A hired crane was needed to load the lorries but only a small area of space was available for the crane and lorry. When these were in position, there was little room to select, lift and place panels onto the lorry flat bed. Consequently panels had to be constructed in exactly the sequence that they would be installed so that upon arrival at the site they could be...
removed from the lorry and located in their specific position within the house. This process is not always as simple as loading in a first come first serve basis. The lorry must be loaded evenly i.e. from its centre line (along the lorry length) outwards. Loading from one side only will cause instability of the lorry and potential overturning.

When panels are installed on site these generally need to be in a sequence which calls for the furthest from the lorry and crane to be offloaded first then working back towards the lorry. As panels are located they need to be immediately supported with bolted push / pull props. Final location of a 7 tonne cavity wall requires delicate skill and the last few cm’s of location involves nudging the load and checking for line and level with a spirit level. Prior to a panel being placed in final position, mortar is applied to the base floor and if necessary the panel verticality is adjusted using steel spacer shims (various thicknesses are made available for this operation). When the panel is in its final position the props are adjusted, bolted down and by means of threaded adjustable length fine tuned for panel accuracy. Caution, skill and training are required to ensure that any site staff present do not move or knock panels during installation. Subsequent panels are installed adjacent to earlier ones and levelled and propped in the same manner. At this point the adjacent panels are tied together using a conventional strap tie process.

No props were removed until the whole ground floor walls were installed and the ground floor walls had to be completed in entirety before the first floor flooring system was installed. It is only at this point that there will be structural stability of the construction completed thus far.

It must be noted that the cavity walls cannot be assumed to be free standing. The weight difference of inner and outer leaf are such that panels cannot support themselves and require tying together for stability. That being said the fully installed structure is very robust and it is the panel connection details that are critical for stability rather than the strength of the panels themselves. Once the structure is completed it is more than adequate to withstand the more conventional loads of self weight, building imposed loads and wind loading. Figure 5.56 shows adjacent panels strapped together at a joint. As may also be seen here a number of

Figure 5.56 Internal and external walls located and tied together across joint.
internal panels were constructed as T shaped components. This provides strength and continuity at junctions.

An appraisal by the architect Penny Shankar best describes the house, its unique characteristics and environmental benefits.

“Horizontal joints between panels are articulated by the brickwork to show that this house has been constructed in a non-traditional way. Also, flush detailing emphasises that, whilst constructed from traditional bricks, this is a contemporary house. All downpipes are set between panel joints and corner junctions, and skylights for upstairs bedrooms are flush with PV and solar thermal panels that form the roof covering.

Solar photovoltaic panels cover the entire south face of the main house, which give electricity back to the national grid when supply exceeds demand in the house. In the summer, solar thermal panels, installed on the south face of the addition, feed hot water into the thermal store. A wood burner with back boiler provides heating and hot water through the winter months. A fully glazed bay window on the sunroom optimised solar gain at all times of the year, with any surplus heat re-circulated to other areas of the house via a Whole House Ventilation System.

The house is designed to meet Lifetime Homes principles, including windows in living rooms low enough to have a view out to the garden when seated, and provision for a lift and downstairs shower to be installed if the needs of the client change.

The brick and block walls also provide thermal mass to ensure even heat throughout the house. Energy efficiency was the driving force behind all the design decisions. I am delighted at how well Hanson’s innovative panel system helped us achieve this, and the client is delighted with her finished home. Embracing new technology is always a risk, and it was a steep learning curve for all of us, but I am really glad that we used this pre-fabricated panel system.”

“The Hanson Yorkshire Red Blend light textured, wirecut facing bricks were chosen to meet the design criteria and to blend in with the local architecture. Each tailored brick panel, insulation and a 100 mm Thermalite inner leaf block were bonded together in the factory with an appropriate high strength modified mortar being employed for each leaf respectively in much the same manner as the Hanson EcoHouse™.
All-in-all, 20 panels were used, weighing up to seven tonnes each and measuring up to nine metres in length, all of which were constructed, lifted and delivered to site without any damage. The result is a house that brings together the most up to date developments in offsite masonry construction, natural ventilation and the benefits of thermal mass.

Inside the house are a number of other sustainable features including a super-insulated thermal store, greywater and rainwater harvesting and a sustainable urban drainage system. In addition, Lawn House is one of the only domestic properties in the UK to feature solar photovoltaic panels across its entire south facing roof.

Water efficiency was another key requirement. A grey water harvesting system means that water from baths and showers is used to flush all toilets, and a rainwater harvesting system collects water from the roof and SUDS paving to provide water for the garden.”

“\textbf{Figure 5.57 The speed of construction demonstrates how quickly and efficiently mass housing can be constructed in the future provided that a repetitious system build process is used rather than an individual design}"

“I was delighted with the results. Lawn House shows what can be achieved by embracing new technology. The quality of the brickwork is excellent and the speed of construction demonstrates just how quickly and efficiently mass housing can be constructed in the future using prefabricated cavity wall panels”.

Lawn House went on to win the ‘Innovative Use of Brick and Clay Products’ category at the 2011 Brick Awards, impressing the judging panel who commented that the house is a
truly innovative construction for a Code 6 house and a great example for sustainable development. The aim for a Code 6 house was because the client, who is committed to making her life more sustainable, wanted to live in a new house that had as small a carbon footprint as possible.” (Figure 5.57)

5.2.3.4 Conclusions
Lawn House is still the only prefabricated cavity walled masonry house to be constructed in the UK (2014). In addition the structure finally achieved a code level 6 rating. However the question must be addressed as to why the system has to date not been considered more widely. This is due to the cost of the system which within the current construction culture is still risk averse to change.

In terms of the economic viability of the exercise, the overall structure is not cost effective when compared with traditional construction if one considers the time taken to fabricate the walls in a factory coupled with crane hire and associated installation costs. However the superstructure in its entirety was completed in a matter of days rather than the several weeks which would be required for a traditional brick / block laying process. Apart from the programme speed, another benefit of the superstructure being completed as quickly as possible relates to the time taken to achieve a water tight structure so preventing cavity wall components from getting exposed to the elements. Figure 5.58 shows the completed house.

It was clear from this project that there are certain benefits of a prefabricated masonry solution including speed of construction, reduced site impact, higher quality construction. However cost has always been identified as a key parameter particularly on a large scale development where it will take preference over other aspects.
5.2.4 Case Study no 9 - Carlisle flood defence system

5.2.4.1 Introduction
Recent changes in climatic conditions have led to both increased severity and frequency of rises in river levels such that significant flooding and widespread damage has been caused extensively throughout many parts of the UK. (Dept of Environment, Planning Policy Statement Planning and Flood Risk, 2006), (DCLG Development and Flood Risk, 2006), (DCLG, Improving Flood performance of New Buildings 2007)

One method of controlling flooding involves containment of water in localised areas by the construction of flood defence walls. These vary in construction type depending upon
- Flood forecasts data for specific areas
- Depth and width of river and forecast of volume of water flowing
- Specific town planning and architectural requirements in particular areas for the structural / aesthetic finish of flood walls.

The requirement in urban areas is often dependent upon local materials and specific masonry finishes may be necessary.

5.2.4.2 Flood wall construction
A number of various defence systems exist including earth embankments with a grass finish – often sufficient in agricultural and rural locations creating minimal environmental impact. Alternatively a structural wall may be provided which will typically comprise either steel sheet piling or reinforced insitu concrete. The walls are then completed by cladding in the specified selected finish.

An opportunity presented itself to develop a variation of the QuickBuild™ prefabricated wall panel which could then be rapidly erected / installed against the structural wall at a significantly higher installation rate than might be achieved by masons laying brickwork or blockwork by conventional / traditional trowel trade techniques. The project was the Carlisle and Caldew river flood defence system for which the main contractor was Volker Stevin (now Volker Vessle) and material and prefabricated panel manufacturer Hanson Building Products.
Prefabricated cavity wall panels had already been used successfully for the construction of two houses at the Building Research Establishment’s Innovation Park for the Offsite 2005 and 2007 exhibitions.

For the flood defence scheme a number of options were considered including:

1. Fully prefabricated composite structural wall panels of reinforced concrete with a cast in masonry brick or brick slip finish.
2. Single skin prefabricated “masonry only” panels which incorporate a high performance mortar.

Although option 1 provides both a structural element with very high resistance to lateral loading and an architectural finish, it also forms a heavy component to handle and transport with the number of panels being limited by a lorry handling capacity. Based on material density, a reinforced concrete wall is 2500 kg/m$^3$ as compared to the heaviest clay brickwork being 2000 kg/m$^3$ and an average being 1500 kg/m$^3$ which is a reduction of between 20% and 40%.

Option 2 provides lighter weight panels which will improve handling and transportation characteristics. However the panels possess lower resistance to lateral loading and require careful detailing to ensure maintained strength and integrity during wall installation.

Trial wall panels were constructed by glue gun and pump methods in a factory environment incorporating a steel framed jig of vertical coursing marked profiles (Figure 5.59) in an attempt to simplify and speed up the setting out process. Of particular importance in the prefabricated wall development was the use of a non skilled labour force for the fabrication of the walls.

It was considered possible to utilise an unskilled labour force under the supervision of a brickwork foreman. It was anticipated that using the pump and gun laying process and framed jigs with courses already set out, an unskilled labour force would be able to achieve an acceptable standard of masonry quality, workmanship and accuracy for the flood wall requirements. Additionally this process and experience level might achieve a
competitive output in terms of both production and cost. Some training and induction would be required and the length of time and extent of this was monitored and recorded.

5.2.4.3 Comparison of flood wall construction processes

A conventionally built river flood defence system may be best illustrated by consideration of the Lancaster Flood control project completed in 2007; a wall of 300m in length. This was constructed by civil engineers Volker and it was based upon this process that one of the project directors, having seen the Hanson EcoHouse™ believed that the prefabricated masonry technique might provide a superior solution to that of the traditional techniques.

Figure 5.60 conventional in-situ cast reinforced concrete retaining

The Lancaster flood scheme included the use of conventional concrete piling (figure 5.60) which was driven into the river embankment. This was capped with a reinforced concrete ground beam and a retaining wall. Due to planning requirements the concrete wall was required to have a stone clad finish which was provided by conventionally laid masonry (figure 5.61) Such a task is slow and labour intensive and in a river bank environment also a hazardous operation.

The key disadvantages of this technique were

- Piled Foundation.
- Environmental risks associated with wet trades working adjacent to a watercourse.
- Inclement weather affecting production.
- Excessive temporary works arrangements necessary to provide weather protection
- Programme duration and nuisance factor which impacts the local environment
A simple comparison of the current conventional flood wall construction system with the prefabricated masonry option serves to illustrate the benefits of the latter for wall installation as outlined in figures 5.62(a) and (b) below.

**Standard flood wall construction using steel sheet piling and masonry cladding finish**
1. Steel sheet pile driven into position
2. Temporary formwork erected to either side of the piles as required
3. Place in situ concrete
4. Remove formwork
5. Construct masonry cladding

![Figure 5.62(a) Conventional sheet piled flood defence wall with traditionally constructed masonry](image)

Flood wall construction using steel sheet piling incorporating prefabricated masonry panels. The basic wall cross section is the same as for the in situ masonry construction.

1. Steel sheet pile driven into position
2. Prefabricated masonry panels placed into finished location with temporary propping also used to contain subsequent wet concrete backfill pour
3. Pour in-situ concrete backfill between piling and masonry

![Figure 5.62(b) sheet piled flood defence wall with prefabricated masonry panels](image)

A typical flood wall design on a river embankment comprises a single wall panel to the promenade side of approximately 1.2m-1.5m height (which doubles as a typical walkway
wall) whilst on the river bank side the masonry is required to be at least the height of the promenade wall dropping down the full depth of the river embankment to the typical river level. This is usually anything from 2.4m – 3.0m. The completed structure is finished with a large concrete overhanging coping which affords weather protection to the walls beneath it.

5.2.4.4 Prefabricated panel design and detailing requirements for the typical flood wall section.

Panel fabrication in terms of length, height, weight, transportation and site handling were key parameters in determining the number of panels required in the cross section arrangement. The cross section in figure 5.63 shows the promenade wall to be typically 1200mm high while the river embankment wall is between 2.5m and 3m high. It is the embankment wall that requires consideration. Steel profiled sheet piling and a typical cross section are shown in figure 5.64.

An optimum size of panel was determined in order to achieve speed and cost of installation, manufacturing cost and ability to transport and lift panels.

![Figure 5.63 Typical cross section survey at river embankment. (Volker Stevin 2008)](image-url)
Figure 5.64 Working drawings of plan and cross section through flood defence wall. (Volker Stevin 2008)
Figure 5.65 illustrates a typical prefabrication detail for a masonry panel including ties, reinforcement and brickwork setting out.

In traditional bricklaying the bricklayers skill ensures correct bonding and setting out are achieved based on working drawings which provide no more than co ordinating dimensions. With prefabricated masonry, working drawings showing full brickwork detailing and setting out of brickwork are particularly important for fast and efficient production of panels.

A number of basic problems exist when a non-skilled labour force are utilised, for example coursing must be such as to ensure continuity of brick bond between adjacent panels and prevention of stack bonding due to course misalignment.

For this first example of mass produced panels by a non-skilled work force additional complications included the incorporation of two courses of stretcher bond engineering bricks at the base of the panels plus the use of English Garden Wall Bond ie 3 courses of stretcher bond followed by one course of headers. Alignment of perpends is paramount to producing quality masonry.

A stock type brick was used for the main body of the wall which manifests typical stock characteristics i.e. irregular shape with soft edges and greater dimensional variation than with engineering bricks – this fact makes greater demands on the brick laying skills. Stock bricks have another significant feature; a frog rather than solid or perforated unit format creating greater mortar consumption and a need to appraise strength properties.
5.2.4.5 Preliminary trial walls – manufacturing techniques, location and set up.

The first flood wall trial panels were developed at the Hanson Precast Flooring Division’s factory at Somercotes, Derbyshire. This was chosen as being a suitable location for a number of reasons including :-

- The factory used for panel manufacture was a geographically convenient location from which to monitor development and progress.
- A large working area was available for production
- Overhead cranes were available for panel movement both for storage and placement onto flat bed lorry trailers.
- An experienced workforce in manufacture and handling of large prefabricated panels was used.
- Factory access – roller shutter doors wide enough for lorries to manoeuvre into position to load up panels if necessary

Figures 5.66(a) and (b) show the factory and panel jig set up

For panel production to be a success it would be imperative to achieve high volume output as economically as possible whilst maintaining consistently high quality and appropriate structural performance such that wall panels could be transported and handled by crane.

Unlike the 2 skin cavity walls for the Hanson EcoHouse™, flood wall panels are single skin masonry and the initial requirement was for a panel size no longer than 6m x 1.5m in height. These dimensions and corresponding weight allow for optimum delivery on a 15m long flat bed standard height lorry which would not require police escort, nor have any height restrictions for motorway bridges.

A larger lorry such as a low loader which would incur higher costs and the need for a police escort would be impractical for the small number of loads to be transported. The intention was to make brickwork panels using a manual construction operation as had been previously done, incorporating the polyjet pump and mortar glue gun system. Omnicol mortar as was used for the in-situ processes was employed here. In an effort to
improve on quality and speed of construction steel frame jigs were fabricated so that dimensions, line, levelling and plumb accuracy might be readily achieved without the need for repetitious setting out processes for each individual panel. Eventually four such steel jigs were set up for full scale production.

More importantly, although initially a brick layer was employed to supervise, check, monitor and advise on panel manufacture, the intention was to evaluate the benefit of using unskilled labour for the process. If successful, unskilled labour could reduce costs provided that the achievable output was comparable to that of skilled bricklayers. Some additional detailing requirements added further complications for the flood walls. Local Planning Authority had requested that brickwork should match nearby Victorian domestic properties in brick type, mortar joints (colour and size) and in a traditional brickwork English bond.

The brick and mortar types were matched with relative ease. However the brick specified was a frogged brick which up until this point had not been used in any UK panel fabrication. The frogged brick, joint thickness and bond type were issues which could affect the panel manufacture, structural performance and also cost. Material cost could increase significantly due to thicker mortar joints, the inclusion of header bricks which increased the frequency of vertical perpend joints and the increased mortar volume used in filling the brick frogs. It had already been demonstrated in trial compression tests that a thicker joint would reduce the flexural strength parallel to the bed joint. (Oxford Brooke, 2004). Using an English bond did not directly affect flexural strength which is still influenced largely by the bed joint performance – and bed joint frequency does not alter for English Bond.

After some initial training for the unskilled work force which comprised glue gun machine use and maintenance instruction as well as brick laying techniques, preliminary trial panels were made recording material volumes and construction times when manufactured by either experienced bricklayers or unskilled operatives.

The high mortar cost requires construction to be done with a minimum of waste so that excess mortar during the bricklaying, is recycled into the mixer rather than be discarded. This must be done with some care, judgement and skill as mortar cannot be reworked by the addition of water which could compromise its strength and workability. In the event it was preferable during panel manufacture to ensure that any waste mortar from bricklaying was used directly in the ongoing brickwork.
Material preparation and good housekeeping regarding machine care and maintenance were essential. These issues underpinned the earlier conclusions from on site case studies that site use of thin joint systems in the UK by this technique is impractical and proven to be non-cost effective. This issue is illustrated in the Case Studies in Chapter 3 of this thesis. The benefit of factory production was already recognised from the EcoHouse™, (Case Study 5.2.2) project, specifically the improved working environment and the availability of maintenance support at short notice. However, speed of output was never a key requirement for the cavity walls whereas a tight programme and high level of panel installation were expected for Carlisle.

**Preliminary trials and outline costs**

The following costs are given as a relative guidance when comparing traditional brickwork with factory built prefabricated panels. The objective of this comparison (and hence the simplicity) is to consider daily output and labour costs on the basis that the factory built panels are constructed by operatives unskilled in bricklaying and their labour rate is therefore lower than that of trade bricklayers.

**Option 1 - Prefabricated panel**

Typical single leaf panel size = 6.0m long x 1.2m high x 102mm thick

<table>
<thead>
<tr>
<th></th>
<th>Panel area (m²)</th>
<th>Number of bricks</th>
<th>Maximum panel output per day (8 hours)</th>
<th>Labour rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>= 7.2 m²</td>
<td>= 90/m² (English bond)</td>
<td>= 2 panel</td>
<td>= 2 x £120</td>
</tr>
<tr>
<td>Labour per panel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bricks per panel</td>
<td></td>
<td></td>
<td></td>
<td>£120</td>
</tr>
<tr>
<td>Mortar</td>
<td></td>
<td></td>
<td></td>
<td>£9 per bag x 6 bags £54</td>
</tr>
<tr>
<td>Bed joint reinforcement &amp; ties per panel</td>
<td></td>
<td></td>
<td></td>
<td>£50</td>
</tr>
</tbody>
</table>

**Total cost per panel**

= £386 (£53.61/m²)

**Value per lorry load = 16 panels x £386**

= £6176

**Haulage**

1 flat bed lorry transports 16 panels

Typical direct to site cost

= £115.2 m² per lorry

= £400 per 16 panels

**Grand total (16 panels £6176 + haulage £400) = £6576 (£57.08/m²)**

(material + labour + haulage)
**Option 2 – Insitu panel**

Typical single leaf panel size = 6.0m long x 1.2m high x 102mm thick

<table>
<thead>
<tr>
<th>Panel area (m$^2$)</th>
<th>= 7.2 m$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of bricks</td>
<td>= 90/m$^2$ (English bond)</td>
</tr>
<tr>
<td></td>
<td>= 648 per panel</td>
</tr>
</tbody>
</table>

Assume equivalent daily output as for prefabricated panels for comparison.

Maximum panel output per day (8 hours) = 2 panel

<table>
<thead>
<tr>
<th>Labour rate</th>
<th>bricklayers</th>
<th>= 2 x £150</th>
<th>= £300</th>
</tr>
</thead>
<tbody>
<tr>
<td>2+1 gang (skilled labour)</td>
<td>Labourer</td>
<td>= £100</td>
<td>= £400/day</td>
</tr>
</tbody>
</table>

| Labour per panel | = £200 |
| Bricks per panel | = 25p each x 648 | = £162 |
| Mortar (equivalent OPC) | = £1/bag x 6 bags | = £ 6 |
| ties per panel          | = £ 5 |

Total cost per panel = £373 (£51.81/m$^2$)

**Equivalent lorry load = 16 panels x £373** = £5968

**Haulage – equivalent haulage for materials to produce 16 panels**

| 1 lorry with 11000 bricks | = £400 |
| 1 pick up truck 96 bags of mortar | = £150 |
| 1 truck 1500lin m bed joint reinforcement | = £ 75 |
| Wall ties | = £ 20 |
| Total haulage | = £645 |

**Grand total (£5968 + haulage £645) = £6613 (£57.94/m$^2$)**

(Prefabricated panels - speed cost of construction)

Daily installation of prefabricated panels = 20 per day = 144 m$^2$ per day

Equivalent to bricklaying 144m$^2$ x 90/m$^2$ = 12960 bricks per day

Installation team = £1000 per day

Cost / 20 panels = (£6576 x 1.25) + £1000 = £9220 per 20 panels per day

(cost of 20 panels plus installation team)

**In-situ panels - speed cost of construction**

Cost / 20 panels = £6613 x 1.25 = £8266 per 20 panels

(Material, labour and haulage)

Note – it is not possible to employ sufficient gangs to produce 20 panels per day due to site working restrictions and health and safety.
Observations relating to cost comparisons of prefabricated v in-situ production.

Cost comparisons of alternative construction solutions are always very difficult and subjective depending on considerations of a variety of parameters. The comparisons in the previous exercise are intentionally very simplistic in order to try and give a practical overview on “relative” costs. The exercise does not include allowance for any site management related costs but simply compares materials, labour, speed of build and haulage.

Taking only these things into consideration it is apparent that the cost of both prefabricated and in-situ formats are relatively similar with a difference of approximately 9% in favour of the in-situ solution.

- Material costs have been kept the same in both analyses.
- Labour cost is favourable for the prefabricated solution.
- The disadvantage of the prefabricated solution is the requirement to hire a specialist installation team (and their daily cost) trained specifically to deal with large components which are craned into position.
- The key benefit of the prefabricated solution is the rapid speed of construction which is a particular requirement of a flood defence system.

Conclusions and observations

As expected, initial panel quality when built by unskilled operatives was inferior to that of a trained bricklayer. Issues included

1. Greater mortar yield with higher waste.
2. Wall quality issues included uneven bed joint size, varying perpend widths, and lack of perpend alignment within the panel.
3. Construction time was slower
4. Lack of attention to detail when cleaning polyjet pump system
5. Lack of appreciation of the desired finish and difficulty in understanding the properties of stock type bricks which have an irregularity of shape.
6. In order to ensure a good bond between the prefabricated panels and concrete backfill, any excess mortar to the rear of the panels was left in place in order to give a rough surface finish.
7. The faced finish of the panel included recessed joints no greater than 10mm. Obtaining consistency and uniformity required training and ongoing quality checks.
8. Ongoing quality control was essential as repetition in the work caused an element of complacency and led to lowering of standards of workmanship.

9. Of the full panel consignment, 3 panels were rejected for poor quality – these were not destroyed but used for test purposes.

10. A report following a client inspection highlighted some disappointment over quality issues and workmanship with an expectation that factory made masonry ought to be of a much higher standard.

5.2.4.6 Panel production output

The first two production panels were built in order to establish strength during handling. The Carlisle project would require some 120 panels and these would need to be constructed at the rate of 4 per day to keep to programme with a final lead in time being 3 weeks and an as yet unknown installation rate but an estimation of 16 panels ie 2 per hour.

An output of 4 panels per day would require 50 working days with no allowance for failure or wastage.

A lead in time of 3 weeks (15 days) enabled a stock of 60 panels to be ready. These would be installed in 4 days!

With extended overtime working the weekly production output was increased to 28 enabling a prepared stock of 84 and a balance of 36.

All prepared panels would be installed in 5 days (working Monday through to Friday). Therefore the production facility had 7 full days within which to prepare the outstanding 36.

A production 28 panels was completed which left a deficit of 8 panels. In the event circumstances on site lead to some delays (not associated with the wall installation) and as such the balance were delivered in time to ensure that the masonry package was successfully completed.

To ensure production continuity it would be essential to move panels to a storage area as quickly as possible. With precast concrete production it is not unusual to have a working programme which entails fabrication of panels in the morning of day 1 and removal to a storage area on day 2. Traditionally constructed brickwork is built in situ and it is not usual to have to consider moving any components. In this case it was necessary to move panels within a 24 hour period.
5.2.4.7 Strength, structural integrity and robustness

At the time of developing the flood defence panels no previous information was available in respect of neither the strength of panels nor the type of loading to which they would be subjected.

During the contract / construction programme where time is of the essence and health and safety are paramount, there can be no on site experimentation and it was essential to ensure that both in situ masonry strength evaluation and strength during handling were assessed.

Key problems relating to structural design and integrity

1. Joints are 10mm rather than the normal 5mm
2. A stock type brick was used which has a sanded finish to the body and a high initial rate of suction.
3. The bricks are frogged rather than solid or perforated
4. Two courses of red Class B engineering bricks formed the base of the wall.
5. The walls were required to be built in single skin English bond rather than stretcher bond.
6. Panels must be moved as soon after fabrication as possible requiring either a sufficiently high initial strength gain or a lifting / handling process which does not allow for any unnecessary internal deformation and loading.
7. Once the panels are located adjacent to the sheet piling they are required to behave as a permanent shuttering to receive wet concrete which must then become an integral part of the structure. No panel movement or deformation could be accepted during this process.
8. During transportation to site the panels must be sufficiently restrained or contained so as to avoid movement which could cause residual cracking. Any damage during this part of the operation could result in panels failing during the lifting and installation process.
9. Lifting of panels should be by a process which ensures that any deformation or internal stresses are negligible and do not cause failure.
10. The lifting mechanism should allow for panels being lifted and then located for storage at the factory, movement and placement onto a lorry and then from the lorry into the final position within the flood defence structure. Such a process should enable all lifting gear to be safely attached and then easily removed without damage to the panel and also without the need for anything which requires bricks to be left out of the panel.
11. Panels must be kept in the vertical attitude – a contradiction to traditional pc concrete panels which contain sufficient strength and are robust enough to be rotated and laid flat during storage and transportation.

5.2.4.8 Initial testing
1. Standard sample wallettes were made of the required brick / mortar combination as per BS EN 1052 2 but using the English bond format and 10mm joints in order to evaluate the \( f_{\text{sk}} \) parallel to the bed joints.
2. A number of trial panels were made of varying sizes up to 6m long x 1.5m high x 102mm thick - the maximum required panel dimension. Smaller panels were also built, including one which was 6m long x 750mm high. The objective here was to observe behaviour under practical simulated loading and transportation conditions.
3. Mortar samples were made and tested for flexural and compressive strength from 1 day to 21 days. It should be noted that with rapid prefabrication and installation it was necessary to allow for the worst case scenario of panels being manufactured on day 1, stored on day 2, delivered to site on day 3 and installed on day 4 with concrete backfill being placed also on day 4.

5.2.4.9 Initial strength trials of masonry panels
Having established the flexural strength for wallettes, some panels were produced for trial lifting in order to evaluate any limitations.
1. Initial vertical lifts of panels 24 hours after manufacture and with underslung straps proved a success with no vertical or horizontal deflection or cracking.
2. Panels were then lifted again vertically with underslung straps and slowly rotated into the horizontal attitude. However in the 3 trials carried out all panels failed by deflection / tensile stress immediately followed by cracking and failure at an angle of approximately 30 degrees to the vertical. Failure was not parallel to the bed joints but at an angle to the vertical - see below.
3. Hence it was concluded panels could not be successfully rotated from the vertical to the horizontal attitude without cracking failure even with some bed joint reinforcement included in the top and bottom of the panel.
5.2.4.10 Storage of panels, handling and transportation

When manufacturing panels on a high volume scale one of the key issues relates to removal from the place of manufacture to a storage location as quickly and effectively as possible.

Panels were made vertically and timber stillages developed which contained 4 panels. Preliminary stillages comprised a timber framed structure with plywood panelling which presented the most efficient method of stiffening to avoid deflection or distortion. (Figure 5.67(a)). Figure 5.67(b) shows the complete stillage plywood carcass.

![Figure 5.67(a) Part of timber panel stillage unit](image)

![Figure 5.67(b) General arrangement of storage frame with masonry panels in position and lifting frames for moving from factory to lorry](image)
Figures 5.68 (a) to (d) show craneage, handling and storage of stillages of the wall panels. Panels were spaced out by at least a wall thickness in order to allow for access with the lifting framework (figure 5.68(b)). The loading sequence was also important for the panels on two counts – firstly it was necessary to take panels in the order they would be installed, secondly panels had to be removed from storage racks in a specific sequence in order to avoid misplacement or more importantly instability of the stillages.

Whilst timber frames were in themselves adequate in terms of strength, it was soon apparent after 3 or 4 transportation journeys that the joints and fixings became weaker and more prone to deformation. This took place with even the slightest movement of panels when in transit – each panel weighs approximately 2 tons and the slightest movement soon wore away at joints / fixings. Lorry motion (acceleration and deceleration) coupled with any uneven road surfaces caused the consistent deterioration of timber stillages.

In order to optimise transport efficiency and minimise cost of delivery from factory to site, the delivery system comprised one lorry cab plus two flatbed 15m long trailers. Each trailer carried 4 stillages each holding 4 panels ie 16 panels in total.
A lorry took the first 16 panels to site and left the trailer / panels to return only as a single lorry cab. The lorry would then take a second trailer to site and return with the first now empty trailer. This allowed for 16 panel installations per day.

With the early development of both panels and stillages, it was thought necessary to minimize panel handling both for individual units and also for a stillage which as previously stated had a finite life in terms of robustness. A full stillage weighed approximately 6 tonnes and it was essential during lifting that all of the panel load was taken directly by the steel lifting frames, not the timber stillage. Early trials demonstrated that lifting the timber stillages directly caused immediate cracking and distortion and in some cases damage to the masonry panels as a complex loading path evolved due to frame deformation. The stillage damage was brought about by the four no., 6 tonne panels moving independently during lifting and loading the stillage joints.

5.2.4.11 Carlisle and Caldew river flood defence scheme – construction sequence.

From the first site delivery of 16 panels the installation scheme progressed in a very straightforward manner with no incidents relating to the first transportation, successful offloading of the 4 stillages and an uneventful installation of the 16 panels in place by the sheet piling. (Figure 5.69). Delivery and installation sequence was occasionally not in keeping with the carefully planned schedule of installation and this became apparent if certain panels were positioned adjacent to each other only to find that the bond configuration did not marry together well. In such cases panels had to be removed before the concrete backfill was placed and set aside until the correct panel was located.

The pouring of concrete backfill was a success and this was due largely to the steel temporary shuttering that was placed immediately in front of the panels as a temporary buttressing structure. (Figure 5.70)
Figures 5.70 (a) & (b) Steel sheet piling in position with a prefabricated single leaf wall located and concrete backfill poured.

Figures 5.71(a) shows the first row of walling in position with temporary propping still in place, and then in Figure 5.71(b), stripped back to reveal finished faced brickwork.

Figure 5.72 highlights the purpose made lifting frame that enables panels to be located directly onto a foundation or to be slid horizontally into a wall panel framework. The finished flood defence scheme is shown in Figure 5.73.
5.2.4.12 Conclusion and summary

Benefits of the Hanson QuickBuild™ Flood defence system:

- Increased safety through reduction of on site activities.
- Environmentally stable product.
- Sustainably produced and transported.
- Rapid on site build times achieved.
- Virtual elimination of formwork.
- Watertight construction.
- Minimal site waste.
- No wet trades required.
- Reduced scaffold requirement.
- Enhanced strength characteristics.
- No down time due to inclement weather.
- Consistent quality.
- Reduced noise during construction.
- Speed of installation / construction when compared with in-situ built masonry.

5.2.4.13 Further stillage development

Clearly any further commercial development of a prefabricated system would involve use of steel framed racking rather than timber.

Additionally the issue of temporary propping was addressed and from these two aspects it became clear that a single operation involving lifting frame, storage and temporary support would provide the most efficient process. The stillage and frame system development are discussed in more detail in chapter 8.

Panel manufacture, although adequate for this exercise the case study was not seen as an optimum way forward for high volume wall panel output. This would require a more sophisticated automated process, two types of which are addressed in chapters 6 and 7. Whatever preferred method might be adopted it became clear that the manually manufactured process would not be an acceptable solution for high volume or repetitious works. Additionally the cost is required to be more competitive than has been verified within this chapter.
Figure 5.73 shows the wall in the completed flood defence scheme.
5.3 Summary and conclusions to chapter 5

This chapter addresses the development, by the author, of prefabricated masonry using manual construction processes.

The procedure was successfully employed to produce insulated brick and block cavity walls for two innovative test houses at the BRE, a private house designed and constructed in Leicestershire which achieved a Code For sustainable homes rating of Level 6 and a civil engineering scheme which included a brick clad single leaf flood defence wall to a river.

After initial introduction of the in situ thin joint masonry system by the writer into the Hanson company product development programme it became apparent that a prefabricated alternative process presented the greater potential for development when compared with an in situ built system.

The concept of thin joint glued brickwork was favourably received for on site construction by architects who find the appearance of an increased proportion of brick to mortar exposed surfaces more appealing along with the ability to produce more ambitious bonding patterns due to the higher flexural and compressive strength properties. However other members of the construction team including structural engineers and contractors had a clear preference for prefabrication. This included those who had worked on the aforementioned case studies and had therefore direct experience as well as individuals who were approached for their views on the process. It was clear from the outset that the prefabricated alternative presented greater potential for both designers and contractors and was considered to be the technique which would be developed.

The method of prefabrication illustrated in the case studies confirmed that the glue gun and pump procedure could be removed from site and used within a factory environment. This has clear advantages that are to be expected with any prefabricated material such as masonry i.e.

- Speed of construction
- Consistent and generally improved quality over traditional workmanship
- Improved structural performance
- Dimensional accuracy which from the outset was to a level not previously expected.
• Use of the thin joint system (established in Europe for glue mortar with joints less than 5mm thick) as a traditional 10mm process which benefitted UK construction for dimensional co-ordination. The thicker joints had not been previously advised or recommended with this mortar type.

• The thicker joints, still constructed in the high performance glue mortar demonstrated that with UK brick products there was no compromise in structural performance, durability or resistance to rain penetration.

• The process as developed by the author clearly demonstrated simplicity in both fabrication and in on-site installation. This was apparent from the fact that all projects were being built for the first time and in all cases there were no delays, design issues or cost issues for the actual walling systems.

• An unskilled labour force had demonstrated that given the bricklaying process and the set-up of a jig system, quality masonry may be built by those with little previous experience of the bricklaying craft.

Areas for further consideration.

• Cost of the prefabricated manual process although comparing favourably with traditional methods, was still identified as an area on which to improve.

• A manufacturing system needed to be investigated which would lead to a more economical technique if the idea of prefabricated masonry was to be received on a larger scale.

• The development of lifting, storage and transportation methods must be investigated in order to provide a safe and efficient method of panel handling.

The above points are investigated further in Chapters 6 and 7.
Chapter 6 – Robotic processes for factory prefabrication

6.1 Introduction

As described in Chapter 3, although the end results for all case study projects built with in-situ thin joint masonry led to a successful building the process of using a pump and gun technique as opposed to traditional trowel methods was not well received by contractors and as such was treated with some reservation by architects.

Manual construction of factory made prefabricated masonry has met with some success in terms of quality, accuracy and performance. However the technique gave very low relative output with no opportunity to deliver any sizeable volume of wall panels for housing which was perceived as a key target market. Consequently factory manufactured masonry with high potential volume is required.

There is currently no system in the UK that will efficiently enable manufacture of both single skin and insulated masonry cavity walls economically and in high volume. One option was to develop a robotic system based upon European techniques but modified to manufacture UK style design and construction. This chapter considers such an automated assembly process and its possible benefits.

6.2 Background to the requirement and development of the automated manufacturing process

The need for a robotic system of manufacture was driven by a requirement to have a high volume output of standardized size and types of masonry panels. This concept was considered in 2008 after the high interest level from architects and developers in the manually manufactured panels which went into the construction of the Hanson EcoHouse™ at BRE Offsite 2007

Robotic techniques enable high volume production output at a relatively low cost but with high initial capital outlay

Current robotic factory manufactured masonry processes are few and far between throughout the world. A number of brands and company names come to the fore (Red Block), (Verbo), (Rimatem) but these often disappear and reappear as a different brand
name in the future. The reason for this is clearly linked to business development and eventual failure of these companies to achieve the necessary volumes to sustain the factory production. Many of the processes demonstrate a seemingly efficient manufacturing procedure but all too often the product costs are too high to maintain a continued output or to compete with traditional masonry costs.

One such company was Veto Vitz (Fanning 2000, 2001). Veto-Vitz was a manufacturing system in the United States which produced a variety of walling solutions incorporating manual and partly robotic assisted production. However this company no longer exists having ceased trading in or around 2008. Figure 6.1 illustrates the system.

In Europe the Belgian privately owned company Danilith (www.damilith.co.uk) has had continued success since its beginnings in the 1930’s as a family business producing complete bespoke houses including all structural components and internal services and fittings.

The houses have a relatively high purchase price but the company services a specific market sector i.e high value end private domestic dwellings. Their annual house production (depending on sizes and types made) is in the region of 250 – 300 dwellings per annum. Danilith set up a UK base in 2004 with a view to creating an interest in the self build market. The development proposal was to follow up this with a UK based factory. To date, 10 years later, Danilith have not sold one house in the UK. The design is either off the shelf created by Danilith’s own in house architect or a specifically bespoke design based on a client’s own architectural brief. The
quality and thermal efficiency of the buildings is of a high standard. The buildings are made of composite brick and reinforced concrete walls with concrete floors. As would be expected the thermal efficiency and insulation are second to none and understandably the durability is such that the structures require minimal long term maintenance. In addition a large 4 bedroomed detached Danilith house can be erected and occupied as a habitable dwelling in less than 4 weeks. Even with so many benefits to the system the Danilith house is still perceived as too costly for the discerning customer with preference usually given to more traditional and conventional build techniques. Figure 6.2 illustrates the typical wall and foundation details, figure 6.3 shows the prefabricated panel and figure 6.4, a completed Danilith house.)

Bergahoff is a Dutch manufacturer of prefabricated houses similar to Danilith with a robotic process. There is currently no record of their continued business. Verbo, also a Dutch company had a robotic wall manufacturing system which produced single leaf clay block walls, popular with continental design but requiring surface finishes (Figure 6.5). Verbo produced large format clay block walls which are adhered together with Omnicol adhesive mortar. They ceased trading during the past two years.

Rimatem, a German prefabrication manufacturer, is currently producing robotically made walls of clay blocks (in a manner similar to the Verbo process) but again these are for a specific European market.

Lack of success of the aforementioned companies clearly indicates that the processes and related costs do not meet favorably with industry requirements although there is still a desire to build prefabricated masonry. The techniques used have not presented viable and cost effective solutions.
6.3 Capital proposal for prefabricated robotic masonry manufacturing process

Setting up a bespoke prefabricated robotic masonry manufacturing process requires an investment of not less than £5million. A Hanson factory proposal, prepared for robotic masonry production would have been the first in the UK to offer a solution to panelised masonry in both single leaf and cavity wall construction. The key driver for constructing such a plant was not only the high interest level in the Hanson House but also the Labour government campaign and promotion of Modern Methods of Construction (MMC, 2006). Panelized or prefabricated masonry provided a unique opportunity to present a competitive alternative to timber framed and to a lesser extent lightweight steel solutions both of which at the time of the MMC promotion were increasing in market share.

Although the system had much wider applications, initially focusing sales on the social housing sector was thought to provide a degree of confidence in context of market growth opportunities. This could build on already established client partnerships where key account / project management communication channels are well established eg major developers such as Persimmon Homes and Taylor Wimpey.

When the Labour Government MMC campaign was launched the key drivers were perceived as prefabrication of high volume output at an economic cost for the buyer. (MMC and the £60,000 house) (2006). Additionally there was a major focus on sustainability and the environment leading to the introduction of the Code for Sustainable Homes (BRE 2007), launched at the BRE Offsite 2007 Exhibition. The robotic factory proposal as described (fabricating both single leaf and insulated cavity walls of any masonry type) has not yet been taken up either by Hanson nor any other company in the UK. Since the initial interest in 2008 there has been a change of government. There have also been significant changes in the state of the economy ie a major downturn (both in the UK and worldwide) and in the construction industry’s approach to building systems.

Whilst the above remit has not been abandoned the economy has suffered one of the most severe recessions in living memory, accompanied by a period of great austerity. This has altered the focus on housing output where national numbers for housing starts reached an all-time low (House Builders Federation, 2014) as indicated in Figure 6.6.

In these circumstances high volume output was not a priority and the capital outlay for a factory was not available since there was no conceivable end to the stagnant construction environment. There was therefore no desire by the housing sector to rapidly produce large
numbers of houses (with no uptake on purchasing and little mortgage funding available) let alone prefabricated masonry ones which were still treated with caution by developers due to the uncertainty over cost and quality. There was also no funding readily available in the Social housing sector.

When it was first introduced the Code for Sustainable Homes demonstrated that to attain a high Code level rating (and an energy efficient building) would in fact cost more than constructing a traditional dwelling. (Rogers, Taylor Wimpey)(2011). This created a contradictory philosophy. Cheap homes that were energy saving could not in fact be built at a low cost if they were to sustain high levels of quality and maintain the Building Regulation 60 year design life (Table 6.1).

<table>
<thead>
<tr>
<th>Code level</th>
<th>Required energy improvement</th>
<th>Additional cost per dwelling type</th>
<th>Estimated range of additional costs per dwelling, depending on site unit and technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code level 3</td>
<td>25% over 2002 building regulations</td>
<td>£6,426</td>
<td>£3,000-£7,000</td>
</tr>
<tr>
<td>Code level 4</td>
<td>44% over 2002 building regulations</td>
<td>£14,996</td>
<td>£15,000-£20,000</td>
</tr>
<tr>
<td>Code level 5</td>
<td>100% over 2002 building regulations</td>
<td>£31,539</td>
<td>£27,000-£35,000</td>
</tr>
</tbody>
</table>

Table 6.1 Increased cost per dwelling for a given Code for Sustainable Homes rating (Taylor Wimpey, 2012)

These are significant additional costs, given that the average selling price per UK home in 2008 was £177,000. In the past 12 – 18 months there has been a steady and continued economic recovery which has been reflected in the UK output of construction materials, manufacturing, increased housing starts, an upturn in the commercial and other non housing sectors and also in infrastructure / civil engineering work. (CPA Forecasts 2013), (HBF forecasts).
Consideration of this market improvement has stimulated further interest, albeit very cautiously, in innovation and prefabrication. This provides further opportunity to resume development work although the commercial approach to this, along with issues relating to construction legislation and sustainability, is still reserved and aims to minimize any potential economic risks.

The original business case for the robotic factory was written in 2007 and is documented in Appendix 5 of this work (Lingl UK, 2007). It was based on market intelligence which was monitored from 2004 – 2008. More recent marketing data (AMA Research, 2014) leads to a conclusion that the use of innovative construction techniques is still desirable and bearing in mind the housing demand, still necessary.

The original cost forecasts have increased with inflation (although not significantly as growth has been steady) and the emphasis on the market sectors has changed such that the business case for constructing a robotic factory whilst still including a focus on housing would now also focus on all non housing sectors such as MoD, Health, Education, retail, industrial, commercial and civil engineering infrastructure. In the latter case masonry walls might again be required as part of flood defence schemes or for free standing and earth retaining walls. All other non commercial projects offer opportunities for single leaf and cavity wall panels for the external walling of framed structures.

Figure 6.6 Number of housing starts (HBF -private, social and local authority) 2005 – 2014.(HBF, 2014)
The specification for the factory has not changed and the key requirements are as outlined below.

6.4 Design specification and requirements for robotic construction of single leaf and insulated masonry cavity walls.

1. Construction of masonry wall panels using a mechanized / automated process.
   At the beginning of the process packs of masonry are placed such that the individual units can be fed manually onto a belt conveyor.

2. Single skin or cavity / double skin panels.
   Single leaf wall construction is a straightforward operation with one belt conveyor and only one masonry material type. For the production of a cavity wall there will be two separate belt conveyors; one feeding an outer leaf the other feeding the inner leaf. Any masonry materials may be used for both conveyors ie brick, aircrete block or aggregate block.

3. The plant should be set up such that leaves of the wall may be constructed in a range of material types of standard and non standard format including
   a. UK standard dimensions (215mm long x 103mm wide x 65mm high)
   b. European standard format dimensions
   c. Clay facing blocks
   d. Aircrete blocks
   e. Aggregate blocks
   f. Concrete facing blocks
   g. Reconstituted stone units

4. Mortar material type and joint dimensions to be varied and to include
   a. thin joint adhesive mortars as per the Dutch Omnicol process used with clay units (2mm – 5mm).
   b. thin joint adhesive mortars for use with aircrete concrete blocks (approximately 2mm).
   c. thin joint adhesive mortars for use with aggregate concrete blocks (2mm).
   d. A thick joint ie between 5 and 12mm in a mortar for which the material specification is to be confirmed. This will be a cement/sand based product incorporating rapid hardening Portland Cement. Recent developments showed that a variation of the Omnicol material ie a high cement content mortar but with an additional bulking agent may be used for thick joints. It was recognized that the 10mm joint was critical to UK prefabrication
manufacture; an issue which had not arisen in the similar robotic systems of Holland and Germany where blocks and a butt joint are usually acceptable.

5. Panel dimensions – Maximum length of 9m as per the current machine specification is acceptable. Maximum height of 3m or to a standard single storey which for domestic dwellings might be up to 2.8m. In commercial panels a storey height of in excess of 4m might be required. In such cases the panel can be built by splitting the height either 50/50 or in any other favorable combination.

6. Panels must accommodate window and door openings as required within the automated assembly. The original concept was to provide clear openings for doors and windows and to fix all frames in-situ. However further trials proved that windows and doors could be factory fitted although this operation would be carried out after the fabrication of the masonry panels.

7. Cavity wall construction
   a. There is a need to construct the outer and inner leaves in identical or different materials - the most common construction format will be clay brick outer leaf and concrete block inner leaf but a block / block combination may be desirable if the external wall is to have a rendered finish. Where this is the case the render would be applied either in the factory or on site. The on site process creates further cost away from the fabrication process but is more practical in terms of application and use of working space.
   b. The inclusion of wall ties and insulation is necessary during the cavity wall assembly. This involves a manual operation and component placement within the walls or the cavity as the masonry panels are being assembled
   c. The inclusion of lintels and damp proofing materials is necessary during the cavity wall manufacture. This would need to be a manual operation during the wall assembly.

8. A construction detail is required to ensure continuity at and around corners. One of the main criticisms by designers of prefabrication is the unsightly position of joints between adjacent panels. These inevitably occur at corners and a detail is required to ensure that where possible the joints are offset from the corners. An automated process was developed for this which allows for the brickwork to return around the cavity and inner leaf of the wall. This process was developed so that it can be carried out automatically by the robotic function. To date this has not been achieved by any other automated masonry fabrication process.

9. Design of lifting points and fixings back to columns, edge beams or restraint detail. Construction details for the robotic assembly method are the same as for the
manually produced panels and typical details and sections are as shown in the previous section (corner details, head, jamb and cill details, panel / floor connections)

10. Transportation type to be fully integrated with the factory handling such that panels can be moved on a track / rail system at a level which allows direct rolling onto the lorry flat bed – this would entail raised factory platforms or ramp down areas for lorries.

11. Details between vertical and horizontal joints.
Vertical expansion joints are required in prefabricated brickwork much in the same way as for traditional masonry construction ie allowance for expansion in the clay brickwork leaf and contraction in aggregate and aircrete block. However the joint spaces will occur at the natural break points brought about by the panel fabrication. With the maximum manufactured panel length of 9m it is not necessary to include any vertical expansion joints for clay brickwork. However if the inner leaf of a 9m cavity wall is constructed in aircrete or aggregate blockwork a contraction joint might be included in the fabricated panel. This would be programmed into the robotic assembly process. Conversely chicken wire bed joint reinforcement has been shown to successfully restrain blockwork contraction. (Hanson Thermalite thin joint specification, http://www.ask-hanson.com).

12. Potential to change masonry types and dimensions during the panel fabrication eg brick colour and texture, change from brick to block, brick to rendered blockwork. This procedure is relatively straightforward with a manual material feed and relies simply on setting up the exact amounts of material to build up to required heights. When a material type is changed, the line is stopped and the feed changed over.

13. The prefabrication technique must allow for interaction with onsite thin joint or traditional construction. This requirement is the same for whichever manufacturing process is used and ensures flexibility allowing for the construction of very difficult localized details and enabling construction continuity in the event of delays or stoppages in the delivery of manufactured panels. This last point is one which it is hoped is not necessary, but it offers alternative options to contractual delays.

14. Robotic machine laying rates must be controllable to ensure an optimum output for a given level of quality, i.e. single skin brickwork panel (60 bricks per m²), single skin blockwork panel (10 blocks per m²) and brick and block cavity wall. Walls which do not require a high quality fair faced finish may be manufactured at a higher output rate than the quality walls.

15. Panel height restrictions – consideration of up to 4m
16. Mortar consumption for the joint style mentioned in point 4 is an important aspect of the output costs and final commercial wall costs. Mortar will be stored in siloes from which it is delivered by pump and hose directly to the point of application onto the walls.

17. Adding value to the prefabricated panels – post working stations
   a. Wall chases or conduits for pipe work or wiring. Alternatively the services can be surface fixed.
   b. Potential of internal finishes i.e. dry lining and wet application plaster
      This would require additional work space for “finishing off” panels – however the additional processes will add value to the walls and reduce additional on site trade specialist and their associated cost and time.

18. When constructing a cavity wall there will be a requirement for different adhesives/ mortars to be used for each leaf respectively including mortar for clay bricks, aggregate blocks and aircrete blocks.

19. Perpend joints must be fully filled by the machine with adhesive / mortar – this process has not been included in any of the previous robotic manufactured systems. In Europe, the thin joint adhesive systems rely only on the bed joints being mortared. This would not be acceptable to UK design as fully filled perpends along with bed joints can increase the resistance to rain penetration.

20. As a brief overview, the equipment itself has the capability to produce both cavity walls and single skin brick and block work of lengths up to 9m by 3m high, linked to CAD/CAM based design and detailing software.

All prefabrication machinery design as described was based on a modification of the original system (Hans Lingl UK, 2006)
Figure 6.7: Preliminary design scheme for robotic manufacturing system for single leaf and insulated cavity walls. View from masonry loading area and panel assembly setting machine. (Lingl, 2007)
6.5 Preliminary design proposals and the manufacturing sequence.

Development of the robotic factory process was carried out in conjunction with Lingl. Figure 6.7 shows an isometric illustrated view of the design outline assembly procedure from raw material input to panel assembly and final roll out for storage and / or placement directly onto a flat bed lorry. The operation starts at the left hand end with packs of masonry (bricks or blocks) being broken down and the individual clay units put onto conveyors.

This operation is carried out by one or two operatives. The process is semi skilled but will rely on supervision of material quality. There may be a need to provide bricks which are “mixed” for multi-colour and this selection must take place here. Similarly if a detail includes banded coursing, this must be dealt with at this point in the process.

Bricks are loaded onto the conveyor in sufficient quantities to make a full wall length. (Figure 6.8). They are placed bed face down as in conventional masonry and are then rotated through 90°. The adhesive mortar is applied to the perpends. Bricks are then rotated back to rest on their bed face and “nudged” into line with sufficient pressure applied to ensure the perpends are adhered and aligned so as to be located in the final position of a full course length. As continental prefabricated masonry does not include perpend mortar joints this process has been developed specifically for a UK system. Additionally the thicker (10mm) mortar joints are a necessary requirement for UK construction.

The mortar bed is applied by the gun. If an opening is to be formed the CAD CAM process feeds information to the setting machine as to where to start and stop laying bricks. For example in a 9m long rectangular panel wall with a 900mm wide door opening in the middle, this will be formed in the correct position with bricks in the door opening being omitted from the full course as laying proceeds. Once the full door height has been constructed the next course of bricks will be placed to include the full wall length with no omission for the opening (Figure 6.9).
If a lintel is required or bed joint reinforcement needs to be placed in the wall, this is done manually with a “pause” control on the laying process. (Some manual operations have been include as an alternative to the robotic process as this proved too complex and too costly at this early stage.) Once any secondary components are put in place the “continue” command ensures the laying process is resumed once more (Figure 6.9).

The above operation also applies for the construction of block walls and also for cavity walls where the aforementioned procedure is replicated with conveyor feed from the opposite side of the setting machine ie the operation is mirrored but the process embraces blockwork for the inner leaf. During cavity wall fabrication the system would lay one course of blocks and a corresponding three courses of bricks after which wall ties would be positioned. The sequence would continue in this manner so that the inner and outer leaves grow at the same pace. (Figure 6.10)

Figures 6.9 and 6.10 show the complete process from masonry load out to panel fabrication and roll off for storage.
Figure 6.11 Brick assembly machine viewed from panel roll out and storage side. (Lingle, 2007)
6.6 Lingl Machinery Process on which proposed UK robotic system is based.

The basic process from 2006 has changed little, but the accuracy and sophistication of the machinery has been refined over the years.(Figure 6.11)

Basic process :-

a. Bricks and blocks are loaded into a stacking area by hand, mixed from several packs as necessary to ensure a consistency in colour.

b. Bricks and blocks are then placed onto the conveyors by hand, they are positioned as soldiers or brick on end in preparation to receive mortar to the perpends.

c. The bricks are then automatically rotated through 90° whilst moving along the conveyor and a stretcher bond (end to end) formed. The bricks will be accurately spaced to give a specific perpend joint thickness.

d. Adhesive is applied to this first course of brickwork via an automated applicator such that a precise volume of material is delivered consistently to the bed.

e. A second course of bricks having had mortar applied to perpends is moved into position, picked up by the machine and slowly lowered onto the first course. Joint thickness and the appropriate amount of pressure for brick laying are precisely controlled.

f. In stretcher bond masonry, headers will have been pre cut and located in the correct position at the ends of a course.

g. This process continues until the full height of the wall is constructed.

h. When the wall is complete, it is moved on its rigid baseplate to a storage area. This transportation is done via a roller conveyor

i. Once moved to the storage area any excess mortar is cleaned off the face of the wall.

j. Formats can vary with typical examples given below :-

The full length of the conveyor or panel assembly machinery can manufacture a single length panel of approximately 9m in either single leaf or cavity wall. In addition the system will enable the fabrication of walls shorter than 9m concurrently on the conveyor. For example two walls, one being 4 m and the other being 3 can be produced on the same run. Some typical combinations are shown in Figure 6.12. In addition development work is underway to provide a short return to wall panels to enable a fully bonded masonry corner rather than to have vertical joints directly at each corner.
Option 1 – full panel 9m long with no openings

2no leaves x 9m long x 3m high solid

Panels can be produced in any multiple lengths up to 9m x any height up to 3m.

Option 2 – two panels each of varying lengths.
Total lengths up to 9 m

Eg. 2 - 2no 4m long x 3m ht solid panels

Max panel dimensions 9m long x 3m high

Options 1, 2, and 3 show possible panel manufacture configurations.

Openings may be incorporated into the system.

Option 3 – 3 panels, including one with an opening

Eg. 2 - 2no 2.5m x 3m 1no 4m x 3m with opening

9m max panel length

The laying rate will be the same for any of these combinations

Figure 6.12 Possible options for panel fabrication on a single 9m run

6.7 Handling and storage

The construction of a purpose made factory for panel fabrication would need to include the installation of either an overhead crane for moving panels by lifting or a rail track car system. In the case of the latter option, panels would be manufactured on small trolleys which would me moved on a track network so that they would be easily removed without the need for lifting.(Figure 6.12).
The process can be extended such that the panels are moved by cars directly onto flat bed lorries whilst still restrained within stillages. The loading bay area would be constructed at the same height as the flat bed lorry level so that panels can be manoeuvred directly onto the lorry without the need for lifting. Alternatively the loading bay area may be lowered by a ramp to enable lorries to be set against the factory floor level.

Another option for panel storage and transportation involves completed panels that could be moved along the rail track system to an area which accommodates a metal container box which after loading with panels can be stored or directly transferred to the flat bed lorry. Panels handled in this manner are protected from the elements once delivered to site and are contained in a structurally stable system which improves safety during handling and transportation.

In a fully robotic system where sufficient space was available no panels would ever be stored externally or in a situation where they were exposed to the elements until the point at which they are lifted and installed in the final location.

The key factors with regards to handling and storage are as follows:

1. Ensure that panels are stored in an upright position.
2. Full panel restraint will be necessary to prevent overturning particularly due to accidental damage or impact from traffic movement.
3. Panels must be protected from rain, moisture and / or dust within the storage area during handling and transportation.
4. Additional protection is required to all openings, panel edges and any areas vulnerable to impact or scratching. This is particularly necessary if surface finishes such as plaster or render have been applied or if fully glazed windows are built in.
5. Providing good protection to masonry during the construction process – particularly cavity insulation, enables a potentially higher performance level from materials.

Figure 6.13 Panel support system during movement and storage. (Lingl 2007)
6.8 Opportunities for masonry constructed by high volume robotic prefabrication

Although the social housing sector has been used as the target for market penetration there are other opportunities for such a product both within housing and other end user sectors.

6.8.1 Other Housing

The panels could be used within the private sector, of which there were over 845,000 apartment completions alone during 2004/05. A conservative estimate would mean around 42.2 Million m² (est. 50 m² per apartment) to target.

6.8.2 Single Skin

For builds where timber or steel frame are used this system could potentially provide either single skin prefabricated brick or block work cladding. With timber frame houses now accounting for around 20,000 house starts in the UK alone a potential market of 1.6 million m² exists.

Internal block walls are possible for all types of housing, enabling a complete walling solution to house builders.

6.8.3 Other Sectors

In addition to housing there are also opportunities within all other end user sectors where traditional brick and block are considered. Research undertaken (AMA 2014) suggests the residential sector only constitutes around 60% of the total pre-fabricated market, with healthcare, education and the defence sectors all estimated to be worth about £75m each by 2009.

6.9 Summary

6.9.1 Financial summary

1. Construction of a fully automated plant will have a capital outlay in excess of £5 million.
2. A payback on capital invested for the plant must be realised in no more than five years.
3. In order to achieve capital payback in 5 years there is a requirement to manufacture 50,000 m² of prefabricated wall per annum at a cost which will be acceptable to the very cost conscious housing construction sector.
4. Running costs include both plant and machinery as well as a labour force and supervisor

5. Successful markets depend on commercial selling prices that are less than those of traditional construction. Other design and construction parameters and benefits are negligible if the manufactured cost is not lower than traditional techniques.

6. **Appendix 5 A provides cost analyses for a proposal made in 2008. It is assumed here that all relative costs have risen with inflation at a similar rate and project viability will depend on selling price and product suitability.**

6.9.2 - Market

1. During the development of this process the social housing sector was considered to be the key source of volume production for cavity walls and internal / separating walls.

2. The civil engineering sector has potential for very large volume production eg retaining walls, sound barriers and flood defence systems where long lengths (up to several km) of single leaf wall cladding would be required.

3. Repetitious components provide the most cost effective return on investment

6.9.3 Design and technical information

1. The Manufacturing process must be versatile and readily adaptable to ensure viable solutions are achievable.

2. Health and safety legislation will be at the forefront of a successful proposal with risk assessments for labour force using machinery and handling traffic within the factory environment.

3. Simplicity in panel assembly is paramount.

4. Adaptability of the system to interact with traditional construction is a key objective

5. A simple and cost effective quality control system must be developed for regular checks on the factory production quality.

6.10 Conclusions

The development of a robotic manufacturing process described in this chapter is based on previous systems (specifically those designed by Hans Lingl (UK) Ltd.) which have been used to assemble blockwork in European prefabrication companies.

However, the author was part of the development team which addressed the manufacturing process and its modification to incorporate automated assembly of both
single leaf and cavity walls. In the case of cavity walls, the two leaves are constructed concurrently with rigid panel insulation, wall ties, lintels and any necessary bed joint reinforcement being included during panel assembly.

The inclusion of short returns on the panels is also incorporated into the process so as to provide continuity of brickwork at the corners. This reduces the “panelised” or prefabricated appearance of the walls and also improves structural stability of the completed building.

These modifications to the robotic assembly system add significant improvements and benefits to the technique and make prefabricated walls (particularly the cavity walls) a more feasible and desirable solution.

This system requires relatively high capital outlay and consequently a consistent high volume production in order to see a successful business return on the required financial investment. Material and production costs must be competitive with existing traditional build cost. With current demands on tradesmen (2014), particularly bricklayers who have increased their day rate labour costs by up to 30% in the last 18 months, this solution is both feasible and achievable in the appropriate building sector.

Repetitious panel layout in all building types will provide the most favourable cost and manufacturing outcome.
Chapter 7 Development of a simplified flatbed prefabrication process

7.1 Introduction

Two methods of prefabricated masonry manufacturing have been addressed thus far, one a fully automated robotic assembly method which requires high capital outlay and produces a high volume of repetitious panels, the other a low cost labour intensive technique which adapts traditional construction methods and utilizes these in a covered factory environment. Volume output is linked to available labour but there is potential for variation and versatility in the latter process.

In practice both processes have advantages and disadvantages. In a construction market with a culture that is risk averse and which will only consider prefabricated masonry if the costs are less than those of traditional build methods as was identified by personal interviews with major house builders, investment is only feasible in a robotic system if sufficient output can be achieved in order to recover capital payback in a finite time period, typically considered to be no more than five years.

The manual prefabrication method allows for versatile and complex wall construction at no significant cost increase to the process. It also has significantly less capital outlay in the factory or, more accurately, the working area. However at the point where demand is over and above what is a relatively small output, it is then necessary to employ an increased number of operatives and the manufacturing / working space becomes a key issue (Lawn House case study, Chapter 5.2.3). This in turn leads to handling and storage difficulties and a working environment that is both busy and potentially an increased safety hazard.

A third alternative to the robotic and manual manufacturing methods is now investigated as a solution which provides medium to high volume output at a cost which is competitive and potentially lower than that achieved with the two alternative techniques. The system employs minimal skilled supervision and unskilled labour and the financial outlay for such a procedure is sufficiently low as to ensure a return on initial capital investment in a comfortable timescale without having to add significant costs to the product selling price.

The simplified panel fabrication development work forms a significant part of this thesis from trial Wallette tests with various brick / mortar combinations to full scale panel fabrication and handling.
7.2 Background to the flat bed manufacturing process development.

Both of the aforementioned techniques involved the fabrication of vertically made panels of either single leaf or double skin cavity walls. There is a benefit to masonry built in this format as it ensures that the self-weight of the materials enhance both the flexural and compressive strength of the finished wall during the setting and curing process (BS EN 1052 – 2: 2002) as outlined in the Code guidance on production of wallets.

Alternative and more established flatbed production provides composite concrete / masonry systems where wet concrete is poured onto masonry units that have been placed into a formwork. This is a “cast” process and the concrete is allowed to set and harden in the conventional method. The following companies offer such products ; Trent, Danilith Techcrete Decomo. Essentially the wall is reinforced concrete faced with brickwork.

Other flat bed processes which have been considered for masonry assembly without a concrete backing include excessive amounts of steel reinforcement which adds a high cost.(Chapter 2.10.5 – Danilith, Bergraaff, Trent, Decomo, Techcrete )

The manually constructed trial wall panels and wall production processes described in Chapter 5 for both the test and actual houses (Case Study No7, Hanson EcoHouse™, BRE 2007), (Case study No 8, Lawn House in Leicestershire, 2010) were carried out at clay brick manufacturing plants. Apart from this being a convenient location and an obvious one for material availability, it presented an environment where those involved were experienced in the manufacture and construction of brick / block masonry. All were familiar with the material properties and characteristics, potential strength and performance levels and also the care which might be required for handling and transportation of walls bearing in mind that brickwork is recognized as being strong in compression and weak in tension. Additionally brickwork curing properties (Chapter 8, Testing) are well known as is the likelihood of structural cracking if handled too soon after brick laying.

Other trials into the development of single leaf prefabricated walls were carried out at a pre cast concrete works rather than a clay brick manufacturing facility. This arose from the need to develop a process which would enable the manufacture of up to 200 walls of single leaf masonry 1.5m high x 6m long in a very short time period. (Chapter 5, Case study No 9, Carlisle Flood Defence Scheme). The panels needed to be moved from the limited workspace as soon as possible after manufacture and this was best achieved by use of an overhead crane. Overhead cranes are not required at clay brick factories but are
a common requirement at a precast concrete plant which makes the latter attractive for such work if set up costs are to be kept to a minimum.

At the time when the Carlisle project was undertaken experience had been gained in manufacturing and handling prefabricated cavity walls so it was accepted that the single leaf walls would be relatively easy to produce by the manual bricklaying construction process.

The production of these 200 walls was undertaken using the pump and gun system. The various case studies of on-site thin joint adhesive construction clearly demonstrated that although the mortar application method differed from traditional processes, bricklaying skills are critical to ensure a high standard of workmanship which was essential for the type of projects being constructed.

In the case of the wall panels requested for the Carlisle flood defence scheme, there were a number of aspects which allowed for the consideration of potentially semi-skilled craftsmen which would reduce labour costs and ultimately drive down the panel cost of the 200 flood defence system wall panels. (Chapter 5, Case Study No 9, Carlisle Flood Defence Scheme). The success of the Carlisle flood defence scheme in terms of manufacturing cost at a reasonably competitive overall cost per square metre was endorsed by the main contractor.

However, further larger schemes could not rely on manual labour as a viable solution. Projects under consideration included flood defence schemes with walling being required for as much as 10km in length. In the majority of cases a typical cross section through a flood defence wall reveals that 3 panels are required – two on the river side of the structural wall (one on top of the other to make a 3m high wall) and one on the pedestrian walkway of the structural wall. This could equate to in excess of 4500 panels each 6m in length. The system used to provide the walls for the Carlisle scheme would not suffice.

With factory based manual labour it is possible to construct one panel per man per day. Site installation of prefabricated walls enables 24 panels a day to be installed (Chapter 5, Case Study No 8). At this rate there would need to be considerable lead in time to ensure that installation was not hampered by lack of available panels. In terms of manual manufacture and storage it is not practical to store high volumes of panels.

Consequently for high volume panel output an alternative manufacturing process is required but still with a technique which is simple and low cost to construct. If high volume is required then a high daily manufacturing output is essential such that panels made
today can be moved and transported the next day. In this alternative approach, a minimal number of operatives need to be considered. Sections 7.3 and 7.4 summarise the basics of the flat bed prefabrication method, which is proposed for large volumes of prefabricated walls. Sections 7.3 and 7.4 also describe how this process was developed to finally come up with a feasible method of wall construction for high volumes.

7.3 Development brief

To prefabricate a large volume of panels the procedure needs to allow for :-

- Low manufacturing cost
- High production output
- Straightforward process that enables a simple mould set up
- Technique which requires minimal skilled labour
- Adequate structural properties during handling.
- Accommodation of lifting eyes for handling or suitable alternative simplistic process.
- Some versatility in manufacture of panel shape and size.
- Process which enables high quality finish to the brickwork.
- Minimal waste from the formwork mould and associated products including where possible reusable products.

Extensive work with precast concrete flooring processes shows that the mind set to manufacturing concrete components demonstrates a number of fundamental differences to that of prefabricated masonry.

Prefabricated or pre cast concrete is moved from the place of manufacture as quickly as possible after casting usually by overhead cranes which are essential for the loads being handled.

The concept of flat masonry fabrication was initially developed on the basis of pre cast floor manufacturing which
involves a continuous formwork or casting bed which accommodates the floor beam thickness and width. Flooring formwork is made using up to 100m long lengths; pours being placed and dividers set at locations which define the beam lengths (figure 7.1).

With manual brick fabrication the process is slow and high in labour / operative numbers. With a robotic assembly being costly there has been a need to determine a manufacturing method which enable simple assembly of clay units and mortar that once completed will have structural properties at least equal to the aforementioned methods where walls are built vertically.

The fastest method of brick assembly has been based on dry laying clay units into a mould which is laid flat. The intended mortar should be of sufficiently low viscosity as to be fluid and readily poured in between the bricks to form the necessary mortar joints. Such a mortar will be required to set and have sufficient strength gain that the flat made panel can be rotated and moved to storage within 24 - 36 hours.

The process must also enable a high enough quality as to present an acceptable mortar joint finish and ensure that brick faces do not become stained or discoloured during manufacture. The method of brick assembly could use a robotic system although this again puts high initial plant installation capital outlay or alternatively the brick setting process could be done by hand. A hand set brick operation would ideally need to be simple enough to enable unskilled craftsmen to carry it out. Mortar once in place needs to be contained and not seep out of the panel. If panels are manufactured flat then they need to include fixings and lifting eyes to enable rotation and movement from the mould to a place of storage. Clearly achieving a successful prefabrication process which increases output at a low and cost effective capital outlay will bring about production problems that must be addressed.

Key aspects include :-

1. Formwork fabrication, assembly and stripping down.
2. A profiled mould base which enables bricks to be easily spaced and located
3. Development of a mortar of sufficiently low viscosity as to fill all joints and perforations.
4. A suitable “sealant” between the brick joints or spaces which prevents the mortar from seeping into the mould base and discolouring the brickwork faces.
5. Mould box edges that are sufficiently robust and adequately supported so as to prevent seepage and / or bursting.

6. Development of a lifting / rotational process to safely move panels from the mould box to their storage location i.e. rotating from horizontal to vertical orientation.

7. A method of ensuring a high quality mortar joint finish without the need for pointing

8. Development of corner details

9. Establishment of a simplified and cost effective testing procedure that enables quick quality evaluation when high volume production is underway.

As has previously been discussed masonry testing and development is an extremely costly exercise due to the very many parameters to consider in establishing an appropriate solution. It was with this in mind that a number of sample panel trials (approximately 600mm x 600mm plan area x 200mm deep) were made in order to evaluate the suitability in terms of performance and quality of various brick / mould box / mortar combinations as well as to consider appropriate materials.

If a horizontal panel manufacturing process is to be developed there will be a need to make simple, versatile and economical mould boxes. The amount of repeat use from mould boxes is directly linked to how robust they are and what their life span is.

In the early trials, samples were not only made of brick / mortar compositions but also concrete / brick slip and concrete/ full brick composition. Some tests were also carried out to evaluate insulated cavity wall construction. This enabled comparison of weight, quality, appearance and structural performance and ease of manufacture of a range of walls.

The various trials manufactures are outlined below culminating in the feasible manufacture of prefabricated masonry wall panels.

7.4 Trial panels - Work undertaken at Hanson Derby Pre Cast Works : April - June 2009- basic mould box and materials

The test sample mould boxes were as shown in Figure 7.2.

General process / procedure and mould box materials are described below with the various brick / grout combinations considered thereafter.

Figure 7.2 Basic timber mould for test panels
The sample mould boxes were fabricated from standard softwood timber in much the same fashion as basic concrete formwork moulds are produced. The box lining is a high impact resin surface fixed to the timber box.

**Mould box / material specification:**

1. Softwood timber formwork with removable sides. The whole structure is bolted together in much the same way as formwork that is fabricated for conventional precast concrete components. Softwood low cost timber is used in standard pre cast concrete manufacturing and this material was replicated for the panel trials. Formwork is constructed by joiners and traditional processes are used in the fabrication. Timber formwork is versatile as it may be constructed into any desired shape to take a casting. Materials are reusable for a finite time period and all connections are made with a combination of screws, nails and bolts to suit the size and complexity of the finished form. The type and frequency of fixings also reflects the loads on the formwork of brick, mortar or concrete. Plywood was sometimes used to form the sheeted areas of the mould, which has the disadvantage of leaving a timber grain / pattern on any cast surfaces.

2. To achieve a higher quality surface finish as an alternative to plywood the lining to the formwork comprised a high impact resistance surface which would be evaluated for reuse.

3. The base of the mould box comprised a lining “template” to receive bricks or brick slips.

Consideration was given to two products;

a. Hanson Wonderwall high impact tracking sheets with ribs spaced at 75mm to form standard brickwork coursing. Although Wonderwall tracking sheet is manufactured of a suitable high quality polymer material, it comprises ribs which are used to set out and support clay brick slip cladding. The sheets do not include any vertical spacers and the horizontal spacers are intermittent to allow moisture drainage. This omission of perpends and some of the bed tracking presents complications in trying to seal the clay unit faces against cement / mortar seepage. It also slows down the operation of setting the bricks or slips into the mould with no perpend guidance.
b. Thermo Mass Versaliner polymer (Figure 7.3) is a high impact material similar to Wonderwall but the moulded perpends and bed joints are such that any brick units are completely surrounded by a joint profile which in itself will form a half round bucket handle mortar joint in the wet mortar mix. A sealant between brick and sheeting is still required but this is easier to provide with this system. Bricks are laid in stretcher or running bond and each panel has a size approximately 900 X 600 mm

4. Full sized clay bricks to be placed in the mould – These should be face down at the top of the formwork or face down in the base of the mould box. The selection of a suitable brick was an important part of the development process as this affects speed of panel fabrication, manufacturing costs and overall quality. Similarly the mould box and sequence of material placement will affect the manufacturing efficiency and quality. The basic clay brick types are as follows :-

   a. Machine extruded bricks present a very regular rectangular shape with straight edges. The finished surface of such bricks can be smooth, sand faced, rusticated or drag faced. Standard house designs often incorporate specifications for extruded brick. High strength low water absorption engineering type products are used in both civil engineering projects and commercial / retail / industrial work.

   b. Traditional handmade / hand thrown bricks or machine thrown bricks are made by taking a “clot” of clay and literally throwing it into a mould box – either manually or by a fully automated factory process. Only a small number of handmade brick factories now exist and the product volume or output is no more than several thousand per week. It is completely labour intensive and it requires a high craft skill level. They are a relatively high priced product and nowadays their use is limited to either one off architectural housing projects or individual buildings where cost for this type of masonry may not be prohibitive. Relative cost of handmade bricks is at least three times that of machine fabricated products and this was considered prohibitive to an economical manufacturing process. Almost all soft mud moulded bricks are machine thrown and they account for approximately 30% percent of UK production. Consequently their
consideration for a prefabrication process is an important one if the process is to receive maximum market interest. Further the effectiveness of the mould sealant between the brick and its surrounding contact area would need consideration.

c. Formation of sealant between bricks or slips and the mould surface face to prevent concrete, grout or mortar seepage onto brick face. Various sealant types have been considered. Finished face joints are required to be either flush, bucket handle or recessed to suite the design requirements. In some cases a recess depth of 15mm may be required to accommodate an alternative surface pointing mortar

5. Clay brick slips – are either cut from standard clay bricks or they can be purpose made. Cut slips can be produced from any manufactured brick. This provides the benefit of a faced finish that is identical to the full clay brick. Cut slip production is labour intensive and the cost of cutting depends on the original brick type. If this is an engineering product cutting is slower (due to the high strength of the clay type) leading to a lower daily output and consequently higher labour cost. The circular saw cutting blades which have carborundum tips are expensive and more of these will be used when cutting harder products. In addition all extruded bricks are manufactured such that they only have one stretcher and two headers of a quality finished face. Soft mud clay bricks are easier to saw cut and all four sides (front, rear and ends) are of a fair faced finish. Hence two slips can be produced from one brick. Purpose made slips are extruded or pressed and the manufacturing process is such that they are generally cheaper than cut slips. Additionally there is no material waste. However the range of colour and texture available is limited to the potential of the production facility. Most manufactured slips are produced in mainland Europe.

6. Sealant between brick or brick slip and template to prevent mortar seepage. When fabricating both brick slips or bricks in concrete or the new system of bricks with a mortar infill, one of the most critical issues is the sealing of the joint areas to prevent the concrete or mortar mix from seeping between the bricks and the mould template surface. Cement within the mix has a very fine liquid consistence and this will readily find its way through the finest of joints. A number of techniques and materials have been investigated and these are outlined below in the various trial samples.

7. Joint filler / panel material composition. In the preliminary trials a number of solutions incorporated a ready mix concrete poured directly onto the preferred brick type finish.
This technique was progressed in order to investigate the cement seepage issues and also the potential problem of bricks "floating" which will occur when a less dense material is submerged in a higher density material. Conversely if a higher density material such as concrete is poured rapidly onto dry set bricks within the mould, there is a high risk of the bricks becoming displaced and again starting to “float” in the mix. Refer to individual trial samples below for procedures, materials and mortar / concrete specification.

The initial trials were with composite concrete and brick slips or bricks. Additionally two leaf prefabricated composite concrete trials were assessed. Further trials incorporated bricks only, with a mortar / grout filling.

Upon completion of this stage, a decision would be made as to which system should be further tested and developed.

The trials undertaken are summarised below :-

- Trial no 1 – Composite brick slip / concrete panel – Engineering quality bricks.
- Trial no 2 - Composite full brick / concrete panel including 327mm (1½ brick) return. Stock brick panel 900mm wide x 8 courses high, 100mm concrete backing.
- Trial no 3 – Insulated composite cavity wall with prefabricated inner and outer leaves. Two insulation types were trialled - Kingspan phenolic foam and Knauf mineral wool.
- Trial no. 04 April 09 - self compacting concrete on reinforced brick / concrete pier section
- Trial no 5 - Small panel – stock brick, high performance polymer modified adhesive mortar (Omnicol Type C mortar with high water content) poured on to panel and brushed into joints
- Trial no 6 – Sept 09 Small panel – stock bricks set face up in the mould box, thin layer Omnicol mortar poured into panel joints. Thermo mass base with 3mm polystyrene bed to accommodate bricks
- Trial no. 7 Sept 09 - Determination of suitable joint sealants in base of the mould.
- Trial no. 8 - 6th October – 3m panel with standard Hanson Kirton Facing Brick
- Trial no. 9 – Fabrication of corner panel - assembly and production sequence
- Trial no. 10 - Dec 09 - 6m long x 1.5m high decorative panel
7.4.1 - Trial no 1 – Composite brick slip / concrete panel – Engineering quality bricks

Objective :- evaluate aesthetic and structural integrity of a brick slip / concrete composite panel. (Figure 7.4)

Material specification and procedure:-

1. Date of manufacture – April 09

2. Finished panel dimensions – 900mm long x 600mm high

3. Panel thickness – 200mm unreinforced concrete +15mm brick slip thickness

4. Brick slip specification

   Class B engineering brick 215mm long x 65mm high x 15mm thick
   - Density 1800kg/m³
   - Slip weight 0.5kg

5. Standard mix concrete 1:2:4

   Cement 400kg
   Sand 600kg
   20mm 1200kg
   Admix 2.4lit
   Slump 200mm
   w/c 0.35 - 0.4

   For masonry, the mix design was adjusted to give 50% / 50% coarse aggregate / sand

   Cement 400kg
   Sand 900kg
   20mm 900kg
   Admix 2.4lit
   Slump 200mm
   w/c 0.35 - 0.4

6. Engineering brick slips were set into MBrick Versaliner template face down.

7. Joints part filled with building sand

8. Lifting points cast into panel to allow rotational and vertical lift

9. Panel dimensions 900mm long x 600mm high Mould / formwork.
10. Construction time = 3hrs
11. Fixing / locating brick slips = 20min
12. Concrete pour time = 5min
13. Setting time and time of striking formwork = 2 days allowed

**Observations**

1. Concrete / brick slip fully bonded, no cracks, good quality finish (figure 7.5(a)).

2. Panel lifting and handling did not present issues – structural integrity was acceptable

3. The visual appearance of masonry, very good, consistent joints, uniform depth

4. Overall integrity of panel excellent finish for engineering bricks but rather bland (figure 7.5(b)).

**Conclusion**

The test demonstrated that an integral adhesion exists between the concrete and the brick slip based entirely upon a bond of the wet cementitious material to the clay. The brick slip / concrete bond was not evaluated further at this stage as this did not form part of the final prefabricated wall development and such research has been carried out by others (Downing, 2001)

The aesthetic properties of the brick finished panel are acceptable for standard extruded clay bricks with regular sized consistent joint profile finishes. Joint colour in standard
concrete is limited to a uniform grey which may not always have an appeal architecturally although colour additives are possible to give a slight improvement to the visual aspect of the masonry. The durability of composite panels of brick slip / concrete using F2 category Engineering bricks of low water absorption (less than 7%) is not in question as both concrete and brick will be capable of withstanding the repeated freeze / thaw cyclic frosting and prolonged saturation due to driving rain. This was evaluated in a standard frost test cabinet (BS EN 772 – 22)

As these trials were carried out at a precast concrete factory by operatives with experience only in pre cast concrete, the end result was very well received and considered within the factory to have great potential for development. This aspect was important when considering the mind set of those helping with the panel development and it was a very important point to bear this in mind as and when later trials were to be carried out using masonry only. As with in-situ thin joint masonry it was demonstrated that in any innovative work where new techniques are being developed, if any reliance is placed on human input for the process this can influence the final outcome and the success. On a construction site, operatives who did not find the thin joint process to their liking were in a position to ensure that it was not a viable solution (either by neglect of the day to day maintenance of the machinery involved or by ensuring that the work output was poor.) The co operation with operatives is a key issue which is referred to again in the Conclusions. Operatives in this process were in support of it.

In spite of the factory workforce’s enthusiasm the need to develop a composite brick slip / concrete wall panel was not considered relevant as this process is already well established and in use by other manufacturers. The importance of this trial was to confirm the concrete / clay bond. Further development would only serve to replicate this process but consideration was given to the procedures used by these established techniques of manufacturers for sealing the joints between brick slips and concrete.

The main objective was to demonstrate that a quality brick / mortar surface finish was achievable and this proved to be a success.
7.4.2 Trial no 2 - Composite full brick / concrete panel including 327mm (1 ½ brick) return. Stock brick panel 900mm wide x 8 courses high, 100mm concrete backing

Objective:- Establish both aesthetics and structural integrity of prefabricated composite wallette made with full size stock bricks and a 100mm structural concrete.

1. Date of panel manufacture – April 09
2. Panel dimensions - 900mm long x 600mm and including 325mm returns (Figure 7.6)
3. Panel thickness – 102.5mm brick + 112mm concrete
4. Brick Spec – stock brick Measham 215mm long 102mm wide x 65mm high frogged format
6. Full size stock bricks were set into MBrick Versaliner template face down with additional bricks used to form returns at both ends (figure 7.7).
7. Joints part filled with building sand up to 15mm thick (figure 7.8).
8. 100mm concrete backing cast onto slips. Lifting points cast into panel to allow rotational and vertical lift (Figure 7.9)
9. Panel dimensions - 900mm long x 600mm high x 200mm o/a thickness (figure 7.10).
10. Time taken for mould construction = 3hours,
11. Position bricks including brick returns = 20min,
12. Pouring concrete = 5min.
13. Striking of formwork = 2 days
Observations

1. Standard concrete mix was used – no additives.

2. Panel lifting and handling – good, no cracking or damage (Figure 7.9)

3. Visual appearance of masonry – very good considering the use of a standard stock type. Facing brick has very deep creased texture and irregular face profile.

4. Overall appearance is similar to vernacular / traditional masonry construction due to the stock brick shape / texture (Figure 7.10)

5. Some mortar staining occurred on brickwork faces due to concrete leakage but this was easily cleaned off by pressure hose (low set) and proprietary brick cleaners which are less damaging to the fine sanded texture of the brick face.

6. Overall integrity of panel with concrete backing - very sound, solid, good structural integrity. There was a complete uniform bond between brick and concrete. This was endorsed by saw cutting various sections of the panel after completion.

Conclusion

The key objectives were:-

1. Construct a sample panel using a full brick rather than a brick slip

2. Use a stock brick with coarse texture and a shape which is not as regular and precise as an engineering product.

3. Construct the trial panel with brick returns rather than straight ends.

A full brickwork sample panel, including brick returns, was cast and demonstrated sound integrity with a reasonable quality finish to the brick / mortar surfaces. A stock brick, which has a coarse sanded surface texture can be used for casting to a standard concrete mix.

Bricks were set face down into the mould as in the first trial. However sealing of joints was more complex as the depth of the brick restricts access to applying any form of sealant. As can be seen from Figure 7.9 the procedure for sealing joints was to pour standard building sand in between the bricks. This was done as a manual operation and relied on a certain
amount of skill to ensure that the thickness of joint fill was consistent. Any inconsistency or irregularity would lead to an irregular depth of the finished joint.

The panel was fitted with four rotational lifting eyes and was easily lifted and rotated into an upright position once the formwork had been struck. The overall appearance of the panel was acceptable and the consistency of joint depths was regular such that the panel in its cast state could be considered to be complete without any requirement to repoint. Although the mortar joints were of a bland concrete grey colour their surface texture was of an acceptable standard aesthetically due to the sand in the mould box joints.

There was a need to pressure wash the finished surface as this displayed cement residue demonstrating that some seepage was still occurring although only to an extent that requires no more than low pressure water jet washing.

The return bricks remained set accurately in position after striking of formwork and it was clear that they had not become dislodged or displaced during the pouring of concrete.

Although the small sized trial was acceptable this was again only a demonstration of a brick / concrete composite panel which was 215mm thick. It was visually acceptable and robust in form and integrity but the solution was one which already exists in other manufacturing processes.

Evaluation of structural properties was not progressed at this time as it was clear that the composite 215mm thick composite panel would achieve greater lateral load and compressive load carrying capacity than a masonry panel and therefore not critical in the development. Additionally had it been desirable to manufacture larger composite brick / concrete or brick slip / concrete panels these could easily incorporate reinforcement to enable adequate load carrying capacity over large spans. Nevertheless this trial still represented a concrete panel with a brick facing, the former material providing the strength. The aim of providing a prefabricated “masonry” panel was still some way off.

7.4.3 Trial no 3 – Insulated composite cavity wall with prefabricated inner and outer leaves. Two insulation types were trialled - Kingspan phenolic foam and Knauf mineral wool.

The third trial considered the potential for insulated cavity walls. A panel was fabricated of composite brick / concrete outer leaf and a concrete inner leaf. The cavity between them was filled with insulation. Two insulation types were incorporated into one panel - Kingspan phenolic foam and Knauf mineral wool.
Objective

- Determine initial strength / integrity of a composite insulated panel including a brickwork outer leaf, insulation and a concrete inner leaf
- To evaluate aesthetics of the brickwork finish

The sample panel was constructed with the two insulation types included ie the left half in phenolic foam, the right half in mineral wool. The key objective was to consider the feasibility and practicality of construction of a composite panel which would use a flat mould base with the panel being built up in 3 sections.

1. Date of panel manufacture – April 09
2. Panel dimensions – overall elevational dimensions 2500mm long x 13 courses high
3. Panel composition – outer leaf 100mm concrete poured onto 15mm clay brick slips.
   - Inner leaf of concrete 50mm poured concrete
   - Insulation types
     - left h s = 100mm Kingspan phenolic foam
     - right h s = 100mm Knauf mineral wool
4. Brick Spec – 215mm x 103mm x 65mm Stock, F2, frogged Terca Class B clay brick from which 15mm slips were cut.
5. Concrete Spec – as in previous test above
6. Ties – MBrick Versaliner Scott Green
7. Fixing bolts for lifting points – 2 no. Halfen 6361-2.5-400 HD Rod Anchors
8. Joints part filled with sand to a depth of 15mm
9. Panel dimensions, brick / concrete leaf 2500mm long x 975mm high x 215mm o/a thickness
10. Approximate time taken for mould for complete fabrication was as follows :-
    
    - a. Mould box preparation = 1 day
    - b. setting of brick slips, = 2 hours
    - c. pouring concrete backing to slips = 20 minutes
    - d. placement of insulation = 2 hours
    - e. pouring of inner layer of 50mm concrete = 20 minutes
11. Setting time and time of striking formwork

Figure 7.11(a) Mould with dry set bricks in position

Figure 7.11(b) Formwork structure

Figure 7.11(c) Insulation with restraint wall ties

Figure 7.11(d) Completed panel

Figure 711 (a) – (d) – Assembly procedure for a composite insulated cavity wall

Panel construction sequence

Outer leaf
- Set up formwork with Versaliner template in base (Figure 7.11(a))
- Locate brick slips (Figure 7.11(b))
- Pour concrete

Insulation
- Locate MBrick Versaliner wall ties through respective insulation types and position insulation on top of concrete outer leaf in mould. This is only completed once the concrete has set. (Figure 7.11(c))

Inner leaf
- concrete – poured directly on top of insulation.
Figures 7.12(a) to 7.12(d) show the completed composite panel which comprises a concrete inner leaf, mineral wool and polystyrene thermal insulation and an outer leaf of composite brick and concrete. Figure 7.12(d) clearly demonstrates the inaccuracies in casting which caused a variable thickness concrete in both leaves. The brickwork faced finish was of reasonable quality after cleaning with a low pressure hose fresh water wash.

Seepage of concrete had occurred into brickwork and at the ends of the panel although this was anticipated since the trial mould was of basic construction without sufficient edge or face sealing.
Observations and future revisions / proposal

Concrete – mix design modification needed.

- Reduce max aggregate size - Use of finer grading
- Improve compacting techniques so as not to move bricks in template
- Use additive / admixture instead of increasing water content to mix to improve flow

Panel lifting and handling – proprietary lifting rings to be specified

Visual appearance of masonry – improve seal against cement ingress on face of bricks

Overall integrity of panel – all materials remained intact i.e. ties / insulation / masonry / concrete.

Conclusions

This type of panel was investigated in order to consider the feasibility of developing a flat bed construction for a composite cavity wall. Concrete and clay brick were incorporated into the panel along with an insulation layer between the two leaves. The sequence of panel fabrication and build up followed that of the simple trials.

The procedure was more complex than the initial trials as it was necessary to cast a number of material layers in succession. The first layer provided the outer leaf of the cavity wall and was made up of 20mm brick slips set into the MBrick Versaliner mould template. This was sealed with damp building sand and a 100mm thick standard concrete mix was poured onto the brick slips. At this stage it was not possible to determine how successful the pour would be and if during the pouring process any of the slips may have become dislodged as the slips are not visible for inspection once the concrete has been poured.

The technique of locating the wet concrete accurately and in a fashion which allowed only small volumes to be thinly and evenly spread across the whole panel proved to be a difficult exercise as the facilities available for such delivery were not designed for this process. In the pre cast factory wet concrete is delivered by a skip (large bucket) using the overhead crane facility and release from the skip was by a manually controlled trap door. The skip contains up to 5m³ of concrete when full and the requirement in the test panel was for 0.5m³. Releasing concrete in small controlled volumes was not possible.
Lifting rings attached to ribbed steel reinforcement bars were located in the panel during the fabrication process prior to placement of the wet concrete enabling removal from the formwork once the wall was completed.

Upon completion of the external leaf of the cavity wall, the insulation materials were placed directly onto the outer leaf. Both the mineral wool and phenolic foam insulation had wall ties with enlarged washers which ensured that these were located and spaced correctly butting up to the inner concrete face of the external leaf.

The final part of the process was to pour an inner leaf of lean mix concrete which was included in order to provide a backing to the insulation. This layer was 50mm thick and comprised a no fines mix.

The completed panel was allowed to cure for 48 hours before being moved. The removal process involved stripping back of the formwork edging and rotational lifting using the lifting rings. Lifting points were included such that there were two in the top edge and two in the bottom edge of the panel which enabled either rotational lifting from one or the other edges. Additionally, with four lifting points it was possible to lift the panel vertically when in a flat or horizontal attitude. Lifting options were kept open at this stage as it had been noted in earlier trials with manually manufactured brick panels (as opposed to composite brick concrete panels) that these performed better when kept in an upright position, or as was evaluated during trials of these manually constructed factory panels, with a rotation out of vertical of no more than 20° – to avoid cracking.

Initial removal from the mould was made using only two lifting points and rotating the panel vertically. Once in the vertical position the panel was inspected and moved to a storage location.

A visual inspection concluded that no apparent damage had been sustained during the fabrication or removal. However the brickwork finish quality was poor with cement seepage having occurred onto the brick slip faces. This was removed with a power jet wash.

The overall quality of the panel, as may be seen in figs 7.12(a) – 7.12(d), was poor. The concrete inner leaf had not retained a consistent shape; it distorted and varied in thickness. The mix was inadequately compacted (due to caution over not wanting to disturb brick slips or the insulation.) The work completed to date shows that this process is not straightforward and further time and funding would be necessary in order to achieve the quality of panel required for external finished brickwork.
Furthermore this trial had again demonstrated that the process being investigated was replicating already established processes such as achieved by Danilith, Techcrete and Decomo and that a high capital outlay would be required to attain a quality level that would be acceptable for a fully composite insulated wall panel. This would be reflected in the final wall costs which would not be competitive based upon the current relatively low demand for composite brick / insulation / concrete panel technology in the UK. Hence the solution is not considered viable. Nevertheless the trial was considered worthwhile and led to one further attempt at prefabricating masonry/concrete wall panels.

7.4.4 Trial 04 April 09 - self compacting concrete on reinforced brick / concrete pier section

Whilst manufacturing the composite brick slip / concrete trial panels, additional trials were carried out using self-compacting concrete (SCC). SCC was considered to be a viable option for the concrete part of the construction with its obvious increased flow property and smaller maximum aggregate size (max aggregate = 5mm) enabling flow into the 10mm joints. During the period when fabrication trials were being conducted, consideration was given to the development of prefabricated masonry piers. The proposal would entail construction of a trial single storey column which could be used in commercial buildings where a height of up to 4m to 5m might be required. Although some thought was given to two storey columns the limit on height was set at a 5m maximum as there would be uneconomical disadvantages of longer lengths with regards to transportation and handling.

A part reinforced pier section was built in stretchers to a width of two and half bricks (552mm) x fourteen stretchers tall (1150mm) (Figure 7.13). This incorporated high tensile steel reinforcement (Figure 7.13(a) and 7.13(b). The manufacturing and quality testing process is shown in Figures 7.13(a) – (f).

Fabrication and casting process :-

Figure 7.13(a) clay bricks in timber formwork

Figure 7.13(b) Steel reinforcement with spacers
Figure 7.13(a) – (f) Prefabricated pier trials with self-compacting concrete

Conclusions

Although the structural integrity of the completed pier was deemed acceptable a major problem was with the finished face appearance and some movement of bricks during the casting. As the SCC mix was poured into the mould the bricks were displaced under the weight of the wet concrete which was poured in to the mould box in layers even though there is a low volume of concrete in the sample.

The process is nevertheless one which has already been tried and tested by prefabrication manufacturing specialists and as with trial sample no 3 referred to previously it was considered impractical to copy an existing technique and to try and develop what has already been successfully produced. In any case the cost of such a development would require a high capital outlay.
Prefabricated brick and mortar trials

Following completion of the composite brick / concrete trials a second series of tests commenced to evaluate manufacturing processes and performance of prefabricated brick / mortar techniques without any concrete component.

As has been previously documented, the structural behaviour and appearance of thin joint masonry including bricks, blocks and stone built by hand or by robotic methods was shown to be successful. It is the construction techniques and costs that proved somewhat prohibitive.

The trials continued with an investigation of bricks and a 10mm mortar joint as a prefabricated method loosely based on the technique previously described in this chapter i.e.panels were cast in the horizontal and not vertical orientation.

7.4.5 Trial no 5 - Small panel – stock brick, high performance polymer modified adhesive mortar (Omnicol Type C mortar with high water content) poured on to panel and brushed into joints

Objectives

Produce trial panel of single leaf masonry comprising clay bricks and Omnical adhesive mortar. Appraisal of manufacturing process. Evaluation of aesthetic finish. Evaluation of structural integrity

1. Date of panel manufacture – June 09
2. Brick Spec - 215mm x 103mm x 65mm Stock, F2, frogged dry laid into mould box, the construction of which has previously been described.
3. Joint filler – Polymer modified mortar adhesive mixed to form a fluid grout. Omnicol Type C mix) The first trial included 6l of water per 25kg bag mixed in a cement mixer for 5 minutes and then poured onto rear face of masonry.
4. No fixings or lifting points were included in the sample – the panel was lifted in the formwork frame.
5. Bricks were set into a Thermo mass template face down.
6. Joints were part filled with building sand to a uniform depth of 15mm.
7. Panel dimensions -900mm long x 600mm high x 102mm o/a thickness
8. No brick units were cut and so only whole bricks were used in the panel such that where a header would be needed to close off a panel this was implemented by a return brick. Hence every alternate brick was turned through 90°.
   a. Time taken for mould construction = 3hours
   b. setting of bricks = 10 minutes
   c. pouring adhesive mortar and finishing off. = 10 minutes

10. Setting time and time of striking formwork = 48 hours

Trial samples - assembly process

The trial panel was similar to that considered in Trial 2 ie with full clay facing bricks. However, instead of using a 200mm depth concrete backing, a high water content mortar was prepared and poured onto the clay bricks which were laid face down. The intention was to fill the joints to be level with the back of the panel.

As with the previous composite brick / concrete trials a wooden mould box was fabricated. This had a MBrick Versaliner brick profiled sheet fixed into the base using staples (Figure 7.14a). Full bricks were placed into the box in a stretcher bond format to match the MBrick Versaliner sheeting. In a plane panel the stretcher bond format leaves a requirement for header bricks at each end of the mould box. However in the trials it was considered both practical and beneficial to place bricks rotated through 90°. As shown in figure 7.14b this would enable evaluation of the accuracy in keeping header bricks standing on end, in the mould after completion of the mortar pouring operation (Figure 7.14c). Once the bricks were in position dry sand was poured into the joints in order to try and create a seal between brick and MBrick Versaliner mould. As these were the first brick samples bonded with thin layer adhesive rather than cement based standard mortar, a query was raised as to the efficiency of dry sand alone in creating a seal and so keep the brick faces clean. The supposition was that the mortar might be of such a viscosity as to not seep through onto the bottom of the mould and the brick faces. The rear of a panel after lifting to the vertical is shown in Fig 7.14d
Sample production

The first mix trialled was deemed too dry and although this would have prevented brick face staining it did not flow sufficiently to provide an extensive enough contact surface.

Efficiency of mortar placement depends upon viscosity of mix. A standard recommended mix uses 5l of water per 25kg of dry pre bagged mortar. This is typical of the mix used in the pump and gun system as employed in the in-situ brickwork construction. One objective in this test was to establish an optimum mortar viscosity which enables material to flow evenly and uniformly into all joints whilst still retaining high compressive and tensile properties and a rapid strength gain. The fluid mix should also be placed in such a manner as to not stain or discolour the brickwork face finishes (which are placed face down in the mould). The mix should have low enough viscosity to “pour” into joints, with perhaps additional encouragement by brushing in with a hand brush. An adequate volume of mortar should be placed so that there is a minimal residue thickness on the upper side (ie the rear face) of the panel since it contributes nothing to the panel composite strength and the additional material only adds extra weight and cost.

It was considered that the more extensive the contact area of brick / mortar the better the bond strength and overall panel integrity. In all traditional masonry the bond is only as good as the contact area which in itself is dependent upon the quality of workmanship. With a suitable semi fluid mortar mix the strength properties are thought to improve. (Chapter 8.3 – Masonry Testing)

As mentioned earlier in the first attempt 6l of water were trialled. The result was too stiff a mix which would not run into joints and needed a helping hand to thoroughly cover the panel. The mix had to be trowelled to ensure uniform spread over the brickwork surface. It
also led to a mortar consumption of approximately 50kg per m$^2$. (too uneconomical when considering the material cost per tonne.)

For the second attempt 7l of water were used per 25kg bag. After further trials the final mix used = 12 l of water / 25kg mortar. Figure 7.15(a) and (b) demonstrate the finished product.

![Figure 7.15(a)](image1)
![Figure 7.15(b)](image2)

**Figure 7.15 Completed panel demonstrating finished quality**

**Conclusions**

Based on initial observations and inspection of the panel when struck from the mould the procedure showed signs of being successful. Handling and inspection of the panel showed the brickwork face finish to be reasonably clean although it still required a low pressure jet wash. The joints were of solid and smooth even surface texture. The rear face of the panel had a mortar film or residue of 2 – 3mm thickness.

This procedure was different from the previous "conventional" composite trials for a number of reasons. The mortar mix had no aggregate particles greater than 3mm and did not require a backing depth over and above the joint infill. The overall masonry panel thickness = 102mm thick plus 2mm maximum mortar backing = 105mm. Pre cast composite concrete trial panels required at least a 100mm thickness finish behind the brickwork. Comparative weight between the two types meant the concrete backed panel was approximately 240% heavier bearing in mind the extra 100mm concrete thickness on the rear of the bricks and the fact that the concrete forming the joint infill is of a higher density than the standard Omnicol mortar. The mortar / brick contact surface is more even and continuous with the fine aggregate composition when compared with the concrete mix and its 5mm aggregate. The procedure was very simple to set up as bricks are dry laid into the mould – a process requiring minimal skill levels - and fabrication was very
straightforward. Some improvement in the finished face quality was considered necessary and methods were investigated into better processes for sealing the external brick surface.

**7.4.6 Trial no 6 – Sept 09** Small panel – stock bricks set face up in the mould box, thin layer Omnicol mortar poured into panel joints. Thermo mass base with 3mm polystyrene bed to accommodate bricks

Objective – to set panel of full bricks face up rather than as previous, face down and pour Omnicol mortar into joints without the need for a sand filler to joints.

The objective here was to dry lay bricks into the mould in a face up position and to carefully pour mortar of a high water content into the joints of the panel such that the joints are flooded until the liquid mortar rises to a level equivalent to a slightly recessed joint ie just below the surface of the brick faces.

The benefit of this technique would be that any mortar seepage to the base of the mould would be staining the rear faces of the bricks, not the front face. In this case a joint sealant would not be critical to the production process and this would save some manufacturing time in panel preparation as well as a marginal saving on joint sealants. It would however, take longer to fill the joints.

Result - This procedure did not work successfully. The water content of the mix was 12l per 25kg which was at the highest level used so far. A number of issues occurred.

Mortar did not flow thoroughly throughout the brickwork panel and there was no way of being able to monitor the extent of mortar movement. The other problem was simply one of workmanship – in order to deploy mortar into the joints and not spill any on the surfaces of the bricks demanded a high level of skill to avoid face staining. This made the process slow and one which could not be considered further until either a mortar of even lower viscosity is established or a process of flooding the mould box from below or at least lower down to provide clean bricks and accurate joints is developed.

Conclusion – This process was not investigated further at this time as the alternative technique of laying bricks face down appeared to provide the preferable solution even though pressure washing is necessary to the slightly stained brickwork faces. It should be noted that with the bricks laid face up, surface staining from mortar spillage rather than seepage is much more difficult to remove.

**7.4.7 Trial 7 Sept 09 - Determination of suitable joint sealants in base of the mould.**
One of the key issues for ensuring that the flat bed manufacturing process is an efficient system lies with the sealing of the joint between the face of the brick (which is face down in the mould) and the mortar to ensure minimal or no seepage and surface staining. Although such staining may be removed by cleaning, this adds another cost aspect to the manufacturing process. An obvious solution to joint sealants in the base of the mould would have been the use of a flat but readily compressible material into which the bricks could be bedded and which would allow them to settle and form a seal under their own self weight. This would seemingly be more practical than sealing individual joints.

However if a compressible base material was employed there would be a need to provide some demarcation to this material in order that the bricks could be accurately set out as quickly as with the MBrick Versaliner profiled sheets which provides a specific location guide in which to place the clay units speedily and with no requirement for human judgement.

**Polystyrene**

The first set of panels encompassed polystyrene onto which the bricks were laid. The thought was that as the bricks became slightly embedded in the polystyrene this would form a natural sealant with brick. Stock bricks were used in the trials. Whilst the pour was itself successful, once the panel was removed from the mould it was immediately apparent that the polystyrene had little effect in providing a sealant, particularly with the irregular faced stock bricks.

The panel was cleaned by using a pressure hose applied to the face but care was needed to ensure that the soft surface texture would not experience erosion or permanent discolouration.

Upon completion of the trial the polystyrene was covered in mortar residue and therefore could not be reused. This presented a high wastage product within the manufacturing process as well as a cost issue since new polystyrene sheets would be required for every panel manufactured.

**Rubber mat sheeting**

An alternative to the polystyrene base was a soft rubber sheeting upon which the bricks could be laid. Setting out presented the same issues as with polystyrene. There was an added problem in that as the bricks were laid they sank into the rubber which was desired to create a seal. However, as more bricks were laid they would not remain upright due to the base mat continuing to distort under more weight. This had the result of making the
bricks unstable before any mortar was poured. No further progress was made with this procedure.

**MBrick Versaliner profiled sheets and mastic beading set into the mould box**

In conjunction with the MBrick Versaliner profiled sheets as previously used in the ongoing trials a mastic beading was introduced to the joints. The set up was time consuming as it entailed individual and manually fixed beading to every bed and perpend joint. The result was that as the bricks were set into the mould they were fixed into the beading as well as being located in the MBrick Versaliner sheet profile such that a seemingly tight joint was formed between the bricks and the template.

Results from a trial panel were not positive. The finished joints in the brickwork were inconsistent in depth and thickness and heavy leakage occurred around the brick faces – not a good finish to the joints. No further progress was made with this procedure.

**Clay dust from the brick manufacturing process**

At brick manufacturing plants there is during the production process an element of waste which is primarily clay “dust”. This is in a powder format and particle sizes are similar to those from cement. When moistened (depending on the water content) this material becomes plastic displaying the properties of a typical pure clay material. A trial was carried out using clay dust instead of sand in the panel trial manufacturing process as it was considered that if this very fine material in powder form was placed into the joints within the MBrick Versaliner template, as the mortar was poured in this would moisten the clay which when damp would form an efficient and tight seal.

The result was some minimal leakage although the brick staining was negligible. However after stripping the mould box there was a wet clay residue which would require disposal. Although this was minimal in a small trial panel it would present a problem with large scale manufacturing as it would result in the need for costly disposal of a clay slurry waste. In short this involves the setting up of settling tanks and allowing the liquid and clay particles to separate. However although this process works successfully for many material particles, the structure of clay material is such that particles would remain in suspension within the water so that an unusable slurry mix would be left. In other sedimentation processes the particles settle to the base and the resulting water is reusable in industrial processes.
Additional trial with pulverised fuel ash (pfa) and then using a mix of clay dust and pfa (50 / 50 mix)

A trial was carried out with pfa and although the material was successfully placed between the bricks in the mould the particle size was such that like the clay dust it is difficult to handle in the process. This was then extended to trying a damp clay / pfa mix but with a minimal water content in the joints. An exact mix design was not critical to its success. Once the wet mortar was poured into the moulds it was apparent that the clay / pfa mix provided a solid sealant which was well moulded to the brick and joint profiles. However upon striking the mould it was noted that the clay / pfa mixture absorbs a high quantity of water and becomes difficult to remove from the panel. It is also not practical to recover the mix or to reuse the separate components. Waste effluent from this process cannot be readily recycled and it is not considered good practice to deposit the mix near the vicinity of fresh or drinking water. The procedure was therefore abandoned.

Standard mix builders sand and sharp sand

Potentially the most economical and easiest material to deal with in masonry panel manufacturer is damp standard builders sand. This was poured into the mould box in between the bricks and joint spaces. With the correct consistency it is possible to place damp sand which readily falls into the joints without “clogging up” and leaving large unforeseen and unfilled voids.

A trial was carried out using dry, plain standard builders sand. This was the easiest material to work into the bed and perpend joints. However, including the addition of sharp sand ( the mix composition trialled was 50 / 50) provides a mix which is slightly more solid and which remains within the base of the joints without filtering through into the mould base. As the wet mortar is poured into the mould and comes into contact with the sand it is apparent that the sand absorbs some of the cement creating a film or layer of weaker mortar which is approximately 2 – 3mm in thickness. This absorption of cement minimises mortar seepage. The finished panel will still require some cleaning although this is considerably reduced with this sand mix and low pressure spray washing easily removed any residue. When the panel was removed from the mould box any residual sand in the base could be readily reused in further production.

7.4.8 Trial 8 - 6th October – 3m panel with standard Hanson Kirton Facing Brick

Brick type – Hanson Kirton Thoresby Red Facing Brick

Objectives –
Produce a 3m x 1m panel using MBrick Versaliner template and sand filled joint seal to base.

Evaluation of quality and general structural integrity of panel

Evaluation of panel removal from mould and lifting process

Load testing of panel -

Flexural bending strength under single point load. Trial samples, manufacture with brick type – Thoresby red

Set up 3m x 1m panel using MBrick Versaliner mould base.

Brush in sand (50/50 builders / sharp sand) Use a depth gauge and compact to form an even joint

Omnicol mortar mix – 9 litres of water per 25kg of powder

Mortar volume required = 5 x 25 kg = 125kg for 3m$^2$ of wall

Recessed joints formed = 25mm typical depth

Set up time = 2 hours

Pour time = 15min

Introduction

This was the first wall panel of a size greater than the standard test sample dimensions produced using the flat bed manufacturing process. It would require crane assisted lifting and individual lifting points ensuring that rotational lift from horizontal to vertical could be progressed without causing localized cracking at the lifting points during panel rotation.

The brick selected was a Hanson Kirton standard facing brick of typically average properties. (Figure 7.16)

A softwood timber mould box was fabricated using 200mm x 50 mm members which were braced along the mould length in order to avoid any
deformation or deflection under the load from bricks and wet mortar mix. (Figure 7.17)

The mould base was a 20mm plywood deck with MBrick Versaliner brick joint profiled polymer sheeting of the specification used in the small sample trial panels. This was glued and stapled into the base of the mould to minimize any movement or deformation which would have manifested itself in the finished brickwork as deformation in the finished face. All formwork sides were bolted together in such a manner that any single part or the total structure could be dismantled to remove the set brickwork.

Once the formwork was completed bricks were dry laid in a stretcher bond format directly onto the profiled sheeting base which was formed of 10mm bed and perpend joints. At the ends of the panel alternate courses of bricks were returned rather than cut to form a toothed vertical edge when the panel was in the upright position. This process was used both to reduce the amount of brick cutting and also to enable bonded continuity of masonry around a corner detail. Additional care was necessary when sealing the end brick joints to stop mortar seepage.

Damp sand comprising a mix of 50% building sand and 50% sharp sand was used to form the brick / mould base sealant and prevent mortar from staining the fair faced finish of the bricks. The bricks were laid external or finished face down. This approach ensured that a complete flat surface exterior finish was achieved replicating traditional brickwork which is always set out such that the external presented face is flat, plumb, line and level.

At this early stage of trials the most difficult part of the process was to ensure that a consistent thickness of damp sand was placed between all of the joints ie both perpends and bed joints. This was achieved more by trial and error and by judgement on the part of the operative at this early stage. It should be noted that setting or placement of the bricks into the mould location requires a minimal skill level.

Joint sealant types and the filling / application process.

In small trials a number of joint sealants were investigated and trialled (ref Trial 7 Section 7.4.6 above))

At this stage damp sand was the preferred solution as it is an economical material, reusable for further panels and of sufficient adhesion and density when damp to allow brushing and compaction into joints to form a relatively tight seal.

In further trials a simple depth gauge was developed which enabled a consistent sand joint depth to be formed rapidly.
Removal of surplus sand from the prepared panel presented a problem as this could not be done by brushing or sweeping. Such a procedure would only deposit more sand into the joints.

Initially the very tedious process of sweeping with a dust pan and brush was applied but this required sweeping of each individual brick – an extremely time consuming practice. This process was further considered in further trial panels.

Joint sealant types and application processes were also given further consideration in the next panel trial.

Use of steel fixings and reinforcement

Previously built panels of both single skin and cavity walls (as for the Hanson Eco House and Carlisle flood defence wall) were manufactured with bed joint reinforcement included in the construction. This was used to increase flexural strength resistance of the panel during handling and transportation where predicted applied loading (largely due to self-weight) is not easy to evaluate. Design calculations assumed panel self-weight multiplied by a factor of 2 to represent dynamic loading. In this initial flat bed prefabrication trial of a 3m panel, bed joint reinforcement was built into every third course (Figure 7.18) as it was considered desirable to investigate the behaviour and performance of the masonry when fabricated using a high water content adhesive.

Placement of mortar into the brick panel.

Once the bricks had been placed in the mould and the joints sealed with damp sand, attention was turned to applying the mortar to the panel.
In the small sample trials previously discussed only minimal quantities of mortar had been mixed and trowelled / poured into position on the dry set bricks. With a panel of 3m$^2$ consideration was required as to how a relatively large volume of mortar could be placed in such a manner as to ensure all joints and perforations would be completely filled without the bricks and joint sealant being disturbed.

As all the current work was carried out as trials it was recognized that some of the processes in panel preparation and production would need to follow a somewhat “belt and braces” approach as investment in any equipment would depend on this early development work. With this in mind preparation of mortar for pouring was made by mixing in a standard small cement mixer. However mortar and water proportions were carefully monitored as it was critical to establish an appropriate mix of suitable viscosity and workability to achieve the desired joint filling technique.

Previous trials had indicated that 12 litres of water to 25kg of dry mix powder would provide the correct mix design. Once the mortar had been mixed for a specific mix time which, after trials, was established at 5 minutes - and bearing in mind that the setting time for this product is faster than for conventional cement sand products (to be used within 45 minutes of initial mixing) application onto the panel was made by pouring mortar into a bucket and delivering to the brick panel. (Figure 7.19)

The panel size was such that ease of access to apply the mortar did not require operatives to stand on the dry set brickwork which was considered inadvisable in case of dislodging any of the units. Initial coverage was found to be 0.8 m$^2$ from a 25 kg = 1 bag of dry mortar mix which does not allow for waste due to mortar within the mixer and buckets. Hence, 3m$^2$ required just under 4 bags of mortar.
One bucket contained the equivalent of half a bag of mortar so 8 buckets were needed to fill the 3m² mould.

Clearly in later developments this was further addressed but for the purpose of producing a structurally sound trial panel of good quality and appearance this technique was acceptable.

In terms of mortar delivery the operative poured the mortar so as to provide as even a distribution as possible onto the brick surface and into the open joints. Observation of the wet mix when placed on the panel showed that it would start to “settle” soon after delivery demonstrating that the mix was successfully filling the brick perforations (Figure 7.20). This was seen as key in the development of the brick / mortar bond and new brickwork with enhanced flexural strength when compared with conventionally applied glue mortar techniques which used the pump and gun, or the traditional trowel technique. In these latter cases, as with traditional brickwork the mortar will never completely fill bed joints, perpends or the perforations of the bricks. This aspect of brickwork in conventional build processes – and indeed with pump and gun techniques – will influence the brickwork workmanship and strength as the contact area in traditional construction is never 100%. It will also affect other performance criteria such as resistance to rain penetration.

Mortar was applied to the entire surface of the panel and then “topped up” after the settlement had taken place to ensure that the final construction had mortar which was as near as possible level with the top surface of brickwork. Any residue of surplus mortar on the top surface of the panel was carefully removed so that it was never thicker than 2 – 3mm. With the current trial process it would be difficult to achieve anything thinner than this but as this was the internal face such an issue would not be a problem. However as previously stated it is important to keep the surface residue to a minimum as excess mortar provides excess panel weight and cost.

Particular care was needed to ensure that the alternate courses of return bricks at each end of the panel did not move or become dislodged during the mortar pouring operation. An early indication of the success of this was to inspect the potential out of plumbness of such bricks which were initially set at a precise 90°. A simple test with a spirit level and square proved that none of the bricks had moved.

Removal of the panel from the mould box
This first 3m$^2$ trial panel was left to cure for 48 hours. After this time the mould box was stripped back and the panel removed. The method of removal was again somewhat unconventional as no lifting points had been built into the panel.

At the end of each panel the return bricks which were projecting one header above the panel were used to accommodate 16mm diameter reinforcement bars which were used as lifting bars. This process is certainly not conventional or orthodox and would not constitute appropriate procedures from the aspect of health and safety although great care and attention was given to supervision of the lifting by experienced operatives used to dealing with larger concrete structures in areas with limited access such as the trial area. Figure 7.21 illustrates a panel after removal from the mould box.

Figure 7.21 mould box after removal of panel

Figure 7.22(a) – 7.22(d) shows the removal and lifting of the panel from the mould box while Figure 7.23(a) and 7.23(b) shows the finished surface.
Figure 7.22(a) to (d) Removal and lifting of panel from the mould box

Figure 7.23 (a) to (b) Completed panel after removal from mould box and low pressure cleaning
7.4.9 Trial no 9 – Fabrication of corner panel - assembly and production sequence

This panel is in accordance with the detail in fig 7.24: long leg = 2950mm = short leg 900mm

One of the key requirements of prefabricated masonry was the necessity to deal with corners and corner details. All forms of prefabricated masonry suffer a disadvantage in terms of architectural flexibility if panels have to be constructed in such a manner that all joints between panels are directly at a corner. This allows no masonry continuity, it accentuates the appearance of prefabrication and joints and it also confines structural integrity to specific details with a possible need for elaborate ties and fixings. In situ built masonry is flexible enough to enable joint locations wherever necessary or desirable.

Current prefabricated systems clearly demonstrate straight vertical joints either at a corner or just one brick width in from it.

With the construction of the Hanson Eco House (Chapter 5, Case study No 7) the architect elected to use a stack bonded clay brickwork outer leaf, largely to demonstrate the strength of the prefabricated panels, but also because it enabled a corner joint to be conveniently blended into the bond pattern.

With the prefabricated masonry of Lawn House in Leicestershire (Chapter 5, Case study no 9), the architect provided a clever rainwater down pipe design which included a square section downpipe hidden in the stretcher bond brickwork which was recessed at the corner so that the pipe could be in effect hidden. Further, this incorporated the joint.

With the success of the 3m long panel the next proposed trial was to manufacture longer wall elements ie up to 6m as might be used in the flood defence system projects. However prior to this, consideration was given to the treatment of corner details.

Two approaches were possible.

- The fabrication of an L shaped corner panel which for convenience of transportation would have a long leg length, say up to 6m, and a shorter return of say 900mm. With this scenario the return would have a straight edge and a joint would be formed there. However there would be continuity of brickwork around the corner.
- The second consideration was to form all vertical edges as toothed stretcher bond brickwork so that a continuous unjointed wall might be achieved when two adjacent panels were stitched together. The corner wall was developed first. Figures 7.24 to 7.27 illustrate the proposed assembly procedure for the construction of a corner.
Variations to this were considered but the key issue was to fabricate stretcher bond panels with toothed brickwork edges at the end to be bonded as continuous brickwork.

**Figure 7.24** Prefabricated corner detail and assembly sequence

External corner panel - fabrication process
1) Manufacture short return corner with projecting headers in the right hand end of mould
2) Include bed joint reinforcement in panel with steel projecting full panel length
3) Leave panel to set for 24 hours before removing from mould
4) After 24 hours position short return in to left hand end of mould with the longest length vertical and plumb.
5) Set up bricks for long panel length as for previous standard panel manufacture process
6) Include all bed joint reinforcement as detailed ensuring continuity into corner of return piece
7) Cast full length piece
8) Do not remove for 24 hours - minimum curing time

**Figure 7.25** Prefabricated walls assembled to form a “box” or planter wall.

**Figure 7.26** Highlights the very good mortar / brick bond as the mortar has filled all brick perforations.
Joint assembly detail

Bricks were dry laid in the full size mould box to form the 900mm long x 13 course high return wall. The required bed joint reinforcement was then located in the panel with projecting lengths which would be bonded into the longer panel. Mortar was poured into the panel and this allowed to set for 24 hours. This was then rotated through 90° and placed in the end of the mould box. The 3m long wall section was then dry laid so that it would bond into the now upright short return wall. Bed joint reinforcement was located in the panel. Threaded couplers were located in the top course brickwork to receive threaded lifting bars. The 3m panel was then mortared and allowed to set and harden for 24 hours.

The completed structure was then removed from the mould box and positioned in an upright stable position. Lifting of the panel was by overhead crane.

The second procedure considered for treatment of continuous corner details involved only a 3m long panel with toothed alternate brick at each end. This panel would interlock into an adjacent panel with alternate bricks interlocking together. These would then be connected by use of mortar to infill the joints and a grout mix of the same mortar to be poured into the perforations within the bricks as these run vertically and continue down through the connected brickwork.

7.4.10 Trial 10 Dec 09 - 6m long x 1.5m high decorative panel

The next panel in the development test programme was 6m long x 1.2m high. The decision to manufacture a trial of these dimensions was to compare buildability and
performance with the handmade panels produced for the Carlisle flood defence system (Chapter 5.2.4, Case study no 9) where some 130 panels were manufactured to the same size. A product of these dimensions provides a solution for a number of market sectors, specifically the civil engineering sector, where walls of this proportion are in demand.

In this case panels were 102mm single leaf thick brick and manufactured in stretcher bond. Both bed joints and perpend joints were 10mm thick. This joint thickness was chosen as it is representative of the most common UK joint thickness and any prefabrication developments will ultimately need to satisfy this dimensional format. A 10mm joint (bed and perpend) is also the most onerous in terms of structural properties as the thicker the joint the lower will be the flexural and compressive strengths. (Ref Chapter 8, compression tests for varying joint thicknesses)

The process of manufacture replicated that of the 3.0m x 1.0m panel described in trials 8 and 9 although this panel incorporated Halfen proprietary lifting rings attached to vertical ribbed reinforcement bars built within the masonry. (Figure 7.28 a - d). Additionally this panel had bed joint reinforcement incorporated into the construction as with the Carlisle panels.

The panel mould was of the same basic construction as trial no 8 although the formwork timber was of increased section sizes to minimize the risk of deflection or deformation of the mould side walls due to the lateral load caused by self weight of brickwork and more particularly the wet mortar which has a density of approximately 2000kg/m$^3$ and a depth of at least 102mm plus the surface surplus to give a total of 105mm.

A single panel was made and as an additional feature bricks were incorporated into a patterned design (Figure 7.28(a) – (f)) in order to demonstrate the ease with which polychromatic brickwork could be fabricated in a mould when compared with manual bricklaying methods. Minimal skill is required to set out even a complex brickwork pattern.

In this case the time and materials used were carefully monitored in order to make a comparison with the standard manually built panels.

**Materials specification**

- **Omnicol mortar** = type 2 mortar with no added bulking agents
- Water content of the mix = 12l per 25kg
- Mortar consumption = 30kg wet mix per 1m$^2$
- Bricks = Hanson Wilnecote Red facing and Blue engineering
- Format = 3no 30mm diameter perforations
- Comp strength = 100N/mm$^2$
Water absorption = <7%
Bed joint reinforcement = BRC BK 60 3mm diameter bars
Vertical steel reinf to lifting points = 12mm diam high tensile steel ribbed
Lifting rings = Halfen HD lifting sockets, 20mm diameter

Material quantities / per panel

<table>
<thead>
<tr>
<th>Panel</th>
<th>6m long x 1.2m high</th>
<th>7.2m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bricks</td>
<td>60 /m² x 7.2m²</td>
<td>432 bricks</td>
</tr>
<tr>
<td>Mortar joints</td>
<td>10mm</td>
<td></td>
</tr>
<tr>
<td>Bed joint reinforcement</td>
<td>6m length x 5 courses</td>
<td>30m per panel</td>
</tr>
<tr>
<td>Vertical steel bars</td>
<td>2no x 1m</td>
<td>2m length</td>
</tr>
</tbody>
</table>

Panel assembly - labour time

Mould set up and construction = 3 days (one off operation)

Set up and prep time = 30 min
Brick setting time = 10 bricks/min = 45min for 1 panel
Placement of reinforcement and fixings = 20 min
Mortar mix ad prep = 20 min
Seal off joints with damp sand = 20 min
Lay, brush in and clean off mortar = 30 min

Total preparation and fabrication time / per panel = 145min = 2 hours 25min

Time for setting and hardening = allow 24 hours minimum

Figure 7.28(a) Full bricks set into mould box, face side down.
Figure 7.28(b) detailed view of dry set clay facing bricks in mould box
As noted from previous panel construction ie manually manufactured cavity walls and single leaf walls, one of the key issues to address is lifting and handling. In the case of vertically built panels (including those manufactured by the robotic processes) it is only necessary to lift the panel vertically and as the panel is already standing vertically the main consideration regarding its structural integrity relates to its strength within the plane of the wall. The panel will behave as a beam and depending upon its ratio of height to depth may be considered to be a deep beam where failure may occur during transportation and lifting predominantly through shear rather than flexural bending. If the panel is always kept in a
vertical attitude, lifted from the base (either by slings or by use of a lifting jig with lifting points in the perpends of the panel base course) and restrained against rotational movement, then internal loads and stresses are kept to a minimum and are likely to be below the allowable strength parameters for the brick / mortar combination.

Bed joint reinforcement near top and base of the wall will ensure that there is additional resistance to flexural and shear strength both in the plane of the wall and at right angles to it. In the case of walls with openings (ref chapter 5.2.2 case studies 7- Hanson Eco House and 8 - Lawn Cottage) placement of bed joint reinforcement at the top and bottom of windows and above doors increases resistance to any localized concentration of stress.

When manufactured in a horizontal position one of the key considerations is the moving of panels from the mould box to a storage area. As the development work was undertaken with the help of operatives from a precast concrete factory their mind-set was such that they perceived the easiest way to move, store and transport panels was flat. It was thought that completed panels would remain horizontal in the mould box and be removed by a four point lift. This is the way in which precast concrete panels would be dealt with, particularly pre cast floor units. Once moved the presumption was that they could be stored on top of each other with timber bearers being placed to provide support points and to enable space between each panel so that a fork lift truck could remove them. With the masonry walls, the proposal was similar; i.e. to place panels horizontally on to flatbed lorries again with timber spacers or bearers in between each panel. Transportation in the horizontal attitude was deemed to be the most stable way to move panels and to provide the least load and stress on them during movement. (Figure 7.29 shows the preferred handling technique for pre cast concrete components)

However this technique offers some complications for the handling of prefabricated masonry which has considerably lower tensile strength than that of reinforced concrete.

![Figure 7.29 lifting and storage – panels lifted from 4 lift points and stacked flat, each panel resting on bearers. This system is acceptable for reinforced pre cast concrete but not advisable for masonry.]
Any unnecessary or accidental loading from impact or mishandling during the installation process could cause damage to the panel and more importantly cracking within bricks and or joints which may not be visible to the installation supervisor. Cracked brickwork – depending on where cracks occur – will have reduced flexural strength.

A four point lift would see panels lifted using high tensile steel ribbed reinforcement bars spanning from what will be the top to the bottom of the panel ie perpendicular to the bed joints. The bars would be threaded at each end and fixed into either the perforations of the standard bricks (which would be aligned in both a stretcher or stack bonded brickwork) or have to be placed in pre drilled holes if solid or frogged units are used. At each end of the bars a rotational lifting eye would be screwed into the threaded hole. (Figure 7.29)

In the flat four point lift there is a need for four lifters which adds to overall panel cost. If however the two point lift approach is used there is some cost saving on lifting components but it will be necessary to rotate the panel through 90° from flat to vertical before moving it to storage. This rotational lift operation is only carried out once. Thereafter panels are kept in a vertical position for transport and handling.

The rotational lift requires design considerations as it means that the panel is under a tensile bending load due to self weight during the move from flat to vertical. Additionally the lifters and the fixing of them to the steel reinforcement and also the bond strength between reinforcement and brickwork all need to be designed and a safety factor included for loading techniques.

In large fully automated prefabricated panel manufacturing process where rotational lifting is a preferred option, panels are manufactured on a tilting table. This is literally a heavy duty flat horizontal table surface on which a panel is produced. When required the table can then be mechanically rotated through 90° so that the panel is now in the vertical attitude. It can be handled by crane or fork lift and moved to storage or onto a lorry for transportation. Using a tilting table will ensure the panel is subjected to minimal stresses during the factory handling. In particular it will experience no internal stresses due to the rotation. In a full prefabricated factory development the tilting table offers the ideal method of factory handling after casting even with the capital outlay of the table.

Halfen special rotational lifting rings (Figures 7.30(a) - (c)) are designed to fully rotate when the panel is lifted from the horizontal to the vertical attitude so reducing any high localised loading and stresses on the brickwork where the load bears directly onto the fixing. Legislation forbids rotational lifting without the use of lifting rings.
In these initial trials the lifting rings were used for rotational lifting only. Thereafter the panels were always moved using sling straps.

Figure 7.30 Rotational lift followed by vertical lift out of mould box

Figure 7.31(a)

Figure 7.31(b)
In the initial flatbed fabrication trials with the simplified prefabrication process there was no tilting table available hence the need to consider rotation by crane lift.

During the dry brick panel assembly in the mould box steel reinforcement bars were placed at ¼ spans from each end. The length of these bars was determined by a minimum anchorage bond length and in practice they were approximately ¾ of the panel height. They were fitted with rotational couplers to be accommodated in the top face of the wall. (Figure 7.31 (a) to (d))

The diameter of the reinforcement bars was determined by the assumed panel load which was taken as the self-weight of the masonry multiplied by a factor of two to allow for the instant / dynamic loading.

As the panel was being lifted it was subjected to an initial tensile strength due to its self-weight and this was resisted by the composite action of bed joint reinforcement and the brick / mortar tensile strength.
An appraisal of testing and modes of failure during lifting was discussed with Halfen Fixing Technical Department (Figure 7.32 Halfen lifting mechanism) and the following was concluded.

- A preliminary pull out test should be undertaken on the brick
- Stack bonded bricks should be tested for 1) the bond between mortar and brick and 2) the bond between mortar and anchor – see stack brick samples used for testing as described in Chapter 8.5.
- As previously stated a factor of safety of at least 2 considered appropriate for anchors. In order to do this on anchors in test walls it is necessary to either secure or add extra weight to the test specimen.
- For vertical lifting, the mode of failure in concrete is referred to as “cone breakout” starting at the foot of the anchor. For a brick panel it may be that delamination of the mortar joints occurs. A full panel may be required to test breakout (Figure 7.33), although if delamination of the joints is the limiting factor it may be possible to produce a mock up that tests just the joint capacity. When securing / adding the reaction to the test rig it is important that this does not encroach upon the stress area as this will actually help the lifting anchor and misrepresent the test data – one possible way around this would be to secure the panel at the bottom as shown in Figure 7.33.

A smaller scale mock up test is also recommended (Figure 7.34) to evaluate the direct tensile strength of a joint.
If the anchors are being used to pitch the panels through 90°, a shear test is required as one is applying the load to a thin section of masonry on one side of the anchor. Typically in a concrete panel extra shear reinforcement is installed in contact with the anchor head to absorb the shear loads, however, due to space restrictions in the brick core this isn’t possible. In practice this means that applying a high shear load to one side of the anchor head could cause the adjacent mortar / masonry to fail. Again if extra weight / reaction is added to the test specimen it is important that it doesn’t interact with the stress cone. Figure 7.35 shows the test and failure mechanism.

Successful manufacture of this 6m long panel provided a milestone in the development of this manufacturing process and in the most recent trials both rotational lifting and handling were undertaken using the lifting rings, connected directly to a lifting beam. (Figures 7.36 and 37)

Lifting from the mould by a crane and rotational lifters is the most practical way of removing the panels from the mould. If an overhead crane is available this will enable efficient and rapid movement within the factory to a suitable storage location.
For the Carlisle project (Ref Chapter 5.2.4 Case Study No 9) panels were lifted somewhat crudely with industrial lifting slings. This is a cost effective but somewhat difficult approach and it puts irregular unpredictable stressing on the panels. In terms of safety legislation, although any lifting slings must be tested to establish a failure load and a suitable safety factor applied to them (usually at least = 2) the technique is not as beneficial as the use of lifting points fixed to reinforcement bars with an anchorage bond length within the panel.

It became apparent during the development programme and from the experience gained through the case studies, that lifting and handling, transportation, stacking and installation are as much a key part of the development of an efficient prefabrication process as is the material specification and structural design and integrity of the panel. These are now documented

7.4.11 Development of a combined lifting beam, temporary prop system and transportation storage racking system.

The aforementioned process (7.4.10) describes removal of panels from the flat bed mould by two point rotational lifting at the top edge of the panel. The panels are then lifted by crane and moved to a place of storage.

During early trials and in the manufacture of the single leaf panels for the Carlisle flood defence scheme all such panels were made by manual processes and were built as vertical panels. These were initially lifted by a crane with lifting beam and two slings; the slings being load tested to a safety factor of 2 but in any event each sling (typical of the type used as strapping on lorry loads), had a tensile strength of 50kN and as such were more than adequate for supporting the self weight of the flood walls which did not exceed 2.5 tonnes.

The problem with using slings lies in their restricted lifting and manoeuvring capabilities as it is not possible to place a wall in its finished location and to then remove the slings.
For walls to be located quickly and without complication they need to be lifted from above (as described in the section 7.4.10) or by a process where they can be positioned without resting on their support straps.

In Chapter 5.2.4, case study No 9 the manufactured prefabricated single leaf walls for Carlisle flood defence were lifted by a purpose made lifting jig / lifting beam specifically designed for this project. (Figure 7.38) The jig had welded vertical plates fixed to the lower end of the downstands (Figure 7.39) The downstand members slide along the lifting beam which enables the perpend lifting plates to be accurately positioned irrespective of the perpend positions. This lifting mechanism allowed panels to be offered horizontally up to a structure and located in their final position after which the lifting frame could be removed and the perpends used for locating the lifting plates filled with mortar or left open as weep vents. The system would be beneficial for positioning panels within a framed building. To ensure stability and verticality during movement the lifting jigs had vertical downstands designed to be located flush with the side of the panel and connected to the top rear face of the panels keeping them in position. (Figure 7.40)

Although the lifter beam enabled removal of panels and relocation into storage stillages (Figure 7.41, 7.42 and 7.43) at this stage the stillages were semi temporary timber structures purpose made for delivering the panels to site.
The quality of the stillage structures was such that they could not be used for more than three lorry trips without signs of wear and tear to the frames rendering them unsafe for further use.

Additionally the lifting beam previously described required further development to improve reliability and versatility. This led to the development of a combination system which addresses the issues of lifting, handling, transportation and storage along with temporary propping of masonry. Hence the lifting problem has been resolved by use of a hybrid lifting unit which then forms part of a propping system and a component of a battery of stillages.

### 7.4.12 Flexible lifting beam with variable height adjustment system for panel restraint

This system can best be described by consideration of the following visual graphics and details.

A single integral “leg”/ prop was developed which has a lifting plate at the base to be located in wall perpends. The “leg” of the prop is of a variable adjustable height. At the top of the prop is a square hollow section tube which will accommodate a lifting beam, also of square hollow section. Any number of props may be used depending on the wall panel shape and size. (Figure 7.44)
In the wall panels developed for the flood defence system three props were used for a panel lift. In the modified / improved version, once the panel has been positioned for storage the vertical members can be detached from the lifting beam and remain in place as temporary supports (either in a storage situation or as a propping when the wall has backfill material placed against it.) (Figure 7.45). Further details of the system can be seen in Figures 7.46 and 7.47.

Figure 7.45 Wall panel being supported by 3 lifters which have been placed in a propping position.

Figure 7.46 Plan, front elevation and end elevation of lifter / prop system in place on a single leaf wall
Chapter 7 - Development of a simplified flat bed prefabrication process

7.4.13 Summary to Chapter 7

This chapter describes research, development and testing work undertaken by the author for the development of a simplified manufacturing process for prefabricated clay brickwork panels and how this was arrived at based on initial experience of manual prefabrication, the use of robotic manufacturing techniques and by considering various combinations of bricks, mortar and concrete composition. The solution derived was also based on a testing regime and a number of construction case studies which led to evaluation of costs and buildability.

The initial objective was to establish the buildability, structural integrity and appearance of panel types of varying composition and including brick slips, bricks combined with concrete and bricks with high performance cement based mortars to identify which of the processes had potential to develop as a full flatbed manufacturing system giving an economical fabrication.

It was proven that the full brick and high performance mortar gave the best solution and was superior to a composite brick slip concrete or brick concrete method.

Panel structural integrity was evaluated – this showed that correct handling of the panels is as important as the manufacturing procedures. Indeed the worst load cases assessed for

Figure 7.47 Lifting units used for wall storage – the vertical posts fit into a base member and are then locked in place at the top to contain a number of panels. The system can be of such a size that it may be transportable on a flatbed lorry.
the panel design occurred during lifting and transportation. Refer to Chapter 8 for information on material and structural testing.

One of the key issues relating to prefabricated masonry is the careful handling which is necessary to ensure that structural integrity is maintained. It was found during fabrication trials that if handled incorrectly masonry may crack in the mortar joints and such cracking can go undetected such that panels are installed but will have lost the anticipated structural integrity in particular a loss of flexural strength due to the joint cracking and failure.

In order to improve panel handling, a system has been designed and developed that will enable safe lifting and handling of masonry panels from the place of manufacture into a safe storage area. The system provides a combination of lifting and storage stillages and enables each lifting frame to be utilised as part of the storage stillage. Additionally the stillages may be used on flat bed lorry transportation to safely transmit wall panels to site.

If necessary on site the frames may then be used to lift a wall and install it in its final position and to utilise built in temporary props which allow for the panels to be supported under a temporary load from wet concrete or backfill.

Panel prefabrication must be priced in real terms to be competitive with traditional masonry processes and the literature research has demonstrated that this is not the case with numerous building systems which have been developed over the years but not progressed with any long term commercial success.

The simplified panel fabrication technique described in this chapter has a low capital outlay compared with the robotic processes and an output which enables high volume production.

Return on capital is readily achievable without the need to add significantly to the final panel price.
Chapter 8 Testing

8.1 Introduction

The comprehensive testing of masonry is a costly exercise when consideration is given to structural performance, durability and workmanship / buildability. It invariably involves evaluation of physical properties on both the individual components such as bricks or blocks as well as the various mortar types. Further information is then required for constructed masonry either as small wall samples (wallettes) or full scale wall panels. It is the fabrication of these sample panels and the number of them required for a recommended test that will add considerable cost. A minimum sample of six, (and preferably a sample of ten) is required for adequate test data as outlined in the appropriate testing standards documents (BS EN1015: 1999). The number of test samples is based on the high variation in results obtained and the high coefficient of variation within a set of results. A major influence on variation in test information is that of workmanship, which is down to human input when making the panels – or indeed full sized masonry - and to the conditions within which masonry is constructed and then allowed to cure.

Extensive masonry testing has taken place over the past 4 decades in an effort to establish vertical load, lateral load and shear capacities for the various brick / mortar or block / mortar combinations along with the interaction of masonry with ancillary components such as wall ties and lintels. Such testing has provided design data for conventional UK construction using standard clay bricks or blocks (of aggregate or aircrete type). Much data has already been established and use can be made of the characteristic strength values as defined in BS5628 Parts 1 and 2 or its successor EC6 based on various masonry unit formats along with various mortar compositions.

Most of the development work carried out for this thesis considers high performance mortars used in varying joint thicknesses and incorporated into both in-situ and prefabricated work.

The original development work on thin joint masonry was carried out largely in Europe and was based on in-situ built masonry with “thin joints” as defined by the European systems (Vekemaans, Ruben 2002) ie joints which are no greater than 3mm generally or 5mm maximum. In addition European thin joint masonry was, and still is frequently constructed with glue mortared bed joints but no mortar in the perpends. It was recognised early on in the UK that building with open perpends was not a favourable option for the testing of thin joint masonry, nor indeed an acceptable option for UK construction.
Development work in the UK did not commence until the Oxford Brooke PII project was commissioned and testing was undertaken at Oxford Brookes, Hanson laboratories and subsequently Kingston University. In the case of the academic establishments the financial commitments were supported by either Government funding (Oxford Brooke PII 2004) or by industry. Hanson Building Products (formerly Hanson Brick) had extensive testing facilities including materials and structures laboratories at a number of sites. This enabled various testing to be carried out prior to commissioning any independent work. The benefit of this is that it enables evaluation of the performance of specific materials, quickly and economically. The tests that indicate a successful outcome are then put forward to independent establishments for formal testing minimizing development costs.

The Hanson structures laboratory inherited equipment from the London Brick Company capable of testing wallets for both lateral loading and vertical compressive loading. The lateral load testing machine can load test wallets which are vertically upright with horizontally applied load rather than being laid flat and subjected to loading in the same format as a horizontal beam. The vertical test more closely emulates the actual full size wall build where the effects of self-weight during construction provide a realistic loading situation i.e. the masonry self weight adding a compressive load to already built brickwork.

The development of masonry with high performance mortars for use in UK type construction requires design data which is not previously documented in the Eurocodes or any corresponding supporting documentation. Additionally much of the masonry developed within this thesis is of a composition or format for which test data was not readily available. During the course of time spent on masonry research and development it became apparent that in order to evaluate structural performance it would be necessary to test masonry either to the standard test procedures referred to in BS5628 Part 1 or its successor the Eurocode BS EN1052 – 2 1999.

However, and more importantly, there was a need not only to try and satisfy current code legislation, but also to ensure that prefabricated wall panels were capable of withstanding far more complex loading and stresses than occur in traditional site built work.

Conventional masonry is constructed at a relatively slow pace so that loading within the walls increases at a very gradual rate. Such loading (ie from self-weight) is being applied as the wall construction proceeds and load application is vertical, where masonry possesses the highest residual strength. In situ thin joint construction is built more rapidly than traditionally laid masonry as a result of the pump and gun application process. (At the
University of West of England new architectural school, bricklaying rates were up to 50% quicker with the system than if a trowelled cement / sand mortar was employed.) Vertically built prefabricated masonry is subjected to self-weight loading at a more rapid rate and when completed the wall panels are subjected to loads and stresses that will not occur once the panel is in its final position. Additional loading occurs from factory handling, lifting onto a lorry and transportation to site and moving by a heavy duty crane. Furthermore, the recently developed flat bed prefabrication system uses high performance mortar with a modified and increased water content to enable rapid and thorough filling of beds, perpends and perforations. The finished masonry will then need to be rotated from a flat to a vertical position as quickly as possible followed again by handling, lifting, transportation and installation. In this flat bed procedure the structural properties were again determined by empirical testing.

8.2 Comparison of compressive and flexural strength properties for various mortar types and mix compositions.

A series of tests were carried out on mortar prisms in order to evaluate and compare the compressive and tensile strength of various mortar types. (BS EN 1015-11:1999). The purpose of this was to consider differences in performance of the mortars and to assess their suitability for use in both in-situ thin joint masonry and prefabricated masonry.

When the thin joint masonry system was introduced into the UK, the European mortars used – referred to as thin joint “glue mortars” - were considered to be the only suitable mortars for clay brickwork. The following tests were carried out in order to establish if this was the case or if commercially available UK mortars might be suitable as an alternative.

The tests were carried out in accordance with BS EN1015 – 11. The mortar samples comprised prisms of 200 mm long x cross section of 40 x 40mm made in steel mould boxes. (Figure 8.1)
BS EN 1015-11 determines the strength of mortars under specified conditions in order to classify them with a view to determining their relative performance in service. The regime adopted does not set out to achieve optimum strength; rather it is one which allows comparison between the various mortars. It would suggest that the main criteria for such testing are that the regime should be relevant to the majority of binder types and the procedure should yield consistent results whilst not being too onerous on the testing laboratory such that the cost of testing becomes prohibitive. It is therefore important that the permitted variations in testing are not so widely different as to create difficulties for the testing laboratory. For the compressive test a load is applied to the prism ends on an overall area of 40mm x 40mm and through the 40mm depth.

Tensile flexural strength is determined by recording the load failure of an applied line load which is placed at mid span between supports that are 160mm apart. The overall prism length is 200mm. In each case prisms are tested to destruction, the flexural strength being tested first and the compressive strength tested using the remaining material. (Figure 8.2)

The following mortars were tested for flexural and compressive strength at various curing time periods. Flow and air content are quoted in the results. The water content was in keeping with the average as recommended in respective product literature.

Mortar types tested:

- **Omnifix type B mortar** - proprietary high performance “glue” mortar (product used within expiry date)
- **Omnifix type B mortar** - proprietary high performance “glue” mortar (product past expiry date)
- **CPI mortar** - high bond render (high strength mortar)
- **M12 - 1:3** - standard cement : sand
- **M4 - 1:6** - standard cement : sand

Tables 8.1 (a) to (e) show the mean flexural and mean compressive strength failures for prisms tested at 1, 3, 7, 14, 21, and 28 days and the standard deviation and coefficient of variation

Graphs 8.1 and 8.2 show the comparison of mean compressive and mean flexural strength results for all mix types.
Mean flexural and compressive strength results for various mortar types:

**Table 8.1(a) & (b) - Omnifix**

mortars – before and after expiry date for usage

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**Table 8.1 (c) & (d) - standard cement mortar mixes**

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**Table 8.1 (e) - CPI high bond render**

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Note information for the 1 : 6 cement: sand mortar and the CPI render was provided by CPI Mortars and no standard deviation or coefficient of variation data was made available.

**Table 8.1 structural properties of various mortar types.**
Graph 8.1 Compressive strength of mortar types over 28 days

Graph 8.2 Flexural strength of mortar types over 28 days
8.2.1 Results, observations and discussion.

1. Two batches of Omnicol Type C mortar were tested; one being at the end of its commercial shelf life and the other being comfortably within its shelf life period. The purpose of this comparison was to examine any discrepancies in structural properties between the two types. The reason for the declared sell by date relates to issues concerning health and safety and hazardous materials rather than structural performance. Specifically the issues are concerned with chromium IV (MPA, 2013). From the tests it was concluded that both Omnicol mortars had very similar strengths at 1 day and again at 21 days onwards in both compression and tension. However it was noted that the compressive and tensile strength gain increased more in the Omnicol sample 1 which was near its expiry date between days 1 - 14. There was no evidence to suggest why this was the case and the graphs for each Omnicol type followed reasonably similar profiles. Additionally the strength profiles were very similar for both flexural and compressive testing. Any future work would be based on the strength parameters defined in the Omnicol sample 2 material. However such is the simplicity of the test that regular testing of all material consignments should be carried out as part of a manufacturing quality system.

2. With both compressive and flexural strength values the initial strength at 1 day is considerably higher for both Omnicol mixes than for both the cement: sand mortar and the CPI High Bond. Although the sample numbers are small it is important to note that the Omnicol strength values are three times the value of the CPI mortar and twice that of the cement: sand. The rate of strength gain continues over the course of 28 days, but of more importance is the strength at 3 days which in the case of prefabricated masonry will be the critical period for panel removal, lifting and storage.

3. Compressive and flexural strengths were consistently higher for cement sand mixes than for CPI mortars during the 28 day period of strength gain with the exception that the CPI mix appeared to have increased flexural strength at 28 days. The cement sand results are similar to (but slightly higher than) those quoted in design documentation.

4. From the four mortar types tested it is clear that higher flexural and compressive properties of the Omnicol mortars are achieved than for those from the conventional cement : sand and the CPI mortars.

5. Tests previously carried out (Brookes PII 2003) for both Omnicol mortar (previously referred to as Ankerplast) and for the proprietary adhesive mortar, Celfix (Celcon technical literature, www.hhcelcon.co.uk) as used in the Celcon thin joint aircrete blockwork system achieved similar profiles of strength gain although the 28 day results
were slightly lower than those obtained from this current research. Graph 8.3 demonstrates these results.

Graph 8.3 – Ankerplast (now known as Omnicol) and Celcon Celfix compressive strengths for mortar tested at 1, 3, 7, 14, 28 days. (Ref Oxford Brooke PII, 2003)

Tests for mortar flexural strength were not carried out at Oxford Brookes.

The Celfix mortar strength properties closely match those of the Ankerfix material.

As previously noted, any development work for prefabricated clay brickwork would be based on Omnicol mortars or similar proprietary types.

8.3 Omnicol mortar tests – influence of water content on mortar performance properties (samples tested at 3 days after casting)

In the previous tests all mortar samples incorporated the typical / manufacturers recommended water content which is set to give optimum structural properties and workability for brick laying using the pump and gun technique.

The following set of tests investigates the effect of increasing the water content of the Omnicol mortars over and above the manufacturer’s recommendations and recording the corresponding compressive and tensile strengths. The reason that only Omnicol was considered relates to its performance when compared with traditional mixes. The latter did not appear to be of adequate specification particularly for the flat bed prefabrication method described in chapter 6 of this work.
8.3.1 Test specification

1. Omnifix type C mix was used and all strengths are recorded for varying water contents.
2. All samples were tested 72 hours after preparation. The most recent set of data was from materials made on 1st July 2014 and tested on Friday 4 July 2014.
3. Mixing time for all samples was 5 minutes - the wet material was put into prism moulds using 25 tamps immediately after mixing.
4. Three prisms were made for each mix, giving three test pieces for transverse strength and six for compressive strength.
5. Prism dimensions = 200mm long 40mm x 40mm
6. The mixing instructions on the bags of Omnifix C give a lower limit water addition of 4.8 litres per 25kg (19.2%) and an upper limit of 5.5 (22.5%) litres per 25kg.
7. With the water content at the upper limit of the mix recommendations, the mortar was not considered to flow well enough for pre-casting, so two other water addition levels were tried.

Samples cast are indicated in Table 8.2

Table 8.2 Omnifix mortar / water content descriptions

<table>
<thead>
<tr>
<th>ref no.</th>
<th>date</th>
<th>Wt Omnifix C kg</th>
<th>Water addition ml</th>
<th>%</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.7.2014</td>
<td>2000</td>
<td>384</td>
<td>19.2</td>
<td>Lowest recommended water addition - workability acceptable for trowel use</td>
</tr>
<tr>
<td>2</td>
<td>1.7.2014</td>
<td>2000</td>
<td>412</td>
<td>20.6</td>
<td>Medium water addition</td>
</tr>
<tr>
<td>3</td>
<td>1.7.2014</td>
<td>2000</td>
<td>440</td>
<td>22.0</td>
<td>Highest recommended water addition - did not flow enough</td>
</tr>
<tr>
<td>4</td>
<td>1.7.2014</td>
<td>2000</td>
<td>468</td>
<td>23.4</td>
<td>Water addition above recommended - reasonable flow</td>
</tr>
<tr>
<td>5</td>
<td>1.7.2014</td>
<td>2000</td>
<td>500</td>
<td>25.0</td>
<td>Water addition above recommended - good flow, likely to be used for pre-cast trials</td>
</tr>
</tbody>
</table>

Prisms were tested for transverse strength at the Hanson Hams Hall laboratory.

Compressive strength tests were carried out using the same testing machine on both halves of the broken prisms previously used for the flexural strength test.

Results are presented in Tables 8.3 and Graphs 8.4.
### Chapter 8 - Masonry testing

#### Table 8.3(a) Flexural strength test results

<table>
<thead>
<tr>
<th>Water content</th>
<th>Max load (kN)</th>
<th>Flex strength (N/mm²)</th>
<th>Dev</th>
<th>Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.20%</td>
<td>1.52</td>
<td>3.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.58</td>
<td>3.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.60</td>
<td>3.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>1.57</td>
<td>3.62</td>
<td>0.09</td>
<td>2.41%</td>
</tr>
<tr>
<td>20.60%</td>
<td>1.40</td>
<td>3.23</td>
<td>0.23</td>
<td>6.93%</td>
</tr>
<tr>
<td>22.00%</td>
<td>1.30</td>
<td>2.87</td>
<td>0.27</td>
<td>9.29%</td>
</tr>
<tr>
<td>23.40%</td>
<td>1.27</td>
<td>2.88</td>
<td>0.03</td>
<td>1.12%</td>
</tr>
<tr>
<td>25.00%</td>
<td>1.15</td>
<td>2.65</td>
<td>0.08</td>
<td>3.09%</td>
</tr>
</tbody>
</table>

#### Table 8.3(b) Compressive strength test results

<table>
<thead>
<tr>
<th>Water content</th>
<th>Max load (kN)</th>
<th>Comp. strength (N/mm²)</th>
<th>Dev</th>
<th>Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.20%</td>
<td>30.00</td>
<td>18.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.60%</td>
<td>30.00</td>
<td>18.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.00%</td>
<td>30.00</td>
<td>18.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23.40%</td>
<td>30.00</td>
<td>18.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25.00%</td>
<td>30.00</td>
<td>18.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>29.94</td>
<td>18.71</td>
<td>0.09</td>
<td>0.50%</td>
</tr>
</tbody>
</table>

#### Graph 8.4(a) water content / flex strength measured for various water contents from 19% to 25%

#### Graph 8.4(b) water content / comp strength measured for various water contents from 19% to 25%
8.3.2 Observations and discussion of results

1. When tested for 3 day strength there is a reduction in flexural strength consistent with an increase in the water content of the mix.

2. In the previous tests comparing rate of strength gain for various mortars, the water content for the Omnicol mix was 19.2%. The corresponding 3 day flexural strength was 3.2 N/mm².

3. In this test with the recommended water addition of 19.2% the corresponding flexural strength is 3.62 N/mm². When the water addition increases to 25% (which is the maximum that we wish to try for prefabrication) the corresponding 3 day flexural strength is 2.65 N/mm². This is a tensile strength reduction of approximately 27%. However the lower strength is still adequate for the masonry design because in terms of overall brick and mortar (brickwork) strength, consideration must be given to the effective mortar contact area which increases with a wetter mortar mix. This is discussed later in the section.

4. For compressive strength values there is also a reduction in strength consistent with an increase in water content.

5. At a water content of 19% there is a compressive strength of 12.7 N/mm² at 3 days.

6. With the water content increased to the maximum proposed value ie 25%; the compressive strength is 9.49 N/mm² at 3 days i.e. a compressive strength reduction of approximately 25%

7. For both the compressive and tensile tests there is a similar and consistent reduction in strength of approximately 25 – 27%.

8.3.3 Comparison of the performance of Omnifix C mortar made at 22% and 25% water content. (Tested at 1 day old up to 14 days)

1. Omnifix C - 15 prisms were made at 25% water content to be tested at 1, 2, 3, 7 and 14 days.

2. Mixing time was 5 minutes - the wet material was put into prism moulds and compacted with 25 tamps immediately after mixing.

3. The mix was of a pouring consistency - tamping was used to make sure that the corners of each sample were filled out.

4. Each prism was tested for lateral transverse strength in the Instron testing rig at Hanson Hams Hall laboratory.

5. Compressive strength was carried out using the same machine on both halves of the broken prisms from the flexural test.
6. Samples were made at 15:00 hours on 9 September 2014. They were stripped from the moulds the next morning and put in plastic bags in five sets of three.
7. All samples were tested at 15:00 hours on the appropriate day.
8. It was noted when the one day (24h hour) test was done that all the samples were warm. This indicates that there was still a chemical reaction in progress.
9. Graphs 8.5 summarise the results.

<table>
<thead>
<tr>
<th>water content = 22%</th>
<th>age of prisms when tested</th>
<th>mean comp strength</th>
<th>stand dev</th>
<th>cv (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.71</td>
<td>0.38</td>
<td>10.34%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>8.81</td>
<td>0.42</td>
<td>4.77%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10.93</td>
<td>0.39</td>
<td>3.57%</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>14.28</td>
<td>0.21</td>
<td>1.47%</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>15.92</td>
<td>0.33</td>
<td>2.07%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>water content = 25%</th>
<th>age of prisms when tested</th>
<th>mean comp strength</th>
<th>stand dev</th>
<th>cv (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.27</td>
<td>0.40</td>
<td>1.55%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6.06</td>
<td>0.50</td>
<td>0.89%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8.07</td>
<td>0.31</td>
<td>3.84%</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>11.45</td>
<td>0.13</td>
<td>1.09%</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>12.72</td>
<td>0.29</td>
<td>2.28%</td>
<td></td>
</tr>
</tbody>
</table>

Graph 8.5(a) – compressive strength vs age at testing

<table>
<thead>
<tr>
<th>water content = 22%</th>
<th>age of prisms when tested</th>
<th>mean flex strength</th>
<th>stand dev</th>
<th>cv (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.21</td>
<td>0.11</td>
<td>9.09%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2.57</td>
<td>0.25</td>
<td>9.70%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.80</td>
<td>0.19</td>
<td>6.79%</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>3.18</td>
<td>0.13</td>
<td>4.09%</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>3.55</td>
<td>0.33</td>
<td>9.30%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>water content = 25%</th>
<th>age of prisms when tested</th>
<th>mean flex strength</th>
<th>stand dev</th>
<th>cv (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.82</td>
<td>0.30</td>
<td>36.59%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.88</td>
<td>0.50</td>
<td>26.60%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.30</td>
<td>0.31</td>
<td>13.48%</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2.86</td>
<td>0.19</td>
<td>6.64%</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>3.21</td>
<td>0.29</td>
<td>9.03%</td>
<td></td>
</tr>
</tbody>
</table>

Graph 8.5(b) – flexural strength vs age of testing
8.3.4 Mortar testing - Conclusions

1. At this stage of product development only the Omnicol mortars or those of similar composition will be considered for brickwork fabrication.

2. The proposed Omnicol manufacturers technical information / guidance relating to the recommended mortar / water content range is considered suitable for either traditional bricklaying processes using a trowel or for use with the pump and glue gun. In either case these mixes will produce a relatively stiff mortar which is necessary for vertically built brickwork in order to prevent mortar settlement when still wet and before the setting process occurs. The higher water content in the Omnicol mix is considered a preferable composition for use with flat bed prefabrication. There are a number of practical reasons for this :-

   a. The flat bed manufacturing process as is being developed by the author and described in chapter 7, incorporates bricks being positioned into a mould box in a particular pattern. The bricks are laid face down and are surrounded by a gap which is equivalent to the desired finished mortar joint.

   b. A stiff mortar mix of high viscosity (such as would be used with the pump and gun system or in traditional bricklaying) will not readily “flow” into the joints.

   c. The water content of the mix must therefore be increased to such a level that it will flow when “poured” not only into the brickwork joints but also into the frogs or perforations of the bricks. The mortar application must be such that there will be complete and continuous surface contact between brick and mortar.

8.4 Flexural strength and Wallette tests

Since the commencement of the Oxford Brookes PII project wallette testing programmes have been undertaken at a number of establishments specifically to investigate the behaviour of thin joint masonry constructed using clay bricks. Work has also been carried out on the performance of both aggregate blocks and aircrete blocks with thin joints although both of these products use different mortar adhesives, each block type having a different material.

Some work has been carried out in Belgium and Holland (Martens, 2000), (Vekemaans & Ruben, 2002), (van der Plume 1994, 1998) but using European sized bricks which are different in length, height and width to UK products. Additionally European glued joints have been thinner than what is considered acceptable by UK designers, who use joints that are typically no thinner than 6 - 7mm. It is also expected that perpends in UK masonry are fully mortared unlike the European construction where perpends are often left open. It
was against this background that Wallette testing was undertaken using UK sized bricks with thicker “thin joints” and the standard UK Wallette testing method as given in BS5628 Part 1 Appendix 3 and eventually its successor BS EN1052-2.

Walette testing has been carried out as part of the Oxford Brookes programme, at Kingston University and also at the Hanson Structures laboratory where the company were fortunate enough to have possession of heavy duty load testing equipment inherited from the London Brick Company which became part of Hanson in 1984.

The Wallette testing procedures were used in anticipation of the development of prefabricated masonry in both single leaf and cavity wall format. Wallette testing results provide information on flexural strength of bed joints of small walls or wallettes. There are many combinations of testing that may be carried out and as such the cost of such work can be astronomical.

8.4.1 Hanson Wallette testing programme.

The Hanson Structures Laboratory Service started to carry out wallette flexural testing of thin joint masonry in 2002 (Figure 8.3). Since that time testing has been undertaken as and when relevant for particular thin joint projects (such as those referred to in the case studies) or for any ongoing research.

The results of some of the testing are documented and discussed in this chapter.

A full standard Wallette test would involve the production of two sets of wallettes with a minimum of 6 samples for a set. One set is tested to obtain flexural strength parallel to the bed joints and the other is for flexural strength perpendicular to the bed joint.

The test is carried out to destruction and will record the failure load at which the wall panels either crack or collapse.

Based on the failure load a mean flexural strength and a characteristic strength can be calculated. Figure 8.4 below is taken from EC6 NAD (Table NA.6) and presents
characteristic flexural strengths which may be used for the design of laterally loaded wall panels.

Flexural strength values as used from the Code are based upon a specified mortar strength and the water absorption of a brick. Figure 8.4 is adequate for all standard UK masonry design. However where any variation occurs such as the use of a non standard mortar, non standard sized brick, or an adhesive mortar as used in the thin joint system, it is suggested that an independent Wallette testing programme be carried out so that the engineer may be satisfied with more accurate design information. This testing procedure is to be carried out in accordance with BS EN1052-2.

It should be noted that even where thin joint mortar has been documented in EC6, the joints are specified as being between 0.5mm and 3mm in thickness. Because of this in the UK it is generally necessary to consider testing. A note in the National Application document to BS EN 1996 states that “For thin layer mortars’ use the values given for M12 mortar.” Testing is likely to result in higher values.

**NA.2.8 Characteristic flexural strength of masonry** [see BS EN 1996-1-1, 3.6.3(3)]
The values of $f_{xk1}$ and $f_{xk2}$ to be used for general purpose mortars are given in Table NA.6. For thin layer mortars use the values given for M12 mortar. For lightweight mortars use the values given for M2 mortar.

![Extract from Table NA.6, BS EN 1996-1 Characteristic flexural strength of masonry $f_{xk1}$ and $f_{xk2}$](image)
The purpose of this work is to demonstrate by testing that under certain conditions, and by employing a testing regime, strengths can be achieved which are higher than those stated for an M12 mortar.

**8.4.2 Flexural strength testing**

Flexural strength tests have been carried out on a number of clay facing bricks relating to the thin joint adhesive test programme both for this research and previously for work relating to testing in the PII project and at Kingston University. The following gives an appraisal of tests on one specific clay brick type where investigation was made on a number of parameters as outlined below.

1. Characteristic flexural strength was determined both parallel and perpendicular to the bed joints using thin joint adhesive
2. Masonry panels were built using mainly Omnicol high performance adhesive although some were made with 1 :3 opc / sand as a comparison.
3. The brick bond configuration was stretcher bond and stack bond. In both formats Wallettes were tested parallel and perpendicular to the bed joint.
4. Panels were made with bed joint reinforcement in both stack and stretcher bond and tested for flexural strength parallel and perpendicular to the bed joints.

The brick type used was the Hanson Arden Special reserve. It is made from Keuper Marl clay and is a product used regularly in large housing developments and for some architectural specification work. It is manufactured at the Hanson Desford factory in Leicestershire. (Figure 8.5)

Typical brick properties are as follows:-

- Extruded wirecut clay facing manufactured at Desford Brickworks.
- Compressive strength = 40N/mm$^2$
- Typical water absorption = 14% (i.e. >12% category)
- Dry weight = 2kg
- Durability rating = F2
- Active soluble salts = S2
- Format = 3 perforations (18% - 23%)

![Figure 8.5 Hanson Arden Special Reserve facing brick used in testing. (Hanson 2009)](image-url)
The product type was also used for the construction of the Hanson EcoHouse™ at the BRE.

In each test a sample of six wallettes were manufactured. These were all built by the same bricklayer and at the same laboratory workshop ie the the Hanson Stewartby Laboratory. In all cases the temperature at which panels were manufactured, cured and tested was kept relatively constant at 15°C.

The main objectives of the test programme were:-
1. To compare the flexural strength of masonry built with traditional mortars with high performance thin joint adhesives such as Omnicol.
2. Comparison was made between strengths achieved with both stretcher bonds and stack bonded brickwork.
3. Panels were made using both plain and reinforced brickwork, the latter incorporating bed joint reinforcement.
4. In each test case flexural strength was determined at 3, 7, 14 and 28 days in order to investigate the rate of strength gain.
5. Most of the panels built in the Omnicol mortar were constructed using the polyjet glue gun which formed 2 mortar beads of approximately 20mm diameter. Additionally some panels were made using Omnicol which was laid by trowel in a traditional bricklaying method. This was done to compare the final strengths due to both systems.
6. All panels were built with joints of 7mm. This is thicker than the thin joint recommendation which suggests no greater than 3mm but was deemed to be necessary for thin joint construction in the UK.
7. All panels made with Omnicol mortar had a consistent water content of 19%. Subsequently trial panels were made using Omnicol mortar with a higher water content as this is necessary for the flat bed panel fabrication process developed and documented in this thesis. The results of this technique are discussed later in this chapter.

8.4.3 Results of the Wallette flexural strength tests
Tables 8.4 and 8.5 along with graphs 8.6 and 8.7 show the results of flexural strengths at ultimate failure load for the various wallettes which were tested at the Hanson Laboratory Testing Services facility. Comparative results were made for testing both parallel and perpendicular to the Wallette bed joints. Wallettes were built in both stretcher and stack bonded brickwork. Wallettes were either plain (unreinforced) or were reinforced with bed joint reinforcement. The bed joint reinforcement was a BK60 stainless steel of 4mm diameter flattened bars.
### Table 8.4 (a) Plain masonry wallets – load parallel to bed joints

<table>
<thead>
<tr>
<th>Mortar type and laying configuration</th>
<th>Brick bond</th>
<th>Reinforced / unreinforced</th>
<th>Time of test (3, 7, 14, 28 days)</th>
<th>Load direction</th>
<th>Ultimate failure load (N)</th>
<th>Standard dev</th>
<th>Coeff of var</th>
<th>log10f_x</th>
<th>Mean flexural strength (N/mm²)</th>
<th>Characteristic flexural strength f_xk1 (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omnicol 2 bead stretcher bond par</td>
<td>no reinforcement</td>
<td>3 parallel</td>
<td>5559</td>
<td>0.195</td>
<td>62.90%</td>
<td>-0.03253</td>
<td>0.31</td>
<td>0.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omnicol 2 bead stretcher</td>
<td>no reinforcement</td>
<td>7 parallel</td>
<td>7734</td>
<td>0.223</td>
<td>20.82%</td>
<td>-0.14487</td>
<td>0.73</td>
<td>0.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omnicol 2 bead stretcher</td>
<td>no reinforcement</td>
<td>14 parallel</td>
<td>8342</td>
<td>0.152</td>
<td>33.64%</td>
<td>-0.09768</td>
<td>0.66</td>
<td>0.33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 8.4 (b) Plain masonry wallets – load perpendicular to bed joints

<table>
<thead>
<tr>
<th>Mortar type and laying configuration</th>
<th>Brick bond</th>
<th>Reinforced / unreinforced</th>
<th>Time of test (3, 7, 14, 28 days)</th>
<th>Load direction</th>
<th>Ultimate failure load (N)</th>
<th>Standard dev</th>
<th>Coeff of var</th>
<th>log10f_x</th>
<th>Mean flexural strength (N/mm²)</th>
<th>Characteristic flexural strength f_xk2 (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omnicol 2 bead stack bond perp</td>
<td>no reinforcement</td>
<td>3 perpendicular</td>
<td>5716</td>
<td>0.16</td>
<td>26.23%</td>
<td>-0.22985</td>
<td>0.61</td>
<td>0.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omnicol 2 bead stack</td>
<td>no reinforcement</td>
<td>7 perpendicular</td>
<td>5899</td>
<td>0.182</td>
<td>18.20%</td>
<td>-0.00687</td>
<td>1.00</td>
<td>0.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omnicol 2 bead stack</td>
<td>no reinforcement</td>
<td>14 perpendicular</td>
<td>6842</td>
<td>0.152</td>
<td>20.82%</td>
<td>-0.14487</td>
<td>0.73</td>
<td>0.48</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Graph 8.6 Mean wallette flexural strength – unreinforced brickwork
### Table 8.5(a) Wallettes with bed joint reinforcement – load parallel to bed joints

<table>
<thead>
<tr>
<th>mortar type and laying configuration</th>
<th>brick bond</th>
<th>reinforced / unreinforced</th>
<th>time of test (7, 14, 28 days)</th>
<th>load direction (par / perp to bed joints)</th>
<th>ultimate failure load(N)</th>
<th>standard dev</th>
<th>coeff of var</th>
<th>$\log_{10}$</th>
<th>Mean flexural strength N/mm²</th>
<th>Characteristic flexural strength $f_{ck}$ N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omnicol 2 bead</td>
<td>stretcher bond par</td>
<td>1 layer reinf mid joint</td>
<td>14</td>
<td>parallel</td>
<td>7965</td>
<td>0.198</td>
<td>25.06%</td>
<td>-0.11914</td>
<td>0.79</td>
<td>0.43</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stretcher</td>
<td>1 layer reinf mid joint</td>
<td>28</td>
<td>parallel</td>
<td>7271</td>
<td>0.119</td>
<td>19.19%</td>
<td>-0.21335</td>
<td>0.62</td>
<td>0.41</td>
</tr>
<tr>
<td>Omnicol full bed</td>
<td>stretcher bond par</td>
<td>3 layer reinf</td>
<td>28</td>
<td>parallel</td>
<td>10090</td>
<td>0.311</td>
<td>36.59%</td>
<td>-0.10567</td>
<td>0.85</td>
<td>0.26</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack bond par</td>
<td>1 layer reinf mid joint</td>
<td>3</td>
<td>parallel</td>
<td>4963</td>
<td>0.116</td>
<td>27.62%</td>
<td>-0.38486</td>
<td>0.42</td>
<td>0.23</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack</td>
<td>1 layer reinf mid joint</td>
<td>7</td>
<td>parallel</td>
<td>4720</td>
<td>0.018</td>
<td>4.50%</td>
<td>-0.38776</td>
<td>0.4</td>
<td>0.37</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack</td>
<td>1 layer reinf mid joint</td>
<td>14</td>
<td>parallel</td>
<td>7732</td>
<td>0.141</td>
<td>21.36%</td>
<td>-0.18845</td>
<td>0.66</td>
<td>0.4</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack</td>
<td>1 layer reinf mid joint</td>
<td>28</td>
<td>parallel</td>
<td>7238</td>
<td>0.110</td>
<td>17.74%</td>
<td>-0.21495</td>
<td>0.62</td>
<td>0.41</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack bond par</td>
<td>3 layer reinf</td>
<td>3</td>
<td>parallel</td>
<td>6449</td>
<td>0.114</td>
<td>20.36%</td>
<td>-0.36133</td>
<td>0.56</td>
<td>0.35</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack</td>
<td>5 layer reinf</td>
<td>7</td>
<td>parallel</td>
<td>6626</td>
<td>0.096</td>
<td>16.35%</td>
<td>-0.23919</td>
<td>0.58</td>
<td>0.4</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack</td>
<td>5 layer reinf</td>
<td>14</td>
<td>parallel</td>
<td>8988</td>
<td>0.130</td>
<td>17.14%</td>
<td>-0.19844</td>
<td>0.77</td>
<td>0.51</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack</td>
<td>5 layer reinf</td>
<td>28 days</td>
<td>parallel</td>
<td>10078</td>
<td>0.192</td>
<td>22.33%</td>
<td>-0.07504</td>
<td>0.86</td>
<td>0.47</td>
</tr>
</tbody>
</table>

### Table 8.5(b) Wallettes with bed joint reinforcement – load perpendicular to bed joints

<table>
<thead>
<tr>
<th>mortar type and laying configuration</th>
<th>brick bond</th>
<th>reinforced / unreinforced</th>
<th>time of test (7, 14, 28 days)</th>
<th>load direction (par / perp to bed joints)</th>
<th>ultimate failure load(N)</th>
<th>standard dev</th>
<th>coeff of var</th>
<th>$\log_{10}$</th>
<th>Mean flexural strength N/mm²</th>
<th>Characteristic flexural strength $f_{ck}$ N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omnicol 2 bead</td>
<td>stretcher bond perp</td>
<td>1 layer reinf mid joint</td>
<td>3</td>
<td>perpendicular</td>
<td>7429</td>
<td>0.310</td>
<td>24.60%</td>
<td>-0.0891</td>
<td>1.26</td>
<td>0.32</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stretcher</td>
<td>1 layer reinf mid joint</td>
<td>7</td>
<td>perpendicular</td>
<td>6566</td>
<td>0.212</td>
<td>19.10%</td>
<td>-0.03971</td>
<td>1.11</td>
<td>0.73</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stretcher</td>
<td>1 layer reinf mid joint</td>
<td>14</td>
<td>perpendicular</td>
<td>7294</td>
<td>0.205</td>
<td>16.94%</td>
<td>-0.07632</td>
<td>1.21</td>
<td>0.82</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stretcher</td>
<td>1 layer reinf mid joint</td>
<td>28</td>
<td>perpendicular</td>
<td>8222</td>
<td>0.273</td>
<td>20.00%</td>
<td>-0.12444</td>
<td>1.35</td>
<td>0.87</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stretcher bond perp</td>
<td>2 layer reinf</td>
<td>3</td>
<td>perpendicular</td>
<td>7982</td>
<td>0.150</td>
<td>9.85%</td>
<td>-0.1269</td>
<td>1.34</td>
<td>1.08</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stretcher</td>
<td>2 layer reinf</td>
<td>7</td>
<td>perpendicular</td>
<td>7483</td>
<td>0.127</td>
<td>9.60%</td>
<td>-0.09833</td>
<td>1.26</td>
<td>1.01</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stretcher</td>
<td>2 layer reinf</td>
<td>14</td>
<td>perpendicular</td>
<td>8591</td>
<td>0.331</td>
<td>22.21%</td>
<td>-0.16469</td>
<td>1.49</td>
<td>0.88</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stretcher</td>
<td>2 layer reinf</td>
<td>28</td>
<td>perpendicular</td>
<td>11210</td>
<td>0.301</td>
<td>16.18%</td>
<td>-0.2641</td>
<td>1.86</td>
<td>1.3</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack bond perp</td>
<td>1 layer reinf</td>
<td>3</td>
<td>perpendicular</td>
<td>3267</td>
<td>0.019</td>
<td>3.45%</td>
<td>-0.20723</td>
<td>0.55</td>
<td>0.31</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack</td>
<td>1 layer reinf mid joint</td>
<td>7</td>
<td>perpendicular</td>
<td>4052</td>
<td>0.116</td>
<td>17.06%</td>
<td>-0.01723</td>
<td>0.68</td>
<td>0.46</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack</td>
<td>1 layer reinf mid joint</td>
<td>14</td>
<td>perpendicular</td>
<td>5943</td>
<td>0.096</td>
<td>15.48%</td>
<td>-0.21520</td>
<td>0.62</td>
<td>0.42</td>
</tr>
<tr>
<td>Omnicol 2 bead</td>
<td>stack</td>
<td>1 layer reinf mid joint</td>
<td>28</td>
<td>perpendicular</td>
<td>4633</td>
<td>0.089</td>
<td>11.39%</td>
<td>-0.10929</td>
<td>0.79</td>
<td>0.62</td>
</tr>
</tbody>
</table>

### Graph 8.7 Mean wallette flexural strength with bed joint reinforcement

The graph illustrates the mean wallette flexural strength at failure load (N/mm²) for different laying configurations and reinforcement types. The x-axis represents the time of test (3, 7, 14, 28 days), and the y-axis shows the wallette flexural strength (N/mm²). The legend highlights various joining and reinforcing strategies, such as stretcher bond perp, stack bond perp, and 2-layer reinforcement.
8.4.4 Conclusion and observations on flexural strength wallette testing

Results are presented for from 3 to 28 day flexural strength tests both for stretcher bond and stack bonded masonry being loaded both perpendicular and parallel to the bed joints.

Wallettes were built with both plain masonry and masonry incorporating bed joint reinforcement.

Unreinforced masonry

1. Graph 8.6 shows predictable results i.e. in each case the strength increases with time from 3 to 28 days.
2. The stack bonded masonry has the lowest set of strength values when tested perpendicular to the bed joints
3. Both the stack bond and stretcher bond panels with failure parallel to the bed joints display similar results for all test periods except at 3 days when the stack panels have a flexural strength value at failure = 0.57 as opposed to 0.31N/mm$^2$ for stretcher bond. This general result was also the case in previous testing (Hanson Laboratory 2004) although at 3 days the stack and stretcher results did not differ by such a margin.
4. Stretcher bond panels with failure perpendicular to the bed joints presented the highest value results.
5. The ratio of stretcher bond results parallel / perpendicular (ie the orthogonal ratio) increases for 3 to 28 day results from 0.32 to 0.74 respectively. A typical orthogonal ratio for 28 day strength masonry as presented in EC6 would be approximately 0.35 – 0.4.
6. The ratio of stack bond results parallel / perpendicular (ie the orthogonal ratio) increases for 7 to 28 day results from 0.97 - 1.84 respectively. However the 3 day result is not in keeping with this increasing sequence and is 2.18. (Table 8.6 shows the orthogonal ratios for each set.)

Orthogonal ratio =

- flexural strength of loaded parallel to bed joints (weak direction)
- flexural strength of brickwork loaded perpendicular to bed joints (strong direction)

Based on Code information from Table N.A.6 the orthogonal ratio for wallettes built of clay bricks (water absorption >12%) and a mortar designation M12 is :-

$$\mu = \frac{0.4}{1.1} = 0.36.$$
This is a typical ratio for clay bricks with standard OPC mortars. It should be noted from the results that the orthogonal ratio for the unreinforced stretcher bond brickwork wallette samples is quite diverse ranging from 0.32 – 0.74 increasing with curing time. For stack bonded wallettes, with the exception of the 3 day result (2.18) the orthogonal ratios are higher which indicates similar flexural strengths both parallel and perpendicular to the bed joints.

7. Strength of stack bonded panels perpendicular to bed joints present lower strengths than stack bonded panels parallel to bed joints. This would be expected due to the straight joints in each direction and also the lack of self-weight to enhance strength when tested perpendicular to bed joints. (Table 8.6)

Table 8.6

<table>
<thead>
<tr>
<th>Orthogonal ratio $= \frac{f_{xk \ strong}}{f_{xk \ weak}}$</th>
<th>load configuration</th>
<th>age at testing</th>
<th>$f_{xk \ strong}$</th>
<th>$f_{xk \ weak}$</th>
<th>orthogonal ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>no reinforcement</td>
<td>stretcher bond perp</td>
<td>3</td>
<td>0.6</td>
<td>0.19</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>stretcher</td>
<td>7</td>
<td>0.68</td>
<td>0.33</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>stretcher</td>
<td>14</td>
<td>0.96</td>
<td>0.48</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>stretcher</td>
<td>28</td>
<td>1.16</td>
<td>0.86</td>
<td>0.74</td>
</tr>
<tr>
<td>no reinforcement</td>
<td>stack bond perp</td>
<td>3</td>
<td>0.17</td>
<td>0.37</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td>stack</td>
<td>7</td>
<td>0.33</td>
<td>0.32</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>stack</td>
<td>14</td>
<td>0.39</td>
<td>0.48</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>stack</td>
<td>28</td>
<td>0.38</td>
<td>0.70</td>
<td>1.84</td>
</tr>
</tbody>
</table>

Flexural strength tests were carried out in the Hanson Structures Laboratory. A summary of the results is shown in Table 8.7 although no record exists of the sample results, mean and coefficient of variation. However personal experience of the writer would confirm that these are typical for the brick / mortar combination with stretcher bond format with a 1 ; 1 ; 6 OPC mortar.

Table 8.7 Flexural strength tests using conventional mortar

<table>
<thead>
<tr>
<th>Brick type – Hanson Arden Special Reserve laid in stretcher bond format.</th>
<th>Loading mode</th>
<th>Mean flex strength $N/mm^2$</th>
<th>Characteristic flex strength $N/mm^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parallel to joints</td>
<td>0.38</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Perpendicular to joints</td>
<td>1.17</td>
<td>0.87</td>
</tr>
</tbody>
</table>

The flexural strengths both parallel and perpendicular to the bed joints are considerably higher for high performance mortars than for conventional mortar highlighted in Table 8.7.
Reinforced masonry

1. For stretcher bond wallettes tested perpendicular to the bed joints, as expected the flexural strength increases with the number of reinforcement layers.
2. Wallettes tested perpendicular to the bed joints presented consistently higher results than for those tested parallel to the bed joints. This was true for all ages of testing although 3 day tests were higher than 7 day tests in the case of both 1 and 2 layers of reinforcement.
3. Stack bonded brickwork, tested perpendicular to bed joints and with 1 layer of reinforcement gave a result of 0.8 N/mm² at 28 days compared with a stretcher bond wallette with 1 layer reinforcement tested at 28 days = 1.3N/mm².
4. An increase in the number of layers of bed joint reinforcement will increase the flexural strength of the wallettes when tested perpendicular to the bed joints.
5. For wallettes tested parallel to the bed joints there was an increase in flexural strength corresponding to an increase in the number of layers of bed joint reinforcement.
6. The orthogonal ratio values for reinforced stack bonded masonry tested at 28 days = 0.785.
7. The orthogonal ratio values for reinforced stretcher bonded masonry tested at 28 days = 0.45.

8.5 Simplified stack / pier test – piers made by bricklayer / trowel technique

With design information in the Code limited such that flexural strength of thin joint masonry cannot be designed where the joints are in excess of 3mm it became necessary to establish an efficient and economical process to determine the required design parameters rather than using Wallette tests every time an alternative brick type is specified for a project. Wallette testing presents additional cost which ultimately is being borne by the client. An alternative economical and reliable procedure will be required.

One alternative is to consider a simplified flexural strength test and to check correlation between results from this test when compared with the results from Wallette tests.

8.5.1 Background to development of stack beams.

Independent flexural tensile load testing to BS EN compliance is costly. Each test requires the construction of a minimum of 6 wallettes for testing in each direction ie perpendicular to and parallel to the bed joints. These panels must be built in the desired brick and mortar combination which is time consuming and expensive in labour costs.
An independently commissioned flexural strength test including the fabrication of panels followed by load testing to destruction and a formal report will cost in the region of £6000.00. Even if this work is carried out by a large manufacturing company such as Hanson who has UKAS approved facilities, the cost for labour is high and the process lengthy.

If a prefabricated manufacturing facility is to be developed with a high volume output it is necessary to develop a structural testing process which is quick, simple, cost effective and most importantly demonstrates the structural properties of prefabricated masonry panels in a format that can be compared with full scale wallette panels. This will need to form part of a quality assured scheme particularly if the system is not underpinned by a BBA certification scheme but rather is one which complies with the relevant BS / Euro codes and standards.

Testing procedures must reflect the brick and mortar combinations of the fabricated panel in terms of material properties and joint thicknesses. It has already been concluded (chapter 5) that a system which embraces standard UK mortar joints ie 10mm thick, will be necessary even with a high performance mortar that has been developed for “thin joint” work. This is to ensure that setting out procedures allow for use of standard sized components such as doors and windows. However there may be circumstances where a thin joint will be desirable architecturally or for aesthetic reasons and in this case again appropriate testing will be required.

Testing must be based on the design guidance which is given in EC6, (or the UK NAD) based on standard test data, or a structural flexural testing programme based on EN1052 part 2.

Fried, Anderson and Gairns (1996) show a comparative study of experimental and testing techniques for determining the flexural strength of masonry. This indicates the correlation between Wallette panel strengths and stack piers. This form of test is easy and economical to carry out and the building of the stack piers is a relatively straightforward operation. Of particular importance is the need to ensure consistency and to establish some correlation between stack pier flexural strengths and those from wallets tested in the recognised format.
8.5.2 Building of brick stacks piers

One of the key areas of potential performance variation is that of workmanship and consistency of construction when building the piers by traditional trowel methods. Important parameters and details to consider include:

- All samples should be built by the same bricklayer
- All piers were constructed vertically with bricks laid frog up
- No additional precompression load was applied to the samples. Only the brick and mortar self weight of the stack added any precompression.
- Brick frogs were fully filled
- All samples were built in the same location, at the same consistent air temperature in the laboratory and at the same part of the day with the same start /end time for each of the build sessions.
- In order to ensure as consistent a mix as possible, sufficient mortar was batched to make a minimum of 2 stack piers after which a new mix was used. In this way there was only a minimal time for the mortar properties to alter during the build process.
- All materials ie mortar, cement, sand and water were accurately measured to ensure the highest level of consistency.
- Brick stacks comprised 12 bricks laid with 7mm mortar joints – when completed these were left to cure standing vertically.

The first part of the test programme focused on the use of one brick type; the Hanson Measham Eco Stock brick built with 4 different mortar types

The brick properties were as follows:-

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>215 mm</td>
</tr>
<tr>
<td>Height</td>
<td>65 mm</td>
</tr>
<tr>
<td>Depth</td>
<td>102.5 mm</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>20 N/mm²</td>
</tr>
<tr>
<td>λ Layer</td>
<td>0.77</td>
</tr>
<tr>
<td>Configuration: Frogged</td>
<td></td>
</tr>
<tr>
<td>Dimensional Tolerance Mean:</td>
<td>T2</td>
</tr>
<tr>
<td>Dimensional Tolerance Range:</td>
<td>R1</td>
</tr>
<tr>
<td>Dry Weight</td>
<td>2.25 kg</td>
</tr>
<tr>
<td>Durability Rating</td>
<td>F2</td>
</tr>
<tr>
<td>Soluble Salts</td>
<td>S2</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>13 %</td>
</tr>
<tr>
<td>Manufacture Type</td>
<td>Stock</td>
</tr>
<tr>
<td>Textures</td>
<td>Stock Pressed</td>
</tr>
<tr>
<td>Factory</td>
<td>Measham</td>
</tr>
</tbody>
</table>

The mortar mixes were

- Omnicol type C thin joint mortar
- CPI high strength mortar
- M12 - 1 : 3 cement : sand mortar
- M4 – 1 : 6 cement : sand mortar
During the first session two sets of 10 samples were built:

Session 1 – 22 July 11
- Sample 1 – mortar Omnicol type B, water content = 19%
- Sample 2 – mortar CPI proprietary mix water content = 9%

An identical procedure was adopted for the second sample building session but using two OPC mortars:

Session 2 – 10 August 11
- Sample 3 – Mortar des M12 1:3 OPC : sand
- Sample 4 – Mortar des M4 1:6 OPC : sand

For each sample a construction start and finish time were recorded in order to determine mortar workability, ease of construction and speed of construction. All panels were air cured in the same factory location for a period of 7 days at which point they were tested to destruction.

8.5.3 Preparation of the pier beam for testing.
Supports comprised two circular solid steel tubes which were placed onto a heavy rubber base to prevent rolling.

The distance between centres of the rollers ie point of contact with the beam was measured – this was based on positioning at half a brick width ie approximately 65/2mm from each end.
The sample was placed low enough to the floor so as to minimize any collapse risk of the applied load which comprised bricks and kiln blocks, sometimes this load amounted to over 300kg. At the point of failure the beam and its load only moved some 30mm. Support mats were placed at either side of the kiln blocks for additional safety. Each sample was lifted vertically from its curing position on to a set of scales to establish its self weight.

Locating a beam for testing involved a two man lift (total load approx 34kg) rotating it from the vertical to the horizontal position. Care was taken to minimize causing any unnecessary loading to the sample by ensuring it was supported throughout its length.

8.5.4 Loading of pier beams.

<table>
<thead>
<tr>
<th>type of load</th>
<th>brick ref</th>
<th>brick single unit weight kg</th>
<th>cumulative weight kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>kiln blocks</td>
<td>1</td>
<td>30.45</td>
<td>30.45</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>33.35</td>
<td>63.80</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>33.10</td>
<td>96.90</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>35.50</td>
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<td>5</td>
<td>33.00</td>
<td>165.40</td>
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<td>6</td>
<td>33.00</td>
<td>198.40</td>
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<td>bricks</td>
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<td>2.433</td>
<td>2.433</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.406</td>
<td>4.849</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.382</td>
<td>7.231</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>2.435</td>
<td>9.666</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>2.401</td>
<td>12.067</td>
</tr>
<tr>
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<td>6</td>
<td>2.392</td>
<td>14.459</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2.421</td>
<td>16.881</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2.430</td>
<td>19.310</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>2.396</td>
<td>21.706</td>
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<tr>
<td></td>
<td>10</td>
<td>2.435</td>
<td>24.141</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>2.391</td>
<td>26.532</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>2.416</td>
<td>28.948</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>2.434</td>
<td>31.382</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>2.430</td>
<td>33.812</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>2.397</td>
<td>36.209</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>2.390</td>
<td>38.599</td>
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<tr>
<td></td>
<td>17</td>
<td>2.411</td>
<td>41.010</td>
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<td></td>
<td>18</td>
<td>2.418</td>
<td>43.428</td>
</tr>
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<td>19</td>
<td>2.406</td>
<td>45.834</td>
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<tr>
<td></td>
<td>20</td>
<td>2.424</td>
<td>48.258</td>
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<tr>
<td></td>
<td>21</td>
<td>2.391</td>
<td>50.649</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>2.395</td>
<td>53.044</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>2.384</td>
<td>55.388</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>2.463</td>
<td>57.861</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>2.397</td>
<td>60.258</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>2.418</td>
<td>62.676</td>
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<tr>
<td></td>
<td>27</td>
<td>2.425</td>
<td>65.101</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>2.440</td>
<td>67.541</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>2.422</td>
<td>69.963</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>2.414</td>
<td>72.377</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>2.440</td>
<td>74.817</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>2.411</td>
<td>77.228</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>2.388</td>
<td>79.616</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>2.406</td>
<td>82.022</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>2.389</td>
<td>84.411</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>2.396</td>
<td>86.807</td>
</tr>
</tbody>
</table>

Table 8.8 Loads applied to brick stack beams

4 sacrificial piers were made in addition to sets of 10. This was in order to try and establish the magnitude of load which would be required in order to attain an approximate pier failure. A simple bending stress calculation suggested that the piers might fail at an applied load of 175kg based on a masonry flexural strength of 0.5N/mm²

Two load types were prepared. The first was a double ribbed profile kiln block which conveniently had downstand supports spaced at 250mm centre to centre. This block weighed 33kg. A further 5 kiln blocks were available each being approximately 30kg.

Thereafter bricks were individually numbered and weighed – these were then applied to the load area one at a time such that a load rate of approximately 2kg per 10 seconds was added. Load at failure was then recorded. Accuracy would of course only be to the nearest 2kg (Table 8.8)
8.5.5 Pier construction times.

During the course of pier construction the pier build times were recorded in order to compare ease of construction and efficiency of workmanship for the different mortar types. Start and finish times were recorded and consequently total build times for each sample and an average for the set obtained. The results are shown in table 8.9 and graph 8.8. This study did not include strength properties.

Table 8.9 Build times for stack beams.

<table>
<thead>
<tr>
<th>Mortar type - Omnicol type C mix</th>
<th>Water content = 17.60%</th>
<th>Start</th>
<th>Finish</th>
<th>Build times (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omni 1.1</td>
<td>7.28</td>
<td>7.42</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Omni 1.2</td>
<td>7.45</td>
<td>7.57</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Omni 2.1</td>
<td>7.59</td>
<td>8.11</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Omni 2.2</td>
<td>8.12</td>
<td>8.26</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Omni 3.1</td>
<td>8.27</td>
<td>8.46</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Omni 3.2</td>
<td>8.43</td>
<td>8.59</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Omni 4.1</td>
<td>8.56</td>
<td>8.99</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Omni 4.2</td>
<td>9.11</td>
<td>9.22</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Omni 5.1</td>
<td>9.24</td>
<td>9.37</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Omni 5.2</td>
<td>9.38</td>
<td>9.49</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Average stack build time</td>
<td></td>
<td></td>
<td>12.1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mortar type - CPI mix</th>
<th>Water content = 17.60%</th>
<th>Start</th>
<th>Finish</th>
<th>Build times (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPI 1.1</td>
<td>10.29</td>
<td>10.38</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>CPI 1.2</td>
<td>10.40</td>
<td>10.49</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>CPI 2.1</td>
<td>10.50</td>
<td>11.01</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>CPI 2.2</td>
<td>11.03</td>
<td>11.17</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>CPI 3.1</td>
<td>11.14</td>
<td>11.24</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>CPI 3.2</td>
<td>11.27</td>
<td>11.36</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>CPI 4.1</td>
<td>11.36</td>
<td>11.46</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>CPI 4.2</td>
<td>11.48</td>
<td>11.57</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>CPI 5.1</td>
<td>12.00</td>
<td>12.09</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>CPI 5.2</td>
<td>12.11</td>
<td>12.21</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Average stack build time</td>
<td></td>
<td></td>
<td>9.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 8.9 Build times for stack beams.

<table>
<thead>
<tr>
<th>Mortar type - standard OPC cement : sand mix - M12</th>
<th>Build times (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M12 1.1</td>
<td>7.26</td>
</tr>
<tr>
<td>M12 1.2</td>
<td>7.37</td>
</tr>
<tr>
<td>M12 2.1</td>
<td>7.56</td>
</tr>
<tr>
<td>M12 2.2</td>
<td>8.04</td>
</tr>
<tr>
<td>M12 3.1</td>
<td>8.22</td>
</tr>
<tr>
<td>M12 3.2</td>
<td>8.31</td>
</tr>
<tr>
<td>M1 2.4.1</td>
<td>8.39</td>
</tr>
<tr>
<td>M1 2.4.2</td>
<td>8.47</td>
</tr>
<tr>
<td>M1 2.5.1</td>
<td>8.56</td>
</tr>
<tr>
<td>M1 2.5.2</td>
<td>9.04</td>
</tr>
<tr>
<td>Average stack build time</td>
<td>7.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mortar type - standard OPC cement : sand mix - M14</th>
<th>Build times (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M4 1.1</td>
<td>9.52</td>
</tr>
<tr>
<td>M4 1.2</td>
<td>9.59</td>
</tr>
<tr>
<td>M4 2.1</td>
<td>10.07</td>
</tr>
<tr>
<td>M4 2.2</td>
<td>10.14</td>
</tr>
<tr>
<td>M4 3.1</td>
<td>10.33</td>
</tr>
<tr>
<td>M4 3.2</td>
<td>10.39</td>
</tr>
<tr>
<td>M3 4.1</td>
<td>10.46</td>
</tr>
<tr>
<td>M3 4.2</td>
<td>10.49</td>
</tr>
<tr>
<td>M3 5.1</td>
<td>10.58</td>
</tr>
<tr>
<td>M3 5.2</td>
<td>11.08</td>
</tr>
<tr>
<td>Average stack build time</td>
<td>7.7</td>
</tr>
</tbody>
</table>
The same exercise was then repeated for stacks but using 3 brick types and one mortar, namely the Omnicol Type C mix. Testing was undertaken at 3 days. (Table 8.10)

Table 8.10 Stacks of 3 brick types and one mortar, Omnicol C

| COMPARISON OF STACK BUILDABILITY AND BUILD TIMES USING OMNICOL TYPE C MORTAR |
|-------------------------------|--------------------------|---------------------|
| **BRICKS**                     | **Water absorption category** | **Water in mix :-** |
| Hanson Desford Buff Multi     | >12%                      | 2.2l water per 12.5kg mortar = 3 sample stacks = 17.60% |
| Hanson Desford Arden Special Reserve | >7 < 12%               | Water content = 17.6% |
| Hanson Wilnecote Red Facing   | 7%                        |                     |

**Test programme - 15th June 2012**

<table>
<thead>
<tr>
<th>Sample ref</th>
<th><strong>start</strong></th>
<th><strong>finish</strong></th>
<th><strong>minutes</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Omni C 1 - 1.1</td>
<td>8.38</td>
<td>8.48</td>
<td>10</td>
</tr>
<tr>
<td>Omni C 1 - 1.2</td>
<td>8.49</td>
<td>8.58</td>
<td>9</td>
</tr>
<tr>
<td>Omni C 1 - 1.3</td>
<td>8.59</td>
<td>9.09</td>
<td>10</td>
</tr>
<tr>
<td>Omni C 1 - 1.4</td>
<td>9.33</td>
<td>9.44</td>
<td>11</td>
</tr>
<tr>
<td>Omni C 1 - 1.5</td>
<td>9.45</td>
<td>9.55</td>
<td>10</td>
</tr>
</tbody>
</table>

Average stack build time: 10.1

<table>
<thead>
<tr>
<th>Sample ref</th>
<th><strong>start</strong></th>
<th><strong>finish</strong></th>
<th><strong>minutes</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Omni C 2 - 1.1</td>
<td>10.15</td>
<td>10.24</td>
<td>9</td>
</tr>
<tr>
<td>Omni C 2 - 1.2</td>
<td>10.25</td>
<td>10.35</td>
<td>10</td>
</tr>
<tr>
<td>Omni C 2 - 1.3</td>
<td>10.36</td>
<td>10.45</td>
<td>9</td>
</tr>
<tr>
<td>Omni C 2 - 2.1</td>
<td>10.46</td>
<td>10.54</td>
<td>8</td>
</tr>
<tr>
<td>Omni C 2 - 2.2</td>
<td>10.55</td>
<td>11.04</td>
<td>9</td>
</tr>
<tr>
<td>Omni C 2 - 2.3</td>
<td>11.05</td>
<td>11.14</td>
<td>9</td>
</tr>
<tr>
<td>Omni C 2 - 2.4</td>
<td>11.15</td>
<td>11.24</td>
<td>9</td>
</tr>
</tbody>
</table>

Average stack build time: 9.0

<table>
<thead>
<tr>
<th>Sample ref</th>
<th><strong>start</strong></th>
<th><strong>finish</strong></th>
<th><strong>minutes</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Omni C 3 - 1.1</td>
<td>11.33</td>
<td>11.42</td>
<td>9</td>
</tr>
<tr>
<td>Omni C 3 - 1.2</td>
<td>11.43</td>
<td>11.51</td>
<td>8</td>
</tr>
<tr>
<td>Omni C 3 - 1.3</td>
<td>11.52</td>
<td>12.03</td>
<td>11</td>
</tr>
<tr>
<td>Omni C 3 - 2.1</td>
<td>12.04</td>
<td>12.13</td>
<td>9</td>
</tr>
<tr>
<td>Omni C 3 - 2.2</td>
<td>12.14</td>
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<td>9</td>
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<tr>
<td>Omni C 3 - 2.3</td>
<td>12.24</td>
<td>12.34</td>
<td>10</td>
</tr>
<tr>
<td>Omni C 3 - 3.1</td>
<td>12.35</td>
<td>12.45</td>
<td>10</td>
</tr>
</tbody>
</table>

Average stack build time: 9.4
Again the previous exercise was repeated for 3 bricks and one mortar type but tested at 7, not 3 days as shown in Table 8.11. A comparison of the findings is given in Graph 8.9.

Table 8.11 Stack build times -

<table>
<thead>
<tr>
<th>Test programme - 22nd June 2012</th>
<th>built to be tested after 7 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>all samples are 12 brick stacks with 7mm joints</td>
<td>Omnicol type C</td>
</tr>
<tr>
<td>Mortar is placed on edges four edges/sides</td>
<td>build times</td>
</tr>
<tr>
<td>3 brick types all perforated</td>
<td>sample ref</td>
</tr>
<tr>
<td>5 bags used</td>
<td>some sifting required</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick type - Hanson Wilnecote Red Facing</td>
<td>Omni C 3 - 2.4</td>
</tr>
<tr>
<td>Water absorption category = 7%</td>
<td>Omni C 3 - 2.5</td>
</tr>
<tr>
<td>Water in mix :-</td>
<td>Omni C 3 - 3.1</td>
</tr>
<tr>
<td>2.3l water per 12.5kg mortar = 3 stacks</td>
<td>Average stack build time</td>
</tr>
<tr>
<td>(note adjusted water to 2.31 as 2.21 too dry)</td>
<td></td>
</tr>
<tr>
<td>water content = 18.4%</td>
<td></td>
</tr>
<tr>
<td>Omni C 1 - 1.1</td>
<td>10.10</td>
</tr>
<tr>
<td>Omni C 1 - 1.2</td>
<td>10.22</td>
</tr>
<tr>
<td>Omni C 1 - 1.3</td>
<td>10.32</td>
</tr>
<tr>
<td>Brick type - Hanson Desford Arden Special Reserve</td>
<td>Omni C 1 - 2.1</td>
</tr>
<tr>
<td>Water absorption category = &gt;7 &lt; 12%</td>
<td>Omni C 1 - 2.2</td>
</tr>
<tr>
<td>Water in mix :-</td>
<td>Omni C 1 - 2.3</td>
</tr>
<tr>
<td>2.2l water per 12.5kg mortar = 3 sample stacks</td>
<td>Omni C 1 - 3.1</td>
</tr>
<tr>
<td>Average stack build time</td>
<td>8.7</td>
</tr>
<tr>
<td>Omni C 2 - 1.1</td>
<td>8.52</td>
</tr>
<tr>
<td>Omni C 2 - 1.2</td>
<td>9.01</td>
</tr>
<tr>
<td>Omni C 2 - 1.3</td>
<td>9.10</td>
</tr>
<tr>
<td>Brick type - Hanson Desford Buff Multi</td>
<td>Omni C 2 - 2.1</td>
</tr>
<tr>
<td>Water absorption category = &gt;12%</td>
<td>Omni C 2 - 2.2</td>
</tr>
<tr>
<td>Water in mix :-</td>
<td>Omni C 2 - 2.3</td>
</tr>
<tr>
<td>2.2l water per 12.5kg mortar = 3 sample sta</td>
<td>Omni C 2 - 3.1</td>
</tr>
<tr>
<td>water content = 17.6%</td>
<td>Average stack build time</td>
</tr>
</tbody>
</table>

Graph 8.9. Stack build times for 3 bricks types of water absorption categories >12%, between 12 and 7% and <7% and 1 mortar. Stack strengths at 3 and 7 days.
8.5.6 Observations

Stack build times for Measham stock bricks (frogged) with four varying mortar types.

1. All stacks built in the stock bricks as described in section 8.5.6 were by traditional trowel laying techniques. The mortar types were standard M4 and M12 along with Omnicol and CPI mix.
2. It is clear from graph 8.7 that the slowest stack construction is associated with Omnicol followed by CPI mortar.
3. The OPC mortars enable faster build times.

Stack build times for 3 brick types of varying water absorption using Omnicol mortar:-

1. All Omnicol mortar used in the tests described in section 8.5.6 was laid by a traditional trowel process in order to determine the ease of buildability when using three brick types with water absorption categories of <7%, >7<12% and >12%. All bricks have three large perforations.
2. Stacks built in the high range water absorption bricks were the easiest to lay and were laid in the fastest recorded average time.
3. Bricks of >7<12% were the slowest to build.
4. In each case two sets of bricks were built by the same bricklayer and in each water absorption category the second set were built faster than the first set. This was down primarily to the bricklayers improved familiarity with the mortar which does not lend itself to ease of laying with a trowel (having been designed to be laid by a glue gun)
5. That familiarity is fairly consistent and amounts to an output improvement of between 13 and 16%

Although the traditional build times with a stock brick are slower when using Omnicol mortar compared with conventional OPC M12 and M4 mortars, it is evident from the work in section 8.5 that overall performance in terms of structural properties is superior. Further testing described later in this chapter shows that with a modified manufacturing process and an adjustment to the Omnicol mix water content, much faster panel manufacture is possible and still with adequate structural properties.

Unlike a wallets it is relatively easy to attain dimensional accuracy when building brick stacks as test samples – the width and depth of the sample being taken as the brick width and depth. Further mortar joint was always made to finish flush with the brick edges.
8.5.7 Structural testing of manually made stack beams

Table 8.12 shows the strength results for stack beam tests. These include failure load, average failure load, flexural strength and characteristic strength. Standard deviation and coefficient of variation are also included. The format of the testing was similar to that used in assessing build times. Firstly one brick was combined with four mortar types then the bricks were combined with Omnicol mortar only.

Table 8.12 Ultimate failure load and flexural strength results for stack beams. (Stock frogged bricks)

<table>
<thead>
<tr>
<th>Stack no</th>
<th>Bricks and Mortars</th>
<th>Ultimate Load (N)</th>
<th>Res. Strength (N mm⁻²)</th>
<th>Flexural Strength (N mm⁻²)</th>
<th>Characteristic Flexural Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Measham Buff CPI mortar trowel laid</td>
<td>1548.80 0.57</td>
<td>3137.83 1.16</td>
<td>339.92 0.13</td>
<td>797.89 0.29</td>
</tr>
<tr>
<td>2</td>
<td>Measham Buff Omnicol mortar trowel laid</td>
<td>1335.63 0.49</td>
<td>2292.11 0.85</td>
<td>606.08 0.22</td>
<td>465.65 0.18</td>
</tr>
<tr>
<td>3</td>
<td>Measham Buff M12 opc mortar trowel laid</td>
<td>1762.46 0.65</td>
<td>2520.01 0.94</td>
<td>790.53 0.29</td>
<td>819.21 0.31</td>
</tr>
<tr>
<td>4</td>
<td>Measham Buff M4 opc mortar trowel laid</td>
<td>1642.78 0.61</td>
<td>2787.51 1.04</td>
<td>698.07 0.26</td>
<td>796.42 0.30</td>
</tr>
<tr>
<td>5</td>
<td>Measham Buff M12 opc mortar trowel laid</td>
<td>1523.99 0.56</td>
<td>2809.49 1.04</td>
<td>793.96 0.29</td>
<td>678.97 0.26</td>
</tr>
<tr>
<td>6</td>
<td>Measham Buff M4 opc mortar trowel laid</td>
<td>1309.54 0.48</td>
<td>2881.30 1.07</td>
<td>651.70 0.24</td>
<td>821.18 0.31</td>
</tr>
<tr>
<td>7</td>
<td>Measham Buff M12 opc mortar trowel laid</td>
<td>1618.26 0.60</td>
<td>3047.28 1.13</td>
<td>745.66 0.28</td>
<td>562.17 0.22</td>
</tr>
<tr>
<td>8</td>
<td>Measham Buff M4 opc mortar trowel laid</td>
<td>1784.93 0.66</td>
<td>2996.72 1.11</td>
<td>720.63 0.27</td>
<td>565.11 0.22</td>
</tr>
<tr>
<td>9</td>
<td>Measham Buff M12 opc mortar trowel laid</td>
<td>1643.27 0.61</td>
<td>3286.45 1.22</td>
<td>629.29 0.23</td>
<td>752.53 0.29</td>
</tr>
<tr>
<td>10</td>
<td>Measham Buff M4 opc mortar trowel laid</td>
<td>1428.92 0.53</td>
<td>3626.02 1.21</td>
<td>628.31 0.23</td>
<td>632.73 0.24</td>
</tr>
</tbody>
</table>

mean (N) 1559.80 0.58 | 2902.87 1.06 | 660.42 0.24 | 689.18 0.26 |

stand dev 0.060 0.117 0.048 0.047

coeff of variation 10.5% 10.8 19.2 17.9

char flex strength f₀ₓ (N/mm²) 0.47 0.86 0.15 0.18

Graph 8.10 sample failure loads.

Graph 8.10 shows individual stack beam failure loads while graph 8.11 indicates individual flexural strengths. Graph 8.12 gives a summary of the mean and characteristic flexural strengths of a Measham stock brick when combined with 4 mortars.
Discussion

It is clear from the results that high performance specialist mortars have significantly higher flexural strength than standard OPC mortars. In addition the Omnicol mortar was over twice the strength of the 1:3 OPC mortar. Both high early flexural strength, and 28
day strengths for the Omnico mix (being up to 4 times the values of conventional OPC mixes) provides an excellent material for prefabricated masonry. As with the build time test this exercise was then carried out again using 3 brick types which were representative of three water absorption categories i.e. <7%, >7<12% and >12%. All brick types were of a 3 hole perforation configuration. The results are shown in Table 8.13 and graphs 8.13 - 8.14.

Table 8.13 Ultimate failure load and flexural strength for stack beams (varying water absorption)

<table>
<thead>
<tr>
<th>Stack no</th>
<th>Wilnecote 7 sets wa&lt;7%</th>
<th>Desford wa &gt;7&lt;12</th>
<th>Desford wa &gt;12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ult. Load N</td>
<td>Flex. Strength N mm-2</td>
<td>Ult. Load N</td>
</tr>
<tr>
<td>1</td>
<td>2934.17</td>
<td>1.08</td>
<td>2210.19</td>
</tr>
<tr>
<td>2</td>
<td>2711.08</td>
<td>1.01</td>
<td>3917.41</td>
</tr>
<tr>
<td>3</td>
<td>2577.58</td>
<td>0.96</td>
<td>3205.91</td>
</tr>
<tr>
<td>4</td>
<td>4567.19</td>
<td>1.69</td>
<td>2509.89</td>
</tr>
<tr>
<td>5</td>
<td>4326.48</td>
<td>1.60</td>
<td>3144.42</td>
</tr>
<tr>
<td>6</td>
<td>4797.15</td>
<td>1.78</td>
<td>2857.90</td>
</tr>
<tr>
<td>7</td>
<td>3996.75</td>
<td>1.48</td>
<td>4105.22</td>
</tr>
</tbody>
</table>

mean (N) 3701.49 1.37 3135.73 1.16 2391.81 0.88
stand dev 0.347 0.256 0.081
coeff of variation % 25.20 22 9.1
char flex strength fxk (N/mm²) 0.8 0.74 0.74

Graph 8.13 Stack beam mean flexural strength

Stack beam mean flexural strength (N/mm²) - bricks of three w.a. categories tested at 7 days

Graph 8.13 Stack beam mean flexural strength

Page | 338
8.5.8 Conclusions relating to hand made stack samples – workability and structural performance.

1. Omnicol mortar has the consistency of tile adhesive rather than cement sand mortar and it does not flow off the trowel as readily as a traditional cement / sand mortar. It has a “sticky” consistency. Due to the below average workability the Omnicol samples took longer to make than all of the others by an average of 2 minutes per sample of 12 bricks. This equates to an increase of 10 minutes per square meter of brickwork.

2. The other three sets were easier to make, taking as little as 6 minutes and averaging 7 minutes for the M3 mix.

3. Both the CPI mortar and the designation 1 mix have the best value of workability.

4. Although Omnicol mortar is not as workable for manual construction its consistency and water content may be adjusted such that it can be incorporated into brickwork by alternative build techniques as demonstrated in all of the case studies in chapter 3 and chapter 5. This involves either laying with a pump and gun process where the productivity output is increased by up to 20% or by the flat bed casting development as
previously described in Chapter 7. In this latter process the factory output is increased significantly without the use of a high labour force or a high capital investment

5. The stack test provides a quick simple method of evaluating flexural strength of masonry

6. Construction and preparation of stack samples allows evaluation of workability and ease of build for a range of mortar types

7. Test results enabled evaluation of comparative structural properties of specific brick mortar samples.

8. Deflection tests showed negligible deformation under loading

9. Performance parameters for traditional OPC cement sand mortars and CPI mortars in terms of flexural and compressive strengths, particularly the lack of early age setting does not make them suitable for the requirements of prefabricated manufactured masonry.

10. The manually made stacks provide an accurate simplistic test when establishing strength and workability properties for manually made prefabricated panels since the mortar composition, consistency and the ease of laying (or lack of it!) reflect the full scale manual manufacturing process.

Experience has shown that panels may crack along random bed joints during handling and lifting. In the prefabrication process great care is required to avoid this scenario as, once placed in their installed location such cracking will not be visible due to the panel self weight compressing the joints. Nevertheless the crack will be there and at the failed joint there is no flexural tensile strength in the masonry but only panel self weight giving the appearance of a sound wall. For certain panels this may affect the structural integrity particularly if the design assumes a full $f_{uk}$ value at the failed bed joint. This aspect is critical when evaluating a material / manufacturing process and a suitable testing regime.

**8.5.9 Further development of the brick stack samples**

Within the factory environment there would be a distinct benefit in being able to assemble mortared stack units without use of a bricklayer or bricklaying skills. Stacks for the testing programme were built by a bricklayer using a gauging rod in order to set out consistent joint thicknesses. It would be preferable to provide a formwork type box into which bricks are spaced out evenly, mortar inserted into joints and the finished boxes lifted and cured under self weight for the specified time.

Provided that the stack manufacture method was consistent this would enable a relative strength indicator to be achieved simply and quickly. The following section describes the
development of a stack mould box for brick test samples based on a flat bed panel fabrication procedure.

8.6 Flexural strength test – stack piers made by horizontal mould box and mortar mix with various water contents

If a flat bed masonry fabrication process is to be developed further it is beneficial to develop a corresponding simplified brick stack test where the stack piers will be more representative of the full sized panels in terms of structural performance.

It is therefore necessary to manufacture sample stacks quickly and by a simplistic process. The flexural strength of stacks manufactured by a bricklayer were compared with the flexural strength of wallettes as tested in accordance with BS EN 1052 2. Although characteristic strengths were calculated the comparison of performance was based more on the ultimate load and corresponding flexural strength as this is considered to be more relevant to the actual masonry strengths as manufactured.

In order to achieve this a stack mould box was developed and a simplified process of “loading” bricks into the stack mould box which requires no skill on the part of the operative. Furthermore this process can be achieved by laboratory trained staff ie those who will ultimately monitor and record the test data; with no bricklaying skills being necessary.

8.6.1 Fabrication of stack test box

The process of fabricating sample stacks using traditional bricklayer / trowel processes has been described in section 8.5. Additionally a measure of buildability, build speed and structural performance was quantified.

If a wall panel manufacturing procedure is to be progressed based on the flat bed development technique outlined in chapter 7 it is important to also develop a test procedure which is fast, simple, cost effective and most importantly replicates the brick fabrication process. Panels that are fabricated horizontally will not gain any enhanced strength from self weight during construction as occurs with traditional build. This would possibly lead to lower levels of adhesion and consequently flexural strength, between the brick and mortar. Brickwork which is tested using a scaled down version of the flat bed process will be subjected to the same brick mortar adhesion properties as the full sized walls. For the initial tests the mould box fabrication was relatively cost effective and easy
to achieve. Figure 8.6 illustrates the plywood fabricated mould box with removable sides, figure 8.7 shows the box filled with units.

![Figure 8.6 Plywood mould box with removable side members. A typical box is set up to provide 3 brick stacks.](image)

![Figure 8.7 Completed mould box with bricks for three sample stacks dry laid and ready to receive high water addition Omnicol mortar.](image)

Preparation of samples

As with the full sized flat bed panels, the base of each stack has a plastic profile spacer sheet inserted which makes it easy to receive bricks evenly spaced when placed face down into the mould. The test is set up such that a minimum of six samples can be fabricated using two mould boxes. A single mould box satisfies the maximum weight restriction and manual handling rules. Once the bricks are located in position the desired mortar mix is poured on top of the stacks and “combed” across the surface such that the mix will adequately fill both joints and the frogs or perforations of the bricks.

Vibration of the mould box is not advisable as this will cause the bricks to become displaced and “float” due to the lower density than the mortar mix. Floating will also cause seepage of the mortar onto the finished face (which is face down in the mould box).
The mortar mix water content is critical in ensuring a combination of rapid setting and hardening, sufficiently high strength and sufficiently low viscosity to ensure that all brick contact surfaces including frogs and perforations are fully filled.

Figure 8.8 shows the trial boxes with dry laid bricks in place. The brick setting or placement for six stacks can be completed in 10 to 15 minutes compared with 45 – 50 minutes for the hand made vertical stacks. When the stacks are completed mortar is poured onto the moulds after which these are left to set and harden for the desired time period which might be required to be as low as 24 hours to replicate fast removal of panels from the manufacturing area of the factory.

Prior to placement of bricks it is desirable, as a practical measure, to paint all contact surfaces with a formwork oil or similar material to stop mortar staining.

The boxes if treated carefully will last for many uses and are extremely cost effective.

8.6.2 Preliminary trial tests

For initial trials of the process Omnicol mortar was used, with three different water contents:

- 6.0l per 12.5kg bag = 24%
- 6.25l per 12.5kg bag = 25%
- 6.5l per 12.5 kg bag = 26%

The chosen brick was a Wilnecote facing:

- water absorption, <12%
- compressive strength >70N/mm²

The purpose of the test was to evaluate flexural strength, the results of which are documented in Table 8.14.
Table 8.14 Flat cast brick stacks

<table>
<thead>
<tr>
<th>Flat cast stacks</th>
<th>Wilnecote facing brick, water absorption &lt;7%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height (b)</td>
</tr>
<tr>
<td></td>
<td>(mm)</td>
</tr>
<tr>
<td>Sample 1 mortar water content</td>
<td>24%</td>
</tr>
<tr>
<td>Sample 2</td>
<td>25%</td>
</tr>
<tr>
<td>Sample 3</td>
<td>26%</td>
</tr>
</tbody>
</table>

Graph 8.15 shows the flexural strengths for stack samples made with mortar of varying water content. In the manufacturing process it is desirable to have the mix with as high a water content as is possible in order to ensure complete brick / mortar bond.

It is apparent that the flexural strength reduces as the water addition increases. This is of concern but does not compromise design performance provided that the flexural strength is adequate for panel design, handling and transportation.
Graph 8.16 shows similar flexural strength results for hand made stacks constructed using three different brick types.

The flexural strength at 7 days using the Wilnecote hand made stack test is 1.32N/mm$^2$. The result for the flat cast range from 0.85N/mm$^2$ down to 0.67N/mm$^2$.

Graph 8.17 compares the flat cast stacks with a hand made stack combined with mortar with a water content of 19%. The latter clearly provides a greater strength.
However when one compares the flat cast panel strengths with the masonry code strength requirements it is apparent that at 24%, 25% and 26% water addition the average flexural strength is in excess of the Code characteristic flexural strengths as anticipated. The characteristic strengths from testing are either similar or slightly lower than Code values although it must be remembered that the test figures are for 7 day as opposed to 28 day results given in the Code. (Graph 8.18)

The code table reproduced here (figure 8.9) shows characteristic flexural strengths of various brick water absorptions / mortar types.
8.7 Conclusions

Testing has confirmed that when using high performance mortars it is possible to achieve flexural strength values for various brick / mortar combinations that are adequate for the design of prefabricated masonry.

Increasing the water content to the Omnicol mortar mix will enable the flat bed fabrication of panels which will attain acceptable long term (28 day strengths) and adequate strengths for early handling after casting.

One manufacturing consideration which will enable the maximum amount of curing time, should this be necessary, will be the development of a handling system whereby the newly cast panels will be moved horizontally into a “drawer” type storage system within their mould boxes. As such they can then be moved rapidly (within 12 hours) to enable further casting thus maximising production.
Chapter 9 - Conclusions

The purpose of this work was to investigate potential markets for masonry, specifically clay bricks as their use in the UK has been in decline over many decades.

The objective was to consider the development of existing material and construction processes and to address new methods for use of masonry which might create renewed interest in it as a cladding, a structural material and as an architectural medium.

Consideration has been given to :-

- Structural brickwork systems
- Composite Cladding
- Methods of bricklaying
- Prefabricated masonry

Market research was carried out into the use of thin joint adhesive or “glued” brickwork which has enjoyed popularity in Europe for over 30 years. The key benefit of this technique involves the use of a pump and gun system where mortar is delivered to brickwork by a gun rather than relying heavily on the craftsmanship and trowel skills of the bricklayer.

An appraisal of thin joint brickwork was undertaken by a working group comprising the Brick Development Association, Oxford Brookes University and members of the brick manufacturing industry including the author. The resulting document outlined the potential for thin joint masonry in the UK and from this the writer sought to find a potential project which might enable demonstration of the system using UK contractors, construction and building legislation.

This culminated in a major project (University of West of England Case Study No 2), and subsequently further case studies followed, all instigated by the author in negotiation with a number of clients, consultants and contractors. All parties were most willing to embark on the thin joint process on the back of the research, testing and appraisal of its suitability for use in the UK.

No less than 5 major projects were constructed including two private houses, two university buildings and an arts college. All were in themselves a success in terms of the quality and desired aesthetic appeal. Additionally the structural performance, durability and resistance to rain penetration were at a standard which provided a direct benefit to the life of the building in terms of quality, low maintenance and aesthetic appeal. However it became evident that the thin joint in-situ bricklaying process did not lie comfortably with UK contractors due to both difficulties in setting up the system for use in this country with little
technical maintenance back up and more specifically, the lack of willingness to change from traditional bricklaying techniques to a process which was radically different.

Whilst thin joint in situ masonry processes were being used for the aforementioned projects, development work was being undertaken to investigate the potential for prefabricated masonry.

Initially this was developed using the same high performance thin joint brickwork along with the pump and gun laying process, but in this case the walls were built in a covered factory environment. Within factory conditions it was proven that the bricklaying rate, already increased by the use of the pump and gun on site, was further enhanced in the comfortable working conditions in which masonry was fabricated.

The process of manually manufactured masonry was well received by contractors and house builders and in particular a number of housing associations. All agreed that the technique would give an end product which had the benefit of traditional durable construction materials whilst anticipating faster construction, improved construction safety, low impact on the environment due to reduced on site time and continuous and consistent higher quality. The timing of this development coincided with the government of the day in 2005 having a major drive towards Modern Methods of Construction which called for investment in prefabrication along with the promotion of high quality, speed of build and low cost.

The government brief was directed particularly at lightweight prefabricated building systems such as galvanised steel and timber frame, composite insulated panel systems and volumetric "pod" units. There was no perception of including heavy materials such as brick and block.

The thin joint in-situ masonry processes met with many of the government requirements for modern methods of construction (MMC) but it was to the prefabricated techniques that interest was directed.

Factory manufactured cavity wall panels, built by bricklayers, are a successful process provided they are directed to one off projects or projects of low volume dwellings. The wall output is dependent on the number of operatives available and the factory working space. As such the desire for clients to have high numbers of properties in quick turn round time would be impractical.

The interest level in prefabricated masonry was due to both the Government promotion of innovative systems and the MMC and the desire to construct solid durable buildings with
traditional tried and tested materials such as masonry. Coupled with this was the benefit of quality, air tightness, natural ventilation and thermal mass, all of which scored highly for masonry.

The manual prefabrication process was used on two demonstration houses, a private individually designed house and also a flood defence scheme where single leaf prefabricated walls were manufactured as cladding panels to a steel sheet piling system. This project highlighted better than any other the potential for prefabricated masonry in a process which was simple, economical and one which embraced rapid construction for projects where time is a critical criteria.

Further manufacturing techniques have been addressed. The most ambitious of these is the robotic prefabrication process which saw the modification and development by the author of an established German system. In the proposed design the robotic technique was developed to automatically build two leafs of a cavity wall concurrently including wall ties, lintels and fixings as the work proceeded. The walls were built side by side with the manual input being the feeding of bricks onto the delivery build system.

The robotic system enables the construction of approximately 50,000m² of cavity wall per annum and the cost would be comparable with traditional construction. However a capital outlay in excess of £5 million is required for the process which would need to be recovered over a five year business plan. The system was intended for masonry cavity wall housing for the social sector where Hanson considered there would be the greatest potential. The author did not agree as it was felt that the walling costs would not be sufficiently competitive for the demanding procurement requirements of the house builders. Over the development period of this work it became apparent that large commercial housing organisations will embrace all of the benefits of prefabricated housing provided that the cost is seen to be less than (not even equal to) traditional techniques. The reason for this was made quite clear; why would they wish to risk an unknown process when the alternative has been tried and tested for many years?

There has always been difficulty in obtaining a true cost comparison as the prefabricated walls manufactured both by a robotic process and by manually made methods will never be completed at a cost which is less than that of traditional methods. However the true savings are made in long term quality and low maintenance and also in the savings of on site management costs which are significantly reduced with a prefabricated system.

One of the key objectives of this thesis was the development of a subsequent manufacturing technique to address the cost issues in an effort to avoid the tedious
process of explaining where costs might be saved even though they were not openly apparent. To this end the flat bed prefabrication technique is of a low capital investment cost compared with other processes and in addition the procedure requires a minimal labour force which may comprise of unskilled operatives with one supervisor. The system uses flat horizontally formed mould boxes, the size of which will depend on the wall panel dimensions. A battery of panels can be set up so that a high number of walls may be made by setting dry laid bricks into the moulds and pouring a high water content high strength adhesive mortar over the brickwork.

The mortar has been extensively tested to ensure that sufficient early strength is achieved to enable removal from the mould, handling for storage, placement on a lorry, transportation to site and installation in position. This thesis demonstrates the structural adequacy of panels for all of the handling processes including removal from the mould box without the need for a costly tilting table which is usually recommended for moving panels from a flat to a vertical attitude.

In addition to the panel development process, a lifting jig, storage stillages for transport and where required temporary propping devices have been designed as a "one piece item" which is reusable after delivery of panels. The jig will finally be developed to take several panels at a time.

Testing of masonry is expensive and simple testing techniques have been developed by the author in order to ensure that regular checks on flexural strength can be correlated between a simple brick stack and previously tested wallettes as used for a standard BS test. The brick stack test process enables manually made samples to be compared with manually made brick panels whilst a new method, the flat cast brick stacks, may be used to evaluate flexural and compressive strength of panels made by the flat bed process. This latter test ensures that the water content of the mix is controlled such that samples – and full wall panels – have sufficient strength for rapid removal from the factory and for safe handling.

Extensive flexural strength tests have demonstrated that adequate strength may be achieved after only a short period of time which will also depend on the brick type, hence allowing movement for storage or direct transportation. The flat stack test is inexpensive making use of plywood reusable mould boxes and it allows for several stacks to be produced concurrently. A three stack mould box can be set up with bricks and the mortar poured on to them in 20 minutes whereas manually built stacks require at least 10 minutes per stack and involve a more complex set up operation. The stack test provides an excellent quality checking process. Tests have been carried out to compare thin joints of 3-
5 mm with conventional 10mm joints. Whilst there is some strength reduction this does not compromise the brickwork integrity.

Testing work for this thesis also demonstrated the performance of stack bonded masonry compared with stretcher bond, the stack bonded being particularly desirable for architectural reasons. Some investigations were also done to compare reinforced and unreinforced brickwork using bed joint reinforcement. Chapter 8 presents these results. The 3 day characteristic flexural strength of walllettes built with Omnicol mortar were 0.19 N/mm² for stretcher bond and 0.37 N/mm² for stack bond. Although these values fall just below that for an M4 mortar (0.3 N/mm²), the results at 14 days exceed the code values at 0.48 N/mm². It should also be remembered that since a factory controlled test programme would be implemented in a production process, the test samples strengths will reflect more accurately the actual strength values, rather than being nominal representative figures. Flexural strengths perpendicular to the bed joints comfortably exceeded the Code characteristic strengths for the >12% water absorption with a comparable 0.9N/mm² at just 3 days and 1.4N/mm² at 28 days, 40% greater than the Code figure. It is notable from the flexural strength results that the ratio of strength in the weak direction to strong direction, the orthogonal ratio, which is typically 0.3 – 0.4, was much closer to parity indicating that the panels have similar flexural strengths in both the weak and strong direction. Improved flexural strength in the weak direction is particularly beneficial in masonry design and further investigations into these properties are recommended.

Design and detailing of prefabricated masonry has been developed such that standard fixing details may be used for the connection of panels and these will comply with the standard detailing recommendations of the current masonry codes. The development of bespoke specialist fixing details only serves to add cost to the system. Structural design for panels once in place follows the same procedure as for conventional masonry with consideration of flexural, compressive and shear strength. Prefabricated masonry, once installed has structural properties which have been found to be at least equal to and usually greater than those of conventional masonry. In prefabricated panels it is the design for handling and transportation which requires more attention and this work has demonstrated to date that regular structural testing currently provides the safest option in obtaining data for the properties of the masonry. In such cases it is considered preferable to use average sample strength data rather than characteristic strengths as the testing is consistently and tightly controlled.

One of the key developments during the course of this work was to successfully implement the use of 10mm mortar joints rather than the recommended “thin” joints. This did not
significantly reduce structural performance and it is critically important when promoting this material for the UK construction industry. All building components are detailed to dimensional co-ordinating sizes which use 215mm bricks and 10mm bed and perpend joints.

Extensive investigations have been made over the use of prefabricated masonry worldwide and at the time of writing there appear to be no successful economically viable or marketable masonry processes available. It is believed that the reason for this is largely down to cost and complexity. If prefabricated masonry is to be successful it is essential to have a solution which is readily understood by both designers and contractors, a simple process to manufacture and one which encompasses standard design and details.

The flat bed process is currently being further investigated by Hanson with a view to consideration of full development which will be undertaken by the writer. In addition the manually manufactured fabrication technique will provide an option for low volumes of masonry with particularly complex detailing which may be best suited to the manual procedure.

With the flat bed process it is preferable to manufacture single leaf walls and these will be particularly beneficial for civil engineering use such as flood walls and retaining walls or for the outer leaf cladding of lightweight steel and timber framed buildings.

Interest has also been shown in recent months in the use of single leaf brickwork cladding on large commercial structures where repetitious use of spandrel panels and piers are desirable.

**Further work**

This thesis has sought to present a number of optional solutions for prefabrication which have various degrees of investment cost, complexity and level of manpower.

Some areas which would benefit from further research and development are outlined below:

**Masonry testing.**

Further investigation is needed to address the water addition to the Omnicol mix and to assess its performance and short term strength.

Masonry using alternative OPC mortars achieving early high strength are being investigated and evaluated by the author for use in the flat bed manufacturing process.
The simplified stack tests have been used to evaluate flexural bending but further work is required to assess compressive strength and shear strength.

Rain penetration through brickwork – flat cast prefabricated masonry will have an integral and continuous bond between bricks and mortar which initial standing head tests have shown not to let any water ingress occur through the masonry joints. Nevertheless further work to fully verify this is required.

Deflection of masonry panels. Some initial testing has shown that masonry built with Omnicol mortar experiences greater deflection than with conventional OPC mortar with no resulting cracking. Deformed masonry panels have been monitored under loading and shown not to return to their original shape ie to display some minor permanent deformation. Further work on this is recommended.

Other areas for further work include cost analysis of the manufacturing and construction processes in order to compare with traditional systems. This is particularly important over the whole life of the building.

The carbon footprint of masonry structures needs to be compared to other materials over the full life of a building. Acoustic and thermal properties of these walls need to be established.
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References

Appendices

Appendix a - Material data
Hanson Con-Fix

High performance mortar for thin-bed masonry using aggregate concrete blocks.

Applications
A thin-layer-glue mortar used with aggregate concrete blocks, suitable for both loadbearing and non-bearing construction. Con-Fix is available in the standard grey colour and is inconspicuous between the masonry units especially important for thin plaster finishes. Compared to traditional masonry, the thin-bed system provides increased speed of masonry construction and significant increase in structural properties and performance.

Advice for use
Con-Fix is extremely easy to work requiring only the following equipment: bucket, mixer, glue mortar dispenser and trowel. The glue mortar is prepared in a bucket (minimum mixing time = 4 minutes) until a consistent mass, free of lumps is achieved.

Mixing procedure / sequence :- clean water is first added to the mixing bucket Make sure that you first add the required quantity of water into the bucket, then slowly adding the powder steadily while mixing.

With the assistance of the glue mortar dispenser you apply the glue mortar on the bed joint. The glue mortar has been applied in the head joint by using the trowel and the following block can be placed. The material is applied in a constant layer of minimum 4 mm thickness, and the blocks need to be pressed down sufficiently. Make sure a 2 mm joint remains. Remove any excess glue, which has leached out, only when it has stiffened.

At higher temperatures it might be necessary to first remix the glue mortar before applying. Never add extra water when doing this.

Consumption
About 50 gr/dm² based on a constant layer thickness of 2 mm for both perpend and bed joints. Due to the large variation in sizes of the blocks, this information is indicative only,

Cleaning
Using water immediately after use should clean tools and equipment.

Composition
Con-Fix is a single component composition of pure Portland Cement, quartz sand (calibrated up to 1 mm) and careful selected additives.

Technical specifications
The underneath mentioned technical values are based on test results archived in our own laboratory and on various sites itself. They serve the purpose of information only, no claims can be accepted based on the following provided data:

Min. process temperature : >0°C
Min. mixing time : 4 minutes
Available colours : grey
Max. grain size : <1 mm
Frost resistance : yes
Suited sort of bricks : concrete blocks

Fresh mortar properties
Mixing water : 5 L / 25 kg
Mortar delivery : 601 L / ton
Mass by volume (wet) : 1997 kg/m³
Open time (2 mm layers) : 15 minutes
Corrections possible : within 6 minutes
Bearing capacity : 4 mm / 16 g/cm²
Process time : > 4 hours
Air content : ± 7 % (m/m)

Flow after 10 minutes : 198 mm (+/-10mm)
Flow after 4 hours : 173 mm
**Mortar properties**

Compressive strength :  >14 N/mm$^2$ (18.14 N/mm$^2$)
Flexural bond strength :  >4.5 N/mm$^2$ (5.36 N/mm$^2$)

**Tensile bond strength**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 24 hours dry</td>
<td>0.25 N/mm$^2$</td>
</tr>
<tr>
<td>After 24 hours dry + 1 day wet</td>
<td>0.63 N/mm$^2$</td>
</tr>
<tr>
<td>After 28 days dry</td>
<td>&gt; 0.91 N/mm$^2$ (rupture through brick)</td>
</tr>
<tr>
<td>After 28 days dry + 1 day wet</td>
<td>&gt; 0.90 N/mm$^2$ (rupture through brick)</td>
</tr>
<tr>
<td>Mass by volume dry</td>
<td>1849 kg/m$^3$</td>
</tr>
</tbody>
</table>

**Packaging**

Con-Fix is delivered in PE-bags of 25 kg, stacked per 60 bags on one-way-pallets (1.500 kg). Individual pallets are covered with a p.e. stretchhood.

**Storage**

Storage of pallets can be done outdoors but for longer periods we advise to store the product in covered warehouses. The powder itself is moist-sensitive. In its original closed packaging and stored under the right conditions Con-Fix has a shelf live of 12 months.

**Health**

Con-Fix contains a/o. pure Portland Cement. Like all cement-based products it does have an alkali reaction in water, therefore eyes and skin should be well protected. In case of contact, rinse with sufficient water. When contact with the eyes have occurred you are advised to obtain medical advice.
PRODUCT SAFETY DATA SHEET FOR THIN LAYER MORTAR (T.L.M.)

December 2007
1. Identification of the preparations and company.

Product details: Cement-based products containing more than 20% Portland cement classified as irritant.

Trade names: Thin Layer Mortar

Manufacturer: Hanson Building Products
Head Office
Stewartby
Bedford
England
MK43 9LZ

Email: thermalitesales@hanson.com
www.hanson.com/uk

2. Composition/information on ingredients.

Chemical characterization

Description:

In different proportions: - cements (cement content > 20 %)
- quartzsands (grainsize > 0.1 mm, without fin proportions)
- calciumcarbonates
- copolymeric powders of vinylacetate/ethylene
- derivates of cellulose
- additives

<table>
<thead>
<tr>
<th>Hazardous ingredient</th>
<th>Classification</th>
<th>%</th>
<th>Index</th>
<th>Risk Phrases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement</td>
<td>CAS No.65997-15-1</td>
<td>&gt;20</td>
<td>Xi</td>
<td>R38, R41</td>
</tr>
<tr>
<td></td>
<td>EINECS: 266-043-4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Hazard identification.

Hazard designation: Xi Irritant.
Information pertaining to particular dangers for man and the environment: R38 Irritating to skin, R41 Risk of serious damage to eyes.
Classification system: The classification is in line with current EC lists. It is expanded, however, by information from technical literature and by information furnished by supplier companies.
4. First aid measures.
   **After inhalation:** In case of unconsciousness bring patient into stable side position for transport.
   **After skin contact:** Instantly wash with soap and water and rinse thoroughly. If discomfort, irritation or other symptoms of irritation occur seek medical advice.
   **After eye contact:** Immediately rinse opened eye for several minutes under running water. If symptoms develop or persist, seek medical attention as soon as possible.
   **After ingestion:** If symptoms develop or persist, seek medical attention as soon as possible.

5. Fire-fighting measures.
   **Suitable extinguishing media:** CO2, extinguishing powder or water jet. Fight larger fires with water jet or alcohol-resistant foam.
   **Protective equipment:** No special measures required.

6. Accidental release measures.
   **Personal safety precautions:** Avoid causing dust.
   **Measures for environmental protection:** No special measures required.
   **Measures for cleaning/collection:** Collect mechanically.

7. Handling and Storage.
   **Handling**
   **Information for safe handling:** Prevent formation of dust.
   **Information about protection against explosions and fires:** No special measures required.

   **Storage**
   **Requirements to be met by storerooms and containers:** Store only in the original container.
   **Information about storage in one common storage facility:** Not required.
   **Further information about storage conditions:** Store under dry conditions. Keep container tightly sealed.

8. Exposure controls/personal protection.
   **Exposure:** Take measures to reduce airborne dust generation during mixing. Occupational exposure must be kept below both 10mg/m³/8 hour TWA total inhalable dust and 4mg/m³/8 hour TWA respirable dust.
   **Personal protection:** Avoid contact with the eyes and skin by the use of safety goggles and waterproof gloves. Remove any contaminated clothing. Wash hands during breaks and at the end of the work. Keep away from foodstuffs, beverages and foods.
9. Physical and chemical properties.
General information
Form: Powder
Colour: Various
Smell: Characteristic
Change in condition
Melting point/Melting range: Not determined
Boiling point/Boiling range: Not determined
Flash point: Not applicable
Self-flammability: Product is not self-igniting
Danger of explosion: Product is not explosive
Density: Not determined
Settled apparent density at 20°C: 1100 - 1700 kg/m³
Solubility in/Miscibility with water: Not miscible or difficult to mix
pH-value at 20°C: ca. 12
Solvent content
Organic solvents: 0.0%
Solids content: 100.0%

10. Stability and reactivity.
Thermal decomposition/conditions to be avoided: No decomposition if used according.
Dangerous reactions: No dangerous reactions known.
Dangerous products of composition: No dangerous decomposition products known.

11. Toxicological information.
Acute toxicity:
Primary irritant effect:
on the skin: Irritant for skin and mucous membranes.
on the eye: Irritant effect.
Sensitisation: No sensitizing effect known.
Additional toxicological information: Irritant

The product shows the following dangers according to the calculation method of the General EC Classification Guidelines for Preparations as issued in the latest version:

Stable in soil. Water hazard class 1 (self assessment): slightly hazardous. Do not allow undiluted product or large quantities to reach the ground water, rivers, drainage and sewage systems.
Product:

| European waste catalogue | 17 09 04 | mixed construction and demolition wastes other than those mentioned in 17 09 01, 17 09 02 and 17 09 03 |

Uncleaned packagings:
Recommendation:
Empty contaminated packagings thoroughly. They can be recycled after thorough and proper cleaning.

Not classified as hazardous for transport purposes.

15. Regulatory information.
These products have been classified and labelled in accordance with the EC Directives and Ordinance on Hazardous Materials.

Code letter and hazard designation of products: Xi Irritant.

| Risk phrases: | R38 | Irritating to skin.  
|  | R41 | Risk of serious damage to eyes. |
|Safety phrases: | S2 | Keep out of reach of children.  
|  | S22 | Do not breathe dust. |
|  | S24/25 | Avoid contact with the eyes and skin. |
|  | S26 | In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. |
|  | S37/39 | Wear suitable gloves and eye/face protection. |
|  | S46 | If swallowed, seek medical advice immediately and show this container or label. |

Water hazard class: Water hazard class 1 (self-assessment): slightly hazardous for water.
This Product Data Sheet does not constitute a workplace risk assessment.
16. Other information.
Use only for the purposes intended. This information is based on our present state of knowledge and is intended to describe our products from the point of view of the safety requirement. It should not be construed as guaranteeing specific properties.

Revision comments: This revision includes new contact numbers and recent amendments to regulations.

References:
HSE Guidance Note EH 40 (Occupational Exposure Limits)
The Control of Substances Hazardous to Health Regulations 2002 amended 2003
The Chemicals (Hazard Information and Packaging for Supply) Regulations 2002
Approved Supply List (Seventh Edition)
Compilation of safety data sheets (Third Edition) Approved Code of Practice
HSE Guidance Note EH 26
Construction Health Hazard Information Sheet No. 1 and No. 7
Gluing of facing brick masonry

Common building materials subjected to different new processing techniques!
Gluing of facing brick masonry

Common building materials subjected to different new processing techniques!

History
In the first instance, it was the clay brick industry that investigated methods to possibly process clay brick faster and cheaper. At the same time it also evaluated the labour requirements for brick laying. Observing other materials such as lime-silicate bricks and cellular concrete, attention was concentrated on the method of gluing. For some time these aforementioned materials had been processed with some success utilizing this method. The first testing programme was therefore set up following this line of thought. However, the enormous variety of facing brick did not simplify this. Next to the gluing of clay brick, the technique developed for this type of brick is also suitable for other types of facing bricks.

Development
Together with the clay brick industry, several suppliers and testing authorities, Omnicol has embarked on an intensive development programme. The first glue projects were completed already in the early 90’s. Through the development of different types of glue, solutions were discovered for the very large variety of facing bricks available.

Glue-mortars have now been developed for clay brick (the most applied facing brick by far in the Benelux), concrete block, silicate facing bricks and high-speed building blocks (interior walls), each with their own specific characteristics. The name glue-mortar was chosen consciously since the product contains a small part of each, glue as well as mortar.

The application of the glue-mortar has also been investigated extensively and has resulted in the development of different processing methods. The glue-mortars for facing bricks may be processed by choice either with equipment specially developed for this purpose or manually.

Standards
As mentioned before, glue-mortar is neither glue, nor mortar. There were therefore no standards available when development was started. At the request of industry, products were created which comply with a number of different properties, such as:

- Improved moisture behaviour
- Higher bond- and tensile bending strengths
- Positive flow behaviour
- Durability

The standardisation of this group of glue-mortars has progressed significantly. In The Netherlands there exists evaluation guideline 1055 from which products may be certified. Omnicol glue-mortars possess KOMO as well as production certificates. The WTCB in Belgium has started with the creation of a specific standard for glue-mortars while in Germany efforts are being made to match DIN standards to the new technique. It is expected that these details will all be included in the relevant European standards at a later date.

Aesthetics
A facing brick layed with glue-mortar provides the outside wall with a different look. The colour intensity of that wall increases because the applied brick determines its level of intensity. In a traditionally layed wall, joints occupy 20% of the surface. In a wall layed with glue-mortar, this has been reduced to approximately 8% or, as it will appear, just brick. The fact that glued outside walls are executed with recessed (thin) joints that are not being filled, emphasizes colour intensity as well as durability. Scientific research has shown that the recessed joint, since it stays cleaner, has a favourable effect on the visual aging of the joint.

Scientific distinctions of glued facing brick masonry
Glued facing brick masonry units have the following characteristics in common:

Higher quality
Work is executed with industrially produced glue-mortars that are always in the correct mix proportions, of consistent quality, delivered pre-packaged to the building site, ready for use. The joint is masonry’s weaker link in as much as durability is concerned. However, the joint is eliminated completely. When using the correct glue-mortar, the glued masonry wall is less sensitive to lime

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staining and efflorescence. This is achieved additionally through the accelerated completion of the glue-mortar reaction. Leaving lap joints open has been investigated and in glue-mortar applications considered favourably. When this method is used, one is advised to use darker coloured glue because of the appearance of a shadow in the joint. The quantity of moisture moving into a cavity wall is rather small because of two reasons:
- the open lap joints are very small;
- an optimum ventilated outside cavity leaf is created resulting in a no pressure differential between the outside and the inside of the cavity.

Based upon physical quantities such as frost resistance, deformation capacity, Modulus of Elasticity, bond-, compressive- and bending strengths, it can be determined that everything that can be achieved with traditional masonry can also be achieved with glue-mortar masonry and even more so. This fact is supported by existing references. The proof that production control, quality control, material properties and processing techniques are at their highest level is that the wall to be glued can be included in an insured guarantee package.

**Extensive construction possibilities**
Throughout the years, clay brick has experienced a reduction in its roll as a construction component. More often it has become the non-load bearing veneer of an outside wall and little more than that. However, by applying gluing techniques, clay brick can now also be successfully used as a construction component in a modern building environment. Its weaker link is no longer its mortar joint but the brick itself. Gluing achieves much higher bond strengths resulting in more homogeneous masonry. In glue-mortar masonry construction, its strength is defined by that of the brick. In comparison with traditional masonry, this increases the strength of glue-mortar masonry by a factor of about 3. Designers can profit from this higher strength in several ways, not only through the incorporation of larger openings, but also by designing more slender structures. Glue-mortar construction allows for smaller cavities since the proper application of the gluing process causes minimal joint protrusion. The multiple increases in strength created by the use of glue-mortar opens the possibility for the incorporation of relatively larger outside wall openings without reinforcing with concrete- or steel lintels. Even larger outside wall openings may be spanned using special joint-reinforcing in the bed joints above the opening. A relatively recent development is the use of glue-mortar in the production of pre-fabricated clay brick masonry units. These units can be constructed using glued clay brick only. They should be contemplated for repeat applications in wall units such as high-rise buildings or sound barriers.

**Durability**
Technical and aesthetical aging of masonry are dependant on the aging of the brick and the joint between the bricks. Not often is technical aging of the mortar the weaker link. Technical and visual aging is usually largely on account of the joint mortar. This weaker link is missing in glued walls. The strength and density of glue-mortar exceed those of clay brick. Because of the possible omission of recessing and jointing, the environmentally unfriendly cleaning of masonry is not required. Pollution of mortar joints is often caused by moss- and algae growth on the joints and later onto the bricks. This is possible because acid rain decreases the alkaliity of the joint. Joints of glued walls have a high density and are water resistant. Therefore, the durability of a glued joint as far as moss- and algae growth is concerned, is much higher when compared to traditional masonry. Because of its water resistance, the glue-mortar joint is dry immediately after a rain shower. This results in insufficient water to stimulate the growth moss and algae. The increased surface of the side with the recessed joints accelerates the drying process of the bricks after a rain shower.

**COMPARISON OF A GLUED OUTSIDE WALL WITH A TRADITIONALLY LAYED ONE**

**Strength**
Partially because of its high cement content, the strength of the glued joint exceeds that of the brick. Because of this there are more application possibilities:
- continuous vertical joints in for example standing bond;
- larger openings without support;
- outside walls with open lap joints;
- pre-fabricated glue- and mesh construction.

**Durability**
In traditional masonry, mortar joints are commonly the weaker link and usually less durable than the mortar. In glued masonry, joints are omitted and replaced by glue-mortar about 3 times stronger. Aging tests series as well as continuous freeze-thaw cycles did not show any measurable aging.
more easily be made thicker by adding extra powder, than a mortar which is too thick can be made flatter through the addition of extra water. The obtained mass should be mixed for 4 minutes into a homogenous mass, free of lumps. When using the glue pump, mixing time is set. When the glue is prepared manually, the mixing time of 4 minutes should be conscientiously adhered to.

Bricks are layed applying traditional methods along a thread used as a guide for linearity and height. When determining the course size, brick tolerances and joint thickness should be taken into account.

With gluing equipment: The row is covered as required with glue by moving a gun over the bricks. The gun levels the placed glue in a desired quantity. Using a small special frame, the heads of the bricks can be covered similarly. A second person can position the bricks, through which a higher rate of production can be achieved. Be certain that the safe usage time of the mortar will not be exceeded. After a long wait and in warm weather it might be necessary to pump the remaining glue out of the hose before restarting. It may be advisable to use the glue remaining in the mixer and fill the hose with water when confronted with a long waiting period.

Manual: Never make too much glue at once. Pick up a brick and hold it upside down. Cover the brick to be layed on the back/underside with glue such that there is no glue coming out of the joint on the front side when it is placed into the wall. Cover the head of the brick at the same time. Place the brick with the glue onto the wall.

Colour
The colour of traditional masonry is strongly influenced by the colour of its joints. Its visual aging is also strongly influenced by the colour change of the joint. Glued masonry has recessed joints. Because of the shadow in the narrow joint it cannot or hardly be seen. Even after years the colour of the outside wall is largely determined by the colour of the clay brick.

Moisture
The cement-rich glue-mortar has low water permeability and is water resistant. Moisture therefore, is largely absorbed and evaporated by the brick. This agrees with the fact that the gluing process shows virtually no staining and because of this opens the way to glue-mortar outside walls with open lap joints.

Construction costs and risks
The cost of glue-mortar walls is arrived at differently. Glue mortar requires:
• more bricks per m²;
• more critical work of bricklayer because of form and deviating brick;
• extra handling because of lap-joints;
• cleaning of equipment;
• accurate building site organization;
• different/adjusted scaffolding required.

The increased cost has to be balanced against the fact that joints disappear. Because of this the period required for scaffolding is reduced, which is cost saving. Costly joint restoration of older outside walls can be eliminated, since a glued outside wall is maintenance free. Gluing veneer has a number of advantages producing cost savings when compared to traditional masonry. Less bricks per m² as well as space saving (a larger net content of the project, or more insulation possibilities), will provide cost reductions in favour of gluing.

Preparations to be made
• Construction site has to be ready for the gluing of facing brick (scaffolding, water power, stacking and transportation of bricks, sawing possibilities, etc.).
• Bricks have to be free of grease and dust, pre-wetting is not necessary.
• Excessive sand on sanded bricks should be removed as much as possible. Suitable scaffolding; sufficient space to accommodate gluing equipment.
• No scaffolding tubes against the wall; these would disturb an uninterrupted placing of glue into the wall.
• Correct measurements; course details are to be determined from randomly selected bricks from several packages. Tests should be performed on samples 10 bricks high and 10 bricks long.
• Required sawing to be done beforehand.
• Care should be taken to ensure that the correct cavity ties will be used.

Processing
Glue-mortars are prepared with clean cool tap water. Glue-mortars react critically to correct parts per mix and proper mixing. Correct quantities are to be determined for each application. They are also dependant on the colour and the desired processing consistency. The correct dose is critical, especially when the mortar has to be pumped. The glue-mortar should be taken that water is first added to the mixer before the powder. Only then should the mixing be started. A mortar that appears to be flat can...
Bulging glue on the front side: let dry minimally for about 15 minutes and have it then removed with a tuck-pointing tool. Bulging glue is a result of too much material used or glue-mortar placed in the wrong spot.

During rain and expected low temperatures (<5°C) fresh gluing has to be sufficiently protected. Freezing should be avoided at all times during placing and hardening.

**Required tools**
- Mixing/pump equipment;
- Small special frames to cover heads;
- Mixing barrel;
- Measuring beaker;
- Trowel;
- Tuck-pointing tool;
- Sawing equipment (wet).

**Consumption**
Laying stretchers in running bond, one should count on the consumption of between 12 and 21kg/m² for glued lap-and bed joints using the Dutch waal-size brick. The exact consumption is dependant on the dimensions of the brick, possible perforations and the joint thickness to be used. Upon receipt of this information, consumption details will be gladly supplied.

---

**Omnicol glue-mortars**
Omnicol is the pioneer when it comes to gluing of facing brick. It has the extensive experience of more than 20 years in the gluing of silicate bricks and cellular concrete. In close cooperation with industry, it has developed a complete gamma of glue-mortars.

We distinguish the following types of glue-mortars, each with their own specific properties and applications:

---

**Omnifix PVM**

**Glue-mortar for clay brick**

**Identifying product properties**
- Suitable for all types of clay brick, including extruded- and pressed bricks, hand formed and soft- and stiff mud types.
- Glue-mortars designed for pumping available in three types (matched with the water absorption of the used clay brick).
- Higher strength providing new possibilities of clay brick as a construction unit.
- Durable walls, with better moisture control and without leakage.
- Standard in 6 colours: grey, red, brown, anthracite, white and yellow.
- KOMO-certificate with production certificate nr. 28031 in accordance with BRL 1005 and classified as a category 1A building material conforming to the Building Materials Agreement.

**Applications**
Suitable for gluing of all possible clay brick types. Because of its very high bond- and tensile strength, it is possible with Omnifix PVM to produce prefab units of clay brick. The narrow joint thickness combined with the moisture behaviour of a glued wall, make it possible to build walls with open lap joints. Standard is the glue-mortar available in three types (A, B, or C) to glue bricks with different water absorptions at the same production speed. Type A is exceptionally suitable for porous bricks, while type C also permits fast gluing of the harder pressed brick or clinker without wall floating. Apart from possibly present soluble salts in the bricks, a colour intensive wall without leakage can be guaranteed.

Next to the common Omnifix PVM, practice has created a slightly modified version, called PVM ZB. This glue is largely the same as the standard PVM but differs because of its grain structure. Through the inclusion of different particle sizes, a sieve analysis has been obtained which is exceedingly suitable for larger and heavier clay bricks. This version has the important characteristic that these more difficult to handle units can still be easily positioned, stacked and aligned with the laying thread.
RENTAL OF GLUING EQUIPMENT

(only available in Benelux)

To facilitate the processing of our construction glue-mortars, Omnicol offers different types of equipment for rent through our rental division Omnirent. Our principal is that all available and suitable equipment will be offered for rental with the client having the final choice. The offered machinery is specially designed for the mixing and pumping of our glue-mortars.

You are not alone during the rental period. Our motto is: Rental has to lead to satisfaction of both parties. We translate that into an excellent service: quick assistance at occurring interruptions ... complete parts; there are no repairs on the building site. Defective parts are inspected and repaired at the plant.

For every type of pump the same conditions apply. Pump rental is always calculated for the minimum period of one week. In the calculations, a week is equal to five working days. By choice, pumps ... also possible to collect the pump yourself. In Weelde (Belgium) you can get the included explanation at a time agreed upon.

We kindly ask you to indicate clearly when reserving when and how you will receive the pump. We always advise to have at least one person attend a glue-mortar course prior to the start of the job. This will facilitate the running of the gluing operation successfully.

Please inquire at least two weeks prior as to the availability of the number of desired pumps and to reserve them in time. We do not charge a deposit but ask for a pre-payment of 50% of the pump rental based upon the rental period indicated prior to delivery. The balance will be calculated upon completion of the rental period. A rental contract will be drafted in which the rights and duties of both parties are unequivocal and clearly stated.

Omnirent: Speedy, reliable service and business understanding when it comes to gluing of facing brick!

OMNIFIX BB
Glue-mortar for concrete bricks

Characteristic production properties
- Glue-mortar which can be pumped for the processing of all kinds of concrete brick.
- Mortar and joint are combined. No post-treatment required.
- High strength with new possibilities for concrete brick as a building component.
- Standard in 6 colours: Grey, red brown, anthracite, white and yellow.
- KOMO certificate with production certificate nr. 28032 in accordance with BRL 1009 and classified as a category 1A building material conforming to the Building Materials Agreement.

Applications
Suitable for the gluing of all kinds of all possible types of concrete facing bricks. Characteristics of this glue-mortar are the specific matching of the distinctions of concrete brick. The higher bond and bending strength than those of traditional concrete brick, is achieved though a narrow joint thickness (3 to 6 mm).

The so-called "glue-ready" time (prime period of about 4 minutes to lay bricks) has been adjusted so that also short walls, columns and pilasters may be constructed fast without bricks starting to float. All bonds are possible.

Next to common Omnifix BB, practice has created a slightly modified version, called Omnifix BB ZS. The glue is basically equal to the standard BB but differs because of its granular content. Through the inclusion of different particle sizes, a slave analysis has been obtained which is exceedingly suitable for larger and heavier concrete bricks or blocks. This version has the important characteristic that these more difficult to handle units can still be easily positioned, stacked and aligned along the laying thread.

OMNIFIX BB
Glue-mortar for concrete bricks

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- Glue-mortar which can be pumped for the processing of all kinds of concrete brick.
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Applications
Suitable for the gluing of all kinds of all possible types of concrete facing bricks. Characteristics of this glue-mortar are the specific matching of the distinctions of concrete brick. The higher bond and bending strength than those of traditional concrete brick, is achieved though a narrow joint thickness (3 to 6 mm).

The so-called "glue-ready" time (prime period of about 4 minutes to lay bricks) has been adjusted so that also short walls, columns and pilasters may be constructed fast without bricks starting to float. All bonds are possible.

Next to common Omnifix BB, practice has created a slightly modified version, called Omnifix BB ZS. The glue is basically equal to the standard BB but differs because of its granular content. Through the inclusion of different particle sizes, a slave analysis has been obtained which is exceedingly suitable for larger and heavier concrete bricks or blocks. This version has the important characteristic that these more difficult to handle units can still be easily positioned, stacked and aligned along the laying thread.
OMNIFIX PVM
Adhesive, thin bed mortar for brickwork

- Suitable for all types of bricks from handmade to stock bricks as well as extruded and wire-cut products.
- For laying bricks using a much thinner layer of mortar.
- Greater colour intensity of façade as the traditional visual effect of mortar joint is almost totally negated.
- Greater strength, durable façades, better moisture behaviour.
- As standard in 6 colours.
- Certified: KOMO certificate with product certificate no. IKB 1358 according to BRL1905

Application
Suitable for laying bricks of all possible types. Because of the increased tensile and flexural bond strength provided by OMNIFIX PVM, it is possible to achieve more radical profiles which until now were not possible using traditional methods. By utilising much thinner joints on both bed and head it is possible to create a completely new appearance using bricks. Because of the wide variety of water absorption rates inherent in bricks, OMNIFIX PVM is manufactured in 3 different types (A, B and C) making it possible to achieve the same rate of construction with all bricks. As a guide, Type A is most suitable for use with more porous handmade and stock bricks progressing up to Type C with bricks of Engineering quality or of a solid extruded nature. The frost resistance, compressive and flexural strength of OMNIFIX PVM make it suitable for use on any project built using traditional construction methods as well as more radical ideas and there are several existing schemes which illustrate the products versatility.

Preparation
- The site must be arranged for the use of thin layer mortar (scaffolding, water, electrical power, stacking and supply of bricks, sawing possibilities, etc.).
- Bricks must be free of grease and dust. Pre-moistening is not needed.
- Carry out any sawing beforehand.

Treatment instructions
- Preparation of OMNIFIX PVM is carried out by a purpose built mortar-pump and gun, which prepares, mixes and applies the mortar to the brick and requires only a water supply to add to the ready mixed compound or manually.
- Use the gun to apply the mortar directly onto the stretcher body of the bricks and a special frame is supplied for application to the heads.
- Clean water supply and the OMNIFIX PVM are put into the machine together before starting the mixing in following ratio: 4.8 – 5.2 litre of water to 25kg powder.
- The computer controlled mixing time is about 4 minutes and after a further 10 minutes the compound will achieve its optimum consistency and will remain in this state inside the machine.
- Bricks can be laid more quickly than by traditional methods and requires only one person to operate the pump and gun whilst another continues to lay the bricks.
- During any break in construction the mortar remains in the pump. When restarting, the mortar inside the length of hose should be pumped through and discarded. The discarded mortar should not be reintroduced to the mixer as it may act as a binding accelerator.
- If the adhesive is made manually the mixing time of 4 minutes must absolutely be respected.
- Manually: never make too much adhesive at once. Take a brick and hold it upside down. Apply adhesive to the brick to be laid on the back/underside in such a way that no mortar comes out of the front of joints when it is placed in the wall.
Supplementary advice on use
- Pump and gun should be kept protected during periods of extreme temperature and not stored in direct sunlight and the water should be of a sufficiently cool temperature.
- Work should not be carried out when frost is evident. Mortar of any kind will not bond properly to frost affected or frozen bricks.
- Should be protected from and during any periods of rain.
- OMNIFIX PVM is reologic pseudo plastic in character, which means it will remain fluid and flowing while moving and only starts to become set when left to stand.

Tools
- Mortar pump and gun
- Trowel
- Pointing trowel
- Sawing machine (wet)
- Measuring jug
- Mixing tub (manually)

Consumption
Normal stretcher bond work will use between 12 and 21 kg/m2 depending on the type of brick and its dimensions as well as the applied joint thickness.

Cleaning tools
Thoroughly clean equipment and tools immediately after use with clean water and then spray with tool oil.

Product composition
OMNIFIX PVM is a single component composition of pure Portland Cement, synthetic resins, calibrated sand (up to 2mm) and careful selected additives.

Technical properties
Satisfies the requirements stipulated in BRL 1905.
The under mentioned technical values are based on test results achieved in our own laboratory, at TNO-Bouw (NL), at the Technical University of Eindhoven (NL) and on various sites itself. They serve the purpose of information only, no claims can be accepted based on the following provided data:

- Form on delivery: powder
- Colours: grey, white, yellow, red, brown and anthracite
- Min. process temperature: > 0°C
- Processing time at 20°C: minimum of 2 hours
- Waiting time: none
- Setting time: Approx. 24 hours
- Hardening: by drying, hydraulic setting and polymerisation
- Max. grain size: < 2 mm
- Volatile solids: < 2.5 %
- Frost-resistance: yes
- Air pore level: < 12 % (v/v)
- Spreading: > 185 mm (+/- 10 mm)
- External certificates: KOMO and BÜV
OMNIFIX PVM
Adhesive, thin bed mortar for brickwork

<table>
<thead>
<tr>
<th>Specification:</th>
<th>Sort of Brick:</th>
<th>Ira value:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>strongly absorbent stones</td>
<td>&gt;30 g/dm²/min</td>
</tr>
<tr>
<td>Type B</td>
<td>moderately absorbent stones</td>
<td>5 to 40 g/dm²/min</td>
</tr>
<tr>
<td>Type C</td>
<td>non-absorbent stones</td>
<td>0 to 15 g/dm²/min</td>
</tr>
</tbody>
</table>

**Fresh mortar properties**
Pot life: >4 min (depending on type of stone and adhesive type A, B or C)
Mortar delivery: between 591 and 609 l/ton, depending on the water quantity applied
Volumetric mass: 1980 kg/m³

**Properties of hardened mortar**
Compression strength: M15
Bending tensile strength: > 4.5 N/mm²
Adhesive strength: after 28 days > 0.5 N/mm²; these values depend on the type of stone
Water absorption coeff. S: ≤ 0.03 kg per (m³ x sec 0.5)
Volumetric mass: approx. 1700 kg/m³

**Packing**
- In pe-bags of 25 kg.
- Stacked per 40 bags on one-way-pallets.
- Individual pallets are covered with a pe-stretch-hood.

**Storage and shelf life**
Storage can best be done in covered warehouses. The powder itself is moist-sensitive. In its original closed packaging and stored under the right conditions, OMNIFIX PVM has a shelf life of 12 months.

**Health and safety**
Omnifix PVM contains a/o. pure Portland Cement. Like all cement based products does it have an alkali reaction in water, therefore eyes and skin should be well protected. In case of contact, rinse with sufficient water. When contact with the eyes have occurred you are advised to obtain medical advice.

*More specific information about safety when working with cement-containing products is available on request.*
Manufacturer product safety data sheet

Date of publication/alteration: 14/01/2005
Valid until: 14/01/2007
Product nr.: 5410279 10040 t/m 10060
Page nr.: 01 (04)

1) Identification of the substance/preparation and company

Supplier details: Product (trade) name: Nr.: 
Ankerplast NV OMNIFIX PVM 10040 - 60
Nijverheidsstraat 14
2381 WEELDE
Tel: +32 14 65 62 85
Fax: +32 14 65 77 50

2) Composition and information on the individual ingredients

Hazardous ingredients: R-phrases: CAS-nr.: 
---- 36/37 14808-60-7

Remaining ingredients:
Copolymer < 2% Hazard symbols:
Quartz-sand 50 - 70 % Xi
Cement 20 - 40 %

This data is significant and specific for this product, but does not specify, nor give the complete composition of the product.

3) Hazards identification

4) First Aid measures

General information: ---
Respiration: fresh air
After contact with skin: wash off with plenty of water and use soap
After contact with eyes: rinse thoroughly with plenty of water during 15 minutes and seek medical advice.
Swallowing: seek medical advice
5) **Fire-fighting measures**

*Suitable extinguishing media:*
- water spray jet
- foam
- carbon dioxide
- dry powder

6) **Accidental release measures**

*Environmental precautions:* Do not allow to enter drains or waterways

*Methods for cleaning up:* Pick up mechanically

7) **Handling and storage**

*Handling:* Advice on safe handling: Avoid contact with skin and eyes

*Storage:* Material is to be stored dry

8) **Exposure controls/personal protection**

*General protective measures:* Avoid contact with skin and eyes, do not eat and drink during use of the product

*Personal protective equipment:*
- Respiratory protection: Dust mask
- Hand protection: Gloves
- Eye protection: safety glasses
- Body protection: protective clothing

9) **Stability and reactivity**

*Hazardous decomposition products:* ----

10) **Physical and chemical properties**

*Appearance form:* powder

*odour:* odourless

*pH value* as powder: n.a.

as mixture: 12 - 14
Melting point: n.a.

Solubility in water: neglectable

11) Toxicological information

Respiration: may have irritant effect
Skin contact: may have irritant effect
Eye contact: may have irritant effect
Swallowing: may have irritant effect
Specific effects: none

12) Ecological information

Biodegradability: the product is biological difficult degradable
Ecotoxic effects: n.a.
Further ecological information: n.a.

13) Disposal considerations

In accordance with local authority regulations

14) Transport information

Road transport: ADR Non-hazardous goods
RID Non-hazardous goods

Inland waterways: ADNR Non-hazardous goods

Marine transport: IMDG/UN Non-hazardous goods

Air transport: ICAO/IATA-DGR Non-hazardous goods

Dispatch by post: Permitted
15) Regulatory information

EEG classification: ----

Hazardous symbols: Xi irritant

R-phrases: 36/37 irritating to eyes and skin

16) Other information

This information is based on our present state of knowledge. It should therefore not be construed as guaranteeing specific properties of the products described or their suitability for a particular application.

Date of printing: September 8, 2015
Appendices

Appendix b - Reports and technical papers
The Role of Mortar Workability (Cohesivity) in the Rain Penetration of Masonry

by

G.K. BOWLER*, P.J. JACKSON** and M.G. MONK***

* Hanson Brick, ** Sampling and Scientific Services, *** Blue Circle Cement

ABSTRACT

The incidence of water penetration of masonry subject to wind driven rain appears to have increased in recent years. Various factors have been blamed, including climate change, increased use of cavity insulation and, above all, workmanship. Traditional lime mortars were reputed to provide excellent workability and good sealing properties. This paper considers the role of mortar cohesivity in producing weathertight joints. Laboratory tests on small masonry panels have shown that different mortar compositions produce widely differing resistance to water penetration with the most cohesive mortars providing the best sealing properties.

1. INTRODUCTION

Rain penetration of masonry is recognised as a potentially serious problem in Northern Europe (including Britain), in the United States and even Australia. Faults seems to have been increasing in Britain over the last 10 years or so. Defective cavity wall insulation is believed to be one relevant factor. Also, episodes of severe driving rain appear to occur more frequently and to affect larger areas of the U.K. than those indicated in earlier Driving Rain Index Maps[1,2].

In Britain, a considerable amount of research was carried out by BUTTERWORTH and SKEEN[3-4]. Test walls were built within steel channel frames to form the front of a sealed box structure. A fan was employed to create a negative pressure within the box, then water was sprayed at a controlled rate to flood the front face of the test wall. The back of this wall was usually painted with a white wash which served to show visually when and where water began to penetrate. Similar work was carried out by THOMAS[5].

A number of important points were established:

(i) High absorption bricks produced walls which (when dry) were initially more resistant to rain penetration than those built with low absorption bricks. This overcame effect gave several hours of protection.

(ii) Damp patches on the back of the test walls usually started along the mortar joints.

(iii) Mortar type affected rain penetration.

(iv) When bricks with low Suction Rate were employed, early water penetration was mainly through the perpend joints.

(v) Optimum bond between brick and mortar requires adjustment of the mortar consistency to suit the specific type of unit.

The findings relating to mortars were incorporated in BRE Digests and in the BS Code of Practice[6].

2. PRESENT PROGRAMME

The test rig developed by BRE requires quite large walls, so is time consuming and expensive. Experiments were, therefore, carried out on small half brick thick panels 3 bricks long by 4 courses high. High porosity clay bricks (pressed Flottons), low porosity clay engineering bricks, and low absorption concrete bricks were tested in combination with a range of mortars. A few panels were constructed by an inexprienced bricklayer in order to assess the workmanship factor.

After curing, the test panels were mounted horizontally in a deep metal tray with a cut-out base, and sealed around the edges with silicone sealer. Panels were tested by subjecting them to a constant head of water applied to their weather face (Figure 1). Typically, water heads of 25mm, 50mm and 75mm were employed representing constant saturation at wind pressures of 30, 60 and 90mph respectively. The latter value is equivalent to the worst storms normally encountered in the Outer Hebrides. The mortar mixes were designation (iii) and (iv).

Figure 1: Constant head water penetration apparatus

(a) Designation (iii) BRE General Purpose Mortar (GPM) is 1:1:5.5 (parts by volume) of ordinary Portland cement:hydrated lime:sand plus an air-entraining agent[7]. This mortar had been developed to provide a universal mortar which would combine good durability and workability and which could be used to construct both outer leaf brickwork and inner leaf blockwork. This concept received considerable support from the National House Building Council who recognised that in practice very few builders employ separate mortar mixes for the two leaves and tend to compromise in terms of desired properties. The background to development and the need to simplify mortar specification is described by HARRISON and BOWLER[8]. The mix used was made using a proprietary masonry cement containing a blend of OPC, hydrated lime and air-entraining agent at mix proportions of 1:3.5 (by volume).

(b) Some designation (iv) mortars were also made with this masonry cement at 1:5 (by wt).

(c) Designation (iii) traditional masonry cement mortar made up with a proprietary masonry cement containing Portland cement, finely ground limestone and an air-entraining agent at mix proportions of 1:4.5 (by volume) masonry cement:sand.

Masonry International Vol 10, No 1, 1996
Table 1

<table>
<thead>
<tr>
<th>Mix</th>
<th>Panel nos.</th>
<th>Drop Ball</th>
<th>Cohesive Rate of leakage (kg/m²/min) for absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CEA</td>
</tr>
<tr>
<td>(a)</td>
<td>F3</td>
<td>E/C1</td>
<td>12</td>
</tr>
<tr>
<td>(b)</td>
<td>F4</td>
<td>E/C3</td>
<td>12</td>
</tr>
<tr>
<td>(c)</td>
<td>F5</td>
<td>E/C5</td>
<td>9</td>
</tr>
<tr>
<td>(d)</td>
<td>F2</td>
<td>E/C2</td>
<td>11</td>
</tr>
<tr>
<td>(e)</td>
<td>F6</td>
<td>E/C8</td>
<td>9</td>
</tr>
<tr>
<td>(f)</td>
<td>F7</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>(g)</td>
<td>F8</td>
<td>nd</td>
<td>nd</td>
</tr>
</tbody>
</table>

Table 1: Properties of mortars used in test panels and results of leakage tests

<table>
<thead>
<tr>
<th>Mix</th>
<th>Cohesive</th>
<th>Rate of leakage (kg/m²/min) for absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>BSCEM (tile adhesive, thin joints)</td>
<td>0.0076</td>
</tr>
</tbody>
</table>

Figure 2: Leakage rates at different heads of water

However, deliberately poor technique, such as not filling the joint properly, did lead to serious leakage.

4. The mortar mix proved crucially important to the brickwork leakage rate.
5. The two masonry cements, when used in designation (iii) mixes, produced very weathertight joints. Masonry cement mortars gave the best performance of those examined.
7. The panels with the most leakage were those made with mortar types of poorer workability as defined by Cohesivity indices.

The serious problem of rain penetration of masonry has been blamed on poor workmanship (and possibly) climate changes. The test programme has indicated the importance of good mortar workability which helps the mason to fill joints properly and improves the brick/mortar bonding. More work is needed to confirm these preliminary findings, but it seems evident that weathertightness of joints should be a major aim of masonry design.

REFERENCES
2. BUILDING RESEARCH ESTABLISHMENT. Bidz (Revised edition 1994).

3. RESULTS AND DISCUSSION

Results of the leakage rates measured for the most onerous condition (75mm WG) are also given in Table 1. Data obtained from a mortar test series covering three different heads of water are illustrated in Figure 2.

The following observations apply to the initial tests:
1. The more absorbent bricks built with dry units and a proprietary thin joint tile adhesive showed no leakage for 6h and subsequent leakage was very low. This indicates that leakage of water through even porous bricks is almost negligible.
2. Overall, leakage rates through panels built with low-absorption bricks were lower than for the corresponding panels built with Portland. However, (1) above suggests that this is due much more to the effects of the porous units on the mortar joints - or on the brick/mortar interface.
3. There was no clear difference in performance between equivalent panels built by professional or amateur bricklayers.
APPENDIX
BRE Report on the upgrade of the Ecohouse to Code levels 5 & 6

Following completion of the Ecohouse in June 07 and the achievement of level 4 status under the code for sustainable homes an investigation was subsequently undertaken by BRE into the prospect of the house being upgraded to achieve Code levels 5&6.

The full report is outlined below.

Part one - an investigation into the potential improvement options to the Ecohouse as it currently stands
Part two - the specification upgrade needed to achieve code levels 5 & 6.

The key issues are summarised as follows;

Potential Improvements to the Ecohouse

- Improvements to reduce the impact of thermal bridging within the structure
- Increased insulation to the underside of the sloping ceiling at roof level to improve U value
- Introduction of a mechanical ventilation and heat recovery system (MVHR system is a requirement of all airtight houses at levels 5&6).

All of these modifications will improve the thermal efficiency of the house and consequently reduce the need for additional heating power input. However the house would still require input from further renewable sources to achieve Codes 5 & 6.

The most straightforward way of providing this input is by introducing a significant area of Photovoltaics.
Needless to say achieving Code 5 would require a smaller area of PV’s than Code 6.

A further suggestion involves changing the current Ground Source Heat Pump to a Woodchip boiler. Woodchip boilers are considered to be fuelled by totally renewable sources unlike a GSHP. However as Hanson has a vested interest in promoting Formpave's Aquaflow and GSHP system this is not a preferred option.
Although the suggested structure improvements should not be prohibitively expensive to carry out, the installation of significant areas of PV’s and MVHR system could be. Furthermore finding enough appropriate and available roof/wall elevation on which to place the required area of PV’s is currently impractical.

Whilst it may be possible to get free or subsidised supplies from interested manufacturers of these systems it must be noted that all of the proposed improvements will not, on their own, achieve a higher code rating for the detached Ecohouse.

The BRE report indicates that it is possible for Flats, Semi-detached and Terraced dwellings to achieve code levels 5&6 with the fabric details used in the Ecohouse. However a significant improvement in overall levels of insulation and air tightness is required for a detached version to achieve these levels due to the higher ratio of external walls to internal floor area (and in the Ecohouse case the large expanse of ceiling area at 1st floor level is an added disadvantage).

To improve the overall fabric insulation of the current Ecohouse would require significant and expensive alteration works that would most likely include adding a lining to the internal face of the external walls. This could detract from one of the key differentiators of the house i.e. thermal mass (although there could be sufficient thermal mass in the area of concrete floors and staircase for it still to perform reasonably well).

Following further discussions with Gavin Hodgson of BRE’s energy department the following points are also worthy of consideration;

1. Biomass as a fuel is likely to be re-rated taking into account both the scarcity of the crop and the distances needed to transport the pellets. This could change the current emphasis favouring this form of renewable heating.
2. There is to be a change to the current methodology used for calculating SAP in the 2009 update. This is likely to increase the CO2 emissions attributable to the use of mains Electricity making direct electric heating less attractive than is currently the case (although heat pump efficiencies are also increasing all the time).
3. In the longer term Electricity Companies have agreed a set reduction in CO2 levels with the Government in the production of electricity and if they are able to bring these reductions through it could significantly improve its prospects. (It may mean that before 2016 is here the use of electricity with a heat pump may even outperform Biomass).
4. Projects using ‘near site’ community heating supply rather than ‘on site’ generation are likely to be more favoured leaving the way open for increased use of Geothermal Installations that are currently looking to be too costly for individual houses.

5. The amended Green Guide coupled with improvements in responsible sourcing schemes targeted by the concrete industry should enable cementitious based products to achieve much higher ratings in the near future than is currently the case. This will improve associated energy calculations under SAP and along with the further points available under the materials section of the code will improve the materials overall performance under the CSH.

My own conclusion after considering all of the issues and discussing the alternatives with various BRE personnel is that we should not undertake the physical upgrade of the house to Code 5 or 6 for the following reasons;

- The house performs well at Code 4 and is still one of the most relevant constructions on the Innovation Park because of it and will remain so for at least another couple of years.
- Moving it to Code 5 will provide little in the way of marketing profile as Code 6 would be the only real motivation and both options will be very costly, disruptive and could even undermine the overall design ethos.
- Achieving Code 6 will only place us at the same level as the Barratt house currently due for completion on the adjacent plot and which undoubtedly will get the higher publicity.
- Although we may not have the physical construction evidence we can provide BRE documentation indicating the steps that can be taken to design a similarly constructed house or flat to Code 6.
- Furthermore by 2016 a Code 6 house is unlikely to be as design constrained as some of the houses being constructed today and we are quite at liberty to indicate that to any interested parties wishing to discuss our decision to remain at Code 4.
- Finally and probably more importantly we need to consider how we wish to re-profile and differentiate the house for Offsite 09 so any spend on alterations should be geared towards this end.

Offsite 09 and the Hanson Ecohouse
The house is on a 2 year tenancy agreement with BRE that is due to expire at the end of May 2009. Technically at that time the house is due for demolition and clearance. This will involve spending a substantial amount of money (maybe £50k).

The other alternative would normally involve some demonstrable change to the property in order that it provides a new and different aspect to attendees of the proposed Offsite 09 exhibition.

However following discussions with the Director responsible for the park the extent of the change required by BRE may not be too onerous. He agrees that the Code 4 house is still very relevant for 09 and has indicated that the theme for 09 will all be about Community living.

It is hoped that BRE can obtain planning permission to use an area of unused land across the other side of the road adjacent to the Stuart Milne house. This will release another 4 to 5 plots that BRE already have clients for. The intent is for these houses to be linked to those already on the Open Hub network (like the Ecohouse) and to perform as a linked community. This may even extend to the supply of renewable community power.

This would allow us to focus on demonstrating to exhibition attendees what we have learned ‘2 years on’. BRE acknowledge that there is a shortage of practical know how and of what works and what doesn't in the industry and are keen for Park Partners to demonstrate these issues at Offsite 09.

Choosing to concentrate more in this area should allow us to reduce further spend and enable us to present the results of the ongoing energy data monitoring initiative within the overall theme of the event.

I will be arranging the next meeting of the Ecohouse Innovation Group shortly at which time the report can be discussed in more detail and the various alternatives open to us for Offsite 09 compiled for submission to the Senior Team.
Hanson Building Products’ second house constructed in the grounds of the Building Research Establishment at Watford aims to provide a concept dwelling that brings together many of the company’s latest developments in sustainable modern masonry construction and ‘Smart’ living.

The Hanson EcoHouse™, officially opened at the Offsite 2007 exhibition on 11th June, effectively demonstrates the progress made since Hanson House 1 (HH1) was built in 2005. Innovations trialled on HH1 have been refined and incorporated into a purpose-designed dwelling that shows all the benefits of offsite fabrication, high thermal mass and natural ventilation that will assist in the achievement of the zero carbon target that housebuilders and developers will have to meet by 2016.

The house, designed by architects TP Bennett, has been created with the client firmly in mind. Mark Stewart, director of TP Bennett, explains: “It was important for us to come up with a design appropriate to Hanson, whilst incorporating the key elements of the brief – modern methods of construction, sustainability and affordability”.

The design principle of the traditional brick kiln has been taken as the inspiration for the form of the house, utilising the ‘stack effect’ to ventilate the accommodation through a distinctive roof lantern. The lantern is ‘intelligently’ operated to open and close as required to meet the prevailing weather patterns, and so regulate internal air temperature. The rather unusual shape of the roof is further emphasised by vertically run zinc sheeting, using Hanson’s Arden Special Reserve facing brick with stack-bonded brickwork to complete the building’s distinctive appearance.

One of the biggest challenges for architects in designing homes is the need to respond to climate change and how to keep buildings cool. Hanson EcoHouse™ take’s full advantage of the benefits of traditional concrete/masonry construction with its high thermal mass to create a structure that copes efficiently with the temperature extremes of summer and winter. This is in direct contrast to more lightweight structures that are unable to benefit from this inherent feature.

As in Hanson House 1, the main structure is constructed using masonry panels manufactured off-site in a controlled factory environment, bringing the benefits of high quality and speed of construction with little or no site waste. This compares with an industry average of 20% wastage incurred in on-site construction that can also be more susceptible to weather delays and difficulties.

Within this context, the Hanson EcoHouse™ demonstrates a range of existing and innovative products that can make substantial contributions towards zero carbon rating. They are:

- A new walling system that provides complete pre-insulated and pre-finished brick/block cavity walls in panels up to 9 metres by 3 metres. The panels are factory-made, ready to transport to site and install directly into position. Fully automated machinery can provide the efficiency of one week’s site work in just one day in the
factory. The process ensures a high degree of air tightness between the individual elements, and the units can be manufactured to enable electrical conduit and sockets, etc, to be pre-fixed in the factory. Although a stack-bonded format will be used on the demonstration house, the machinery is capable of producing a wide variety of brickwork patterns. Because the system uses conventional bricks and blocks, the system has a further advantage in that it permits extensions and modifications to the original structure in a traditional way.

- Market-leading, super-insulated Jetfloor for the ground floor which easily exceeds current Part L requirements of the Building Regulations.

- Pre-stressed Hollowcore units for the first floor providing thermal mass, long spans, excellent fire and sound resistance, and complete freedom of partition wall layout.

- Pre-cast staircase, with the inherent strength, durability and squeak-free properties of pre-cast concrete that can be craned into position at the same time as the floor units, providing immediate working access.

- Formpave’s Aquaflow sustainable urban drainage system that uniquely combines with a water retaining layer, supporting a ground source heat pump to provide a highly efficient underfloor heating supply.

The building also features other sustainable products, including high performance windows with three-layered, argon-filled glazing, high performance external doors, sophisticated wall coatings and solar panels. Provision has also been made for the installation of a disabled lift platform.

The house contains the latest in ‘Smart’ building solutions technology that enables the remote operation of heating, lighting, energy monitoring, security provision and an interactive web-based hub that enables full community support for health, education, welfare and leisure.

With housing associations and local authorities seeking cost-effective, durable and flexible dwellings, the Hanson EcoHouse™ provides all of these benefits, using factory manufactured components with fast build times and proven whole-life costings.
SAP Hanson report

Prepared for: Gerry Feenan Hanson

16th April 2008

Client report number 121043
Prepared by

Name     Gina Yuzbasioglu
Position Senior Consultant

Signature

Approved on behalf of BRE

Name     Gavin Hodgson
Position Senior Consultant
Date     16th April 2008

Signature

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E enquiries@bre.co.uk
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Customer Satisfaction Survey

Please assist us in improving our service to you by giving us your feedback. All replies are treated as commercial in confidence and should be returned to Corporate Marketing at BRE.

Customer: Hanson

Project Title: SAP Hanson report

BRE Report Number: 121043

Project Manager: Gina Yuzbasioglu

How would you rate the quality of service?  
- Unsatisfactory
- Needs Improvement
- Meets Requirements
- Exceeds Requirements
- Not Applicable

Did we understand and meet all your needs?  
- Unsatisfactory
- Needs Improvement
- Meets Requirements
- Exceeds Requirements
- Not Applicable

Did we deliver on time?  
- Unsatisfactory
- Needs Improvement
- Meets Requirements
- Exceeds Requirements
- Not Applicable

Did we provide value for money?  
- Unsatisfactory
- Needs Improvement
- Meets Requirements
- Exceeds Requirements
- Not Applicable

How would you rate the clarity of our written reports?  
- Unsatisfactory
- Needs Improvement
- Meets Requirements
- Exceeds Requirements
- Not Applicable

How do you rate our technical competency?  
- Unsatisfactory
- Needs Improvement
- Meets Requirements
- Exceeds Requirements
- Not Applicable

Would you use our services in the future?  
- Yes
- No

Would you recommend our services to other clients?  
- Yes
- No

We would appreciate your comments on how we could improve our service to you:

Completed by:

Name:

Email:  
Telephone:

Date:

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Executive Summary

This report includes 2 sections. The first section was originally produced in December 2007 and details the potential improvements which can be made to the existing Hanson House II on BRE’s innovation park. The second section evaluates the specifications required to achieve CSH lv. 5 and lv. 6 of the Code for Sustainable Homes for a variety of build forms and then relates this to Hanson’s current product offerings.

Highlights from each section are as follows:

Section 1: Evaluation of potential improvements to Hanson House II

- Six scenarios are modelled to show the impact of various improvements on the SAP rating and emissions reductions.
- Of the improvements modelled that could be implemented to the existing house it is felt that the most significant would be to improve the thermal bridging to 0.04 W/mK, add a mechanical ventilation system with heat recovery, and insulate the sloping ceiling.
- If these improvements were made then the lowest photovoltaic provision in conjunction with the existing heating system would be 3.4 kWp for CSH level 5 and 5.8 kWp for level 6.
- By changing to a wood chip boiler these requirements would be reduced to 1.9 kWp for level 5 and 4.2 kWp for level 6. Associated embodied energy and fuel supply issues should be considered before a decision were made to replace the existing heating system.
- Future houses should optimise the fabric envelope at the design stage to eliminate the need for a conventional heating system, thereby offsetting the cost of better fabric measures.

Section 2: CSH 5 & 6 specification requirements for build form types

- The Hanson Quickbuild system is more than capable of achieving CSH lv 6 for semi-detached and end-terraced dwellings, however detached dwellings need exceptional fabric performance to achieve a HLP of 0.8 W/m²K (typically U-values of 0.10 W/m²K or better with high performance triple glazing). The Hanson Quickbuild system does not meet this elemental requirement.
- Mid-terraced dwellings and flats are able to achieve a HLP of 0.8 W/m²K with relatively common practice U-values, thus the Hanson Quickbuild system is suited to these scenarios, although MVHR is required to enable this.
- The use of Whole House Mechanical Ventilation with Heat Recovery (MVHR) is essential for almost all dwelling types to achieve a HLP of 0.8W/m²K – ventilation losses when specifying natural ventilation are too high to overcome in almost all instances by specifying improved fabric performance. Selecting a SAP Appendix Q MVHR system provides additional benefit.
Contents

Section 1: Evaluation of potential improvements to Hanson House II 5
   Description of the project 5
   Hanson II House as-built 6
   Hanson II House improvements 7
   Conclusion and recommendations 12

Section 2: CSH 5 & 6 specification requirements for build form types 13
   Stage 1: Achieving a 100% improvement over building regulations 16
      A) Build form, ventilation and its affect on HLP 16
      B) Calculating the Dwelling Emission Rate and the effect of fuel types 20
      C) Achieving a 100% improvement over the DER 22
   Stage 2: Achieving CSH lv 6 ‘True Zero Carbon 27
      A) Offsetting the CO₂ emissions from cooking and appliances 27
   Summary 29
Section 1: Evaluation of potential improvements to Hanson House II

Description of the project
The initial stage is to carry out a SAP calculation based on detailed measurements of the Hanson II House in order to establish the current energy performance of the building and to create a base case from which to measure modifications.

Technically feasible changes that would have a positive impact on the Ene 1 score will be identified and will be categorised into two groups:

- Readily undertaken with ‘relatively’ minor works
- Substantive alterations

This allows identification of the highest possible rating for the current dwelling

The report will then identify improvements and modifications that could be made to the existing dwelling in order to achieve the Carbon Dioxide emission reduction requirement for levels 5 and 6 of the Code for Sustainable Homes. Design/performance specifications are suggested for each level of the Code.

Changes will be identified that could be made to subsequent house to achieve the Carbon Dioxide emission reduction requirement for levels 5 and 6 of the Code for Sustainable Homes.

The evaluation will assess the following types of changes:

- Fabric standards and construction detailing
- Ventilation and air-tightness
- Heating systems
- Hot water provisions
- On and off site renewable energy sources
Hanson II House as-built

<table>
<thead>
<tr>
<th></th>
<th>SAP original</th>
<th>SAP final</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAP rating</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>TER</td>
<td>29.26</td>
<td>34.41</td>
</tr>
<tr>
<td>DER</td>
<td>15.07 kg/m(^2)</td>
<td>16.56 kg/m(^2)</td>
</tr>
<tr>
<td>DER over TER and CSH level</td>
<td>48.5% improvement (Code 4)</td>
<td>51.9% improvement (Code 4)</td>
</tr>
</tbody>
</table>

Changes to original specification identified:

- A pressure test has been carried out and an actual figure of 4.83m\(^3\)/(hr.m\(^2\))@ 50Pa inserted into the SAP worksheet. The design air leakage rate was 5m\(^3\)/(hr.m\(^2\))@ 50Pa.

- Some differences to initial dimensions have been amended following re-measurement and this has changed the TER. Notably, the wall type 1 dimensions have changed from 135.18m\(^2\) to 150.8m\(^2\). The roof type 1 area has changed from 48.8m\(^2\) to 73.84m\(^2\).

- Some minor changes to U-values have been identified

<table>
<thead>
<tr>
<th></th>
<th>Previous U-values W/m(^2)/K</th>
<th>New U-values W/m(^2)/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground floor</td>
<td>0.2</td>
<td>0.16</td>
</tr>
<tr>
<td>Walls 1</td>
<td>0.18</td>
<td>0.19</td>
</tr>
<tr>
<td>Walls 2</td>
<td>0.15</td>
<td>0.12</td>
</tr>
<tr>
<td>Roof 1</td>
<td>0.14</td>
<td>0.12</td>
</tr>
<tr>
<td>Roof 2</td>
<td>0.18</td>
<td>0.21</td>
</tr>
<tr>
<td>Roof 3</td>
<td>0.18</td>
<td>0.19</td>
</tr>
<tr>
<td>Door</td>
<td>0.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Windows 1</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Roof window 1</td>
<td>1.38</td>
<td>1.38</td>
</tr>
<tr>
<td>Roof window 2</td>
<td>1.38</td>
<td>1.38</td>
</tr>
</tbody>
</table>
Hanson II House improvements

Scenario 1: Existing house fabric and construction detailing

- Add insulation to critical junctions to improve psi values and reduce thermal bridging. These include changes of pitch in roof, under soffit to overlap frame of terrace windows, behind skirtings.

- A calculation of expected improvement has been made based on Energy Saving Trust work on three specific construction details (wall to floor, lintels, and ceiling level insulation to gable wall) which specifies an average generic y value of 0.04 W/m²K, with no element being worse than 0.07 W/m²K, and accredited details being used for all other junctions.

N.B. Before improvements are implemented, detailed calculations using actual measurements and accurate psi values (Ψ) should be made. It is anticipated that because of the number of junctions causing thermal bridging, further improvements above assumptions shown may be realised.

- Improve roof U-values by addition of 50mm polyurethane backed insulating board.

N.B. The service void will need to be removed and replaced on the internal (warm) side of the new insulation.

<table>
<thead>
<tr>
<th>Base case</th>
<th>Improve psi values (if carried out individually)</th>
<th>Improve roof U-value to average 0.1 (if carried out individually)</th>
<th>Combined improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAP</td>
<td>81</td>
<td>82</td>
<td>82</td>
</tr>
<tr>
<td>DER</td>
<td>16.56 kg/m²</td>
<td>15.59 kg/m²</td>
<td>16.31 kg/m²</td>
</tr>
<tr>
<td>CSH level (Ene 1 improvements only)</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

The benefits of installing high specification windows with insulated frames were considered too small to warrant calculation.

The above combined improvement DER or 15.34 kg/m² would result in a improvement over the TER of 55.4% (i.e. 3.5% improvement over the as built scenario).
**Scenario 2: Existing house ventilation and air-tightness**

The house was pressure tested and the areas of air leakage were established with a smoke pencil. These should be sealed and the house re-tested. The results of the smoke test are included in the Appendices and this should be referred to for details.

- Aim for an improved air leakage rate of 1 m$^3$/hr.m$^2$@ 50Pa Pascals
  
  This is a challenging target, but the results of the smoke test reveal many areas for improvement.

- A mechanical ventilation system with heat recovery is recommended for this level of air-tightness. For this scenario we have assumed the MVHR system being specified is a Vortice HRU ECO 3 from Appendix Q (this is currently the highest efficiency model).

<table>
<thead>
<tr>
<th></th>
<th>Base case</th>
<th>Increase air-tightness to 1 m$^3$/hr.m$^2$@ 50Pa (if carried out individually)</th>
<th>Add best case MVHR (if carried out individually)</th>
<th>Combined improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAP</td>
<td>81</td>
<td>81</td>
<td>82</td>
<td>82</td>
</tr>
<tr>
<td>DER</td>
<td>16.56 kg/m$^2$</td>
<td>16.38 kg/m$^2$</td>
<td>15.00 kg/m$^2$</td>
<td>15.00 kg/m$^2$</td>
</tr>
<tr>
<td>CSH level (Ene 1 improvements only)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

The above combined improvement DER or 15 kg/m$^2$ would result in a improvement over the TER of 56.4% (i.e. 4.5% improvement over the as built scenario).
Scenario 3: Existing house heating system

- Replace existing system with a wood chip fuelled boiler, gas boiler or air-to-air heat pump

<table>
<thead>
<tr>
<th></th>
<th>Base case</th>
<th>Wood chip boiler</th>
<th>Gas boiler</th>
<th>Heat pump air to air</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAP</td>
<td>81</td>
<td>85</td>
<td>82</td>
<td>79</td>
</tr>
<tr>
<td>DER</td>
<td>16.56 kg/m²</td>
<td>7.73 kg/m²</td>
<td>21.77 kg/m²</td>
<td>17.29 kg/m²</td>
</tr>
<tr>
<td>CSH level (Ene 1 improvements only)</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>
Scenario 4: base case ‘as built’ + 24m² PV

- Addition of photovoltaic cladding (24m² is the estimated maximum area of PV which can be integrated)
- Addition of 1m² of solar water heating panels to south elevation

<table>
<thead>
<tr>
<th></th>
<th>Base case</th>
<th>Addition of 24m² PV panels (vertical plane)</th>
<th>Addition of 24m² PV panels (45° plane)</th>
<th>Add 1m² solar water heating panels</th>
<th>Combined improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAP</td>
<td>81</td>
<td>85</td>
<td>87</td>
<td>82</td>
<td>88</td>
</tr>
<tr>
<td>DER</td>
<td>16.56 kg/m²</td>
<td>10.23 kg/m²</td>
<td>7.61 kg/m²</td>
<td>15.84 kg/m²</td>
<td>6.88 kg/m²</td>
</tr>
<tr>
<td>CSH level (Ene 1 only)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Scenario 5:

As per scenario 4, but using the biomass boiler base case and 24m² PV panels.

<table>
<thead>
<tr>
<th></th>
<th>Base case</th>
<th>Biomass boiler</th>
<th>Addition of 24m² PV panels at 30°</th>
<th>Combined improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAP</td>
<td>81</td>
<td>85</td>
<td>87</td>
<td>91</td>
</tr>
<tr>
<td>DER</td>
<td>16.56 kg/m²</td>
<td>7.73 kg/m²</td>
<td>7.44 kg/m²</td>
<td>-1.39kg/m²</td>
</tr>
<tr>
<td>CSH level (Ene 1 improvements only)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
Scenario 7: Different options to illustrate level of renewables required to achieve CSH level 5 and 6

<table>
<thead>
<tr>
<th></th>
<th>Base case GSHP</th>
<th>Base case improvements</th>
<th>Air to air heat pump</th>
<th>Gas boiler</th>
<th>Wood chip boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ψ value</strong></td>
<td>0.08 W/mK</td>
<td>0.04 W/mK</td>
<td>0.04 W/mK</td>
<td>0.04 W/mK</td>
<td>0.04 W/mK</td>
</tr>
<tr>
<td><strong>Insulate ceiling to sloping roof (area weighted average)</strong></td>
<td>0.13 W/m2/K</td>
<td>0.1 W/m2/K</td>
<td>0.1 W/m2/K</td>
<td>0.1 W/m2/K</td>
<td>0.1 W/m2/K</td>
</tr>
<tr>
<td><strong>Improve air-tightness and MVHR App. Q</strong></td>
<td>4.83 m³</td>
<td>1 m³</td>
<td>1 m³</td>
<td>1 m³</td>
<td>1 m³</td>
</tr>
<tr>
<td><strong>To achieve CSH 5</strong></td>
<td>PV required</td>
<td>4.5 kWp</td>
<td>3.4 kWp</td>
<td>3.5 kWp</td>
<td>4.1 kWp</td>
</tr>
<tr>
<td></td>
<td>SAP</td>
<td>92</td>
<td>99</td>
<td>98</td>
<td>103</td>
</tr>
<tr>
<td></td>
<td>TER</td>
<td>34.41 kg/m²</td>
<td>34.41 kg/m²</td>
<td>34.41 kg/m²</td>
<td>34.41 kg/m²</td>
</tr>
<tr>
<td></td>
<td>DER</td>
<td>-0.23 kg/m²</td>
<td>-0.23 kg/m²</td>
<td>-0.6 kg/m²</td>
<td>-0.35 kg/m²</td>
</tr>
<tr>
<td></td>
<td>Code level%</td>
<td>-101</td>
<td>-101</td>
<td>-100</td>
<td>-101</td>
</tr>
<tr>
<td><strong>To achieve CSH 6</strong></td>
<td>Additional allowable electricity generation kWh/m²/y</td>
<td>14 kWp</td>
<td>5.8 kWp</td>
<td>6 kWp</td>
<td>6.5 kWp</td>
</tr>
</tbody>
</table>
Conclusion and recommendations

It can be seen from the various scenarios presented that some measures will bring significant improvements in SAP ratings, whilst others may mean a lot of work and expenditure for very little result.

Of the improvements modelled that could be implemented to the existing house it is felt that the most significant would be to improve the thermal bridging to 0.04 W/mK and to add a mechanical ventilation system with heat recovery. These measures would reduce the demand load for renewables when progressing to levels 5 and 6 of the Code for Sustainable Homes.

If these improvements were made then the lowest photovoltaic provision in conjunction with the existing heating system would be 3.4 kWp for CSH level 5 and 5.8 kWp for level 6.

By changing to a wood chip boiler these requirements would be reduced to 1.9 kWp for level 5 and 4.2 kWp for level 6.

Each of the fabric measures evaluated produce relatively small improvements in SAP rating and emissions reductions due to the law of diminishing returns. Although the very best fabric standards have not been universally reached in the Hanson House envelope, they are of a good enough standard that minor additions show only a small improvement. However, it is still important to optimise the fabric specifications at the design stage to reduce the amount of renewable technologies required to achieve code levels 5 and 6.

Replacing the existing heating system with a wood chip boiler would bring about a significant reduction in DER. Careful thought should be given to this, however, as it is normally recommended when a boiler is due for replacement, since the embodied energy involved in replacing a new and working system is unnecessarily high. The reason for the improved ratings come not necessarily from increased efficiency but from the ‘carbon neutral’ status of biomass, but there can be associated issues with this, such as availability and location of supply. If a local supply of fuel is not available then there are emissions associated with transport.

For future houses it is recommended that the envelope of the house is optimised for thermal performance at the design stage. U-values of no more than 0.15 W/m²K for opaque elements and no more than 0.80 W/m²K for all glazed elements are suggested, which together with an air-tightness of 1 m³/(hr.m²)@ 50Pa Pascals will mean that there should be no need for a conventional heating system, since the heat requirement can be met through pre-heating the MVHR air. This will offset the cost of improved fabric standards. These measures should achieve level 4 of the Code for Sustainable Homes.
Section 2: CSH 5 & 6 specification requirements for build form types

For a dwelling to qualify as a ‘zero carbon home’ in accordance with the Code for Sustainable Homes (CSH) level 6 definition all of the criteria in table 1, as provided within the CSH technical guidance document¹, must be achieved.

Table 1: Headline requirements for a Code 6 ‘zero carbon home’

<table>
<thead>
<tr>
<th>Code Category</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling Emission Rate (Ene 1)</td>
<td>15 credits must be achieved, of which 14 of these credits must be attained by accomplishing a 100% reduction in the calculated SAP CO₂ emissions. As opposed to the currently SAP 2005 calculation, the resultant Dwelling Emission Rate must also include the CO₂ emissions resulting from the provision of mechanical cooling. To achieve ‘true zero carbon’ the final credit is awarded when all of the CO₂ emissions from all lighting, cooking and appliances in the home are offset by renewable technologies. This calculation is currently done separately to SAP. When renewable technologies specified to offset CO₂ emissions from lighting and appliances are not integrated into the building fabric, contributions supplied by renewable technologies connected via a private wire within the area of the building, it’s grounds, or elsewhere within the development may be used. If the renewable technologies are external to the development grounds the renewable capacity must be via private wire and also be in addition to existing plans. A private wire arrangement can be used to achieve any level of the CSH.</td>
</tr>
<tr>
<td>Building Fabric (Ene 2)</td>
<td>The dwelling shall have a heat loss parameter of 0.8 W/m²K or less</td>
</tr>
</tbody>
</table>

NOTE: to achieve CSH level 6 all mandatory standards and a total of 90 points, or greater, must be achieved in addition to the above.

HM Treasury’s Stamp duty land tax relief for zero carbon homes is linked to the CSH criteria provided in table 1, a dwelling achieving these requirements will be eligible for exemption if the dwellings costs less than £500,000. Dwellings costing more than this are eligible for a fixed £15,000 reduction in tax liability.

Meeting the requirements of Ene. 1

The basis of the calculations for Ene.1 is the Standard Assessment Procedure (SAP) for the energy rating of dwellings. The latest version is SAP 2005 with an update being planned for launch prior to the amendment for building regulations in 2010/11.

SAP is the underpinning calculation methodology used to assess whether or not a dwelling passes building regulations, and thus the extension of it’s use in the CSH is clearly of benefit. To understand how to achieve higher levels of the CSH the SAP methodology and how it is used within building regulations must first be understood. Some of these aspects are summarised in Figure 1.

¹ The CSH technical guidance document can be downloaded from www.planningportal.gov.uk
14 Development of Hanson II design and performance

Figure 1: How does SAP fit in with buildings regulations and CSH assessments?

SAP 2005
Designer enters the dwelling dimensions from plans along with fabric and service specifications into SAP software

- SAP software produces
  - a SAP rating (which is an energy cost rating) which has a scale of 1 to 100, where 100 represents zero energy cost; and
  - the dwellings carbon dioxide emission rate
- Because SAP is used for building regulations purposes it calculates the results based upon assumptions for household size and composition, heating patterns, geographical location and currently models space heating, water heating, ventilation and lighting only.
- SAP is also the basis for producing Energy Performance Certificates

SAP results are used to check compliance with building regulations

\[ \text{TER} = (C_H \times \text{fuel factor} + C_L) \times (1 - \text{improvement factor}) \]

- If the Dwelling Emission Rate (DER) of the modelled dwelling sourced from the SAP worksheet is less than the Target Emission Rate (TER) the dwelling is deemed to comply (provided other additional criteria are also achieved).
- Most SAP software packages include a built-in 'compliance checker' so the user does not need to calculate the TER manually.
- The TER is based upon a notional house of the same size and shape of the house being modelled. The fuel factor used is based upon the primary heating system specified (e.g. a mains gas boiler), with the CO\textsubscript{2} emissions due to space heating and hot water (C\textsubscript{H}) and internal fixed lighting (C\textsubscript{L}) of the notional house being calculated from the reference values provided in SAP 2005. These reference values are based upon a typical 2002 elemental specification, thus an improvement factor is used to increase the target - current building regulations require a 20% improvement over 2002 standards.

SAP results and resulting DER value is used to assess compliance with the CSH, with different improvement factors being adopted depending upon the desired level of Code required.

Some key differences and additional steps:
- The Code Assessor must also account for the CO\textsubscript{2} emissions arising from the specification of mechanical cooling – this is presently done manually as SAP 2005 does not model mechanical cooling.
- The DER calculation used assumes a fixed amount of internal lighting being provided, this is based upon the current building regulations requirement of 30%. Credit for specifying extra amounts of dedicated low energy internal lighting outlets is therefore not given within the calculation of CO\textsubscript{2} emissions up to CSH lv. 5 (as it is linked with the building regulations definition), however for CSH lv. 6 full credit is provided (please note that credit is also provided separately within Ene 3.)
- The Heat Loss Parameter is checked from the SAP worksheet (Ene 2.) – for CSH lv. 6 this needs to be 0.8 W/m\textdegree K or less.
- SAP does not currently model cooking and appliance use – thus a calculation to estimate CO\textsubscript{2} emissions from these sources is undertaken externally to software. This estimation based upon the floor area of the modelled dwelling. The calculated CO\textsubscript{2} emissions for cooking and appliances must be offset in addition to the 100% reduction in CO\textsubscript{2} emissions calculated as a part of the SAP DER calculations.
Thus as can be seen from figure 1 there are two key stages for designers to consider when designing a ‘True Zero Carbon’ dwellings in accordance with the CSH criteria:

**Stage 1: Achieving a 100% improvement over building regulations (i.e. CSH lv 5)**  
**Stage 2: Offsetting the CO\textsubscript{2} emissions from cooking and appliances**

The next section provides Hanson with guidance and an indication on the specifications required to achieve the above aims.
Stage 1: Achieving a 100% improvement over building regulations

Because SAP is used for checking compliance against the CSH the major factors which affect the result will need to be considered. To achieve a Code 6 ‘true zero carbon’ home it first makes sense to start with how the building fabric ‘heat loss parameter’ (HLP) requirement of 0.8 W/m²K may be achieved.

After this the remaining SAP variables can be adjusted to achieve a 100% improvement over the Dwelling Emission Rate. This will include examining the primary and secondary heating system efficiencies, their controls and the types of renewable technologies specified.

A) Build form, ventilation and its affect on HLP

The HLP is calculated in SAP as follows:

\[
HLP = \frac{(Total \text{ fabric heat loss} \div Total \text{ ventilation heat loss})}{Total \text{ floor area}}
\]

The total fabric heat loss includes the sum of all fabric element heat loss plus heat losses due to non-repeating thermal bridges. Because the total heat losses are divided by the floor area the ratio of total exposed fabric area to floor area is an important factor when designing a zero carbon home – compact build forms with less exposed area will be easier to specify to a 0.8 HLP.

Table 3 provides a summary of the balance required between fabric performance and ventilation system type depending upon the build form.
## Development of Hanson II design and performance

### Table 3: Indicative specification requirements to achieve HLP of 0.8 W/m²K

<table>
<thead>
<tr>
<th>Detached bungalow</th>
<th>Detached house</th>
<th>Semi-detached</th>
<th>End-terrace</th>
<th>Mid-terrace</th>
<th>3 Storey townhouse</th>
<th>Flat (exposed ground or roof)</th>
<th>Flat (mid floor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposed fabric to floor area ratio</td>
<td>3.2</td>
<td>2.4</td>
<td>2.2</td>
<td>2.2</td>
<td>1.7</td>
<td>1.4</td>
<td>2.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ventilation strategy</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systems without heat recovery (e.g. natural ventilation based upon local extract fans and trickle vents, passive stack ventilation or centralised mechanical extraction)</td>
<td>Not achievable</td>
</tr>
<tr>
<td>Whole House Mechanical Ventilation with Heat Recovery (SAP2005 default, 86% efficiency assumed)</td>
<td>Not achievable</td>
</tr>
<tr>
<td>Whole House Mechanical Ventilation with Heat Recovery (SAP Appendix Q 'best of class', 93% efficiency assumed)</td>
<td>HLP 0.76 with base case</td>
</tr>
</tbody>
</table>

### Recommendations for this dwelling type

- Specify a higher performance MVHR system and design to U-values of 0.10 W/m²K or better for walls, roofs and floors and use high performance triple glazing with a U-value of 0.8 W/m²K
- As per detached bungalow, although there is some possibility of a non-SAP appendix Q system being specified and the roof U-value possible being relaxed.
- Use a SAP appendix Q MVHR system as this will potentially allow the base case U-values to be relaxed to 0.15 W/m²K for the walls, roof and floors (although all other requirements remain).
- As per semi-detached dwelling, but the slightly lower HLP achieved also offers the potential to relax the window specification to 1.1 W/m²K
- The compact nature and reduced amount of exposed building fabric means that natural ventilation becomes an option with the base case specification, however it is probably more pragmatic to use an MVHR system, especially a SAP Appendix Q system, as the elemental specification can be relaxed inline with more common building practices, e.g. 0.2 W/m²K floors, 0.15 W/m²K walls, 0.13 W/m²K roof and 1.3 W/m²K high performance double glazed units.
- As per mid terrace, but better exposed fabric to floor area ratio because of the narrow frontage results in a very low HLP when specified with an SAP Appendix Q MVHR system thus allowing further relaxation of the building fabric to almost typical building regulations requirements.
- As per end terrace, but with better exposed fabric to floor area ratio because of the narrow frontage results in a very low HLP when specified with an SAP Appendix Q MVHR system thus allowing further relaxation of the building fabric to almost typical building regulations requirements.
- It is difficult to achieve the HLP of 0.8 using natural ventilation in this case, however it can be argued that an average of multiple dwellings in the block can be used to enable natural ventilation to be viable.

### Assumptions

- The base case for each example was as follows: Wall and Floor U-values s to 0.10 W/m²K
- Roof U-value to 0.06 W/m²K
- Insulated core doors to 1.0 W/m²K
- Triple glazed windows to 0.8 W/m²K
- Thermal bridging to 'EST enhanced construction details' spec (Ψ = 0.04)

The basic elemental specifications provided above are at the current limit of building technology and where ‘Not achievable’ has been indicated in table 1 the ventilation system is the only aspect which can be upgraded to assist the dwelling type in question in achieving the HLP target.

The examples ‘without heat recovery’ are based upon an airtightness of 5 m³/(hr.m²) @ 50 Pa for natural ventilation and also 3 m³/(hr.m²) @ 50 Pa with the centralised mechanical extract ventilation – in either case with the above examples improving the air-tightness to less than 5 and swapping the ventilation system made little impact on the HLP as the bulk of the heat losses are through ventilation heat loss. Please note that it is not recommended to rely solely upon natural ventilation when a dwelling achieves an air permeability of less than 5, a purpose provided whole house mechanical ventilation system should generally be considered in these cases.

Both of the whole house mechanical ventilation with heat recovery options assume an air-tightness of 3 m³/(hr.m²) @ 50 Pa – as with the natural ventilation examples varying the airtightness level between a value of 4 and 1 results in little overall difference to the HLP calculated within SAP. However, should a designer wish to make a potential saving by omitting a traditional heating system (inline with the PassivHaus principles) and air-tightness of 1 m³/(hr.m²) or better is generally required.

2 Please see www.PassivHaus.org.uk for further information.
As can be seen in table 3, the bulk of dwellings designed to achieve the CSH ‘zero carbon’ requirements will in most instances need a highly airtight building fabric, with continuous insulation and a whole house mechanical ventilation system with heat recovery. Natural ventilation is possible with some build forms however the ‘base case’ elemental specifications required are not commonly achievable at present and may not be practical for Hanson to implement at the time of writing.

What can be concluded for Hanson based upon table 3?

Assuming a current Hanson Quickbuild U-value of 0.18 W/m²K

- For detached dwellings it is not envisaged to be possible to meet the HLP requirement required by CSH lv. 6 using the current Hanson Quickbuild system. A U-value of 0.10 W/m²K would be required as all of the other elements are assumed to be current state-of-the-art with no further room for improvement. It is therefore preferable to pursue designs such as link or semi-detached.
- CSH lv 6 is achievable with the Hanson Quickbuild system for semi-detached or smaller build forms provided that an MVHR system is specified. A ‘best of class’ SAP appendix Q MVHR system is required to achieve the HLP for semi-detached dwellings, and for flats it will allow, in some cases, more pragmatic and readily achievable U-values to be adopted.
- CSH lv 6 is not presently achievable using natural ventilation and the Hanson Quickbuild system because the HLP would be too high (the HLP is only just achieved with wall U-values of 0.10 W/m²K).
- CSH lv 5 is readily achieveableas this is not directly linked to needed a HLP of 0.8 W/m²K, although the renewable contribution required will vary according to the ventilation strategy and fabric performance.

The following summary requirements state what range of U-values is generally required to achieve a HLP of 0.8 W/m²K

**Specification requirements**

<table>
<thead>
<tr>
<th>Doors and Windows</th>
<th>0.8 to 1.3 W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achieving a window U-value of 1.3 W/m²K would typically involve a high performance double glazed unit with a 12-16mm gap (Argon or Krypton filled) with a ‘super low-e’ coating and a thermal break. Windows with a BFRC window energy rating in band A would also likely achieve this elemental requirement.</td>
<td></td>
</tr>
<tr>
<td>Achieving a window U-value of 0.8 W/m²K requires triple glazing with a similar specification to above. Some windows, such as PassivHaus windows, also come with thermally broken frames thus helping to improve the overall window performance and reduce thermal bridging through the frame.</td>
<td></td>
</tr>
<tr>
<td>Insulated core doors are commonly available with U-value of approximately 1.0 W/m²K or better, one side benefit of insulated core doors is that they come as a door set and thus aid the achievement of improved levels of air permeability.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Floors</th>
<th>0.10 to 0.20 W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat loss through exposed floors depends on the size and shape; the type of floor; and the conductivity of the ground below it. Heat loss is greatest around the edges of the floor, so shape is important. Losses would differ between, say, a mid-terrace and an end-terrace dwelling. For a solid floor to achieve a U-value of 0.20 W/m²K an insulant with an R-value of better than 2.5m²K/W will generally be required (dependant upon floor shape).</td>
<td></td>
</tr>
</tbody>
</table>
A floor U-value of 0.10 W/m²K is not common practice and could require the use of innovative products, such as Vacuum Insulation Panels (VIP) or Aerogel insulation, in addition to standard insulation products to achieve the required level of performance.

**Walls**

- **0.10 to 0.20 W/m²K**

Wall U-values in the region of 0.10 W/m²K, is relatively common for some modern methods of construction such as insulated concrete formwork (ICF), Structurally Insulated Panels (SIPS) and some prefabricated timber frame products.

Traditional masonry products achieving U-values of less than 0.15 W/m²K are not common at the time of writing, however custom solutions are possible, for example a full fill 300mm cavity wall, the use of VIP panels within a partial fill cavity wall construction or the use of external insulation capable of achieving a U-value down to 0.10 W/m²K.

The Hanson Quickbuild product with a U-value of 0.18 W/m²K is sufficient in most circumstances provided that MVHR is specified, but a higher performance product would generally be required for detached dwellings. Perhaps the adoption of VIP or aerogel panels could be an option.

**Roofs**

- **0.06 to 0.13 W/m²K**

A U-value of 0.13 W/m²K is common building practice and requires 300mm of insulation between and above the joists. Achieving a U-value of 0.06 W/m²K would require in excess of 400mm of traditional mineral wool insulation, alternatively high performance insulation board could be used which would also provide the opportunity for boarding out a loft space providing a usable storage area. Insulating at the pitch of the roof would require insulation between the rafters to be supplemented with a high performance insulation backed plasterboard in most cases, although some prefabricated roofing system may also be available to achieve these levels of performance.

**Thermal bridging**

\[ Y = 0.04 \times \text{total exposed surface area (W/K)} \]

Accredited Construction Details (ACD) provide the minimum recommended performance levels of construction details, however the \( Y = 0.08 \) which is not of sufficient performance for most Zero Carbon Homes. A \( Y \) value of 0.04 of better is achievable by adopting the Energy Saving Trust ‘Enhanced Construction Details’, by adopting PassivHaus construction details or by calculating the thermal bridging using computer software for custom details (BRE Information Paper 497 may be consulted).

Hanson should seek to verify their construction details against these standards.

**Whole house mechanical ventilation (MVHR)**

Minimum heat recovery efficiency 66%

Recommended, ‘best of class’ Energy Saving Recommended SAP Appendix Q MVHR system specified with 150 or 125mm diameter rigid ductwork or 200mm rectangular rigid ductwork, specific fan power of unit should also ideally be less than 1 watt per litre per second (w/l/s)

The units installation and commissioning should also be inline with the installation checklists provided in www.sap-appendixq.org.uk
B) Calculating the Dwelling Emission Rate and the effect of fuel types

Once a HLP of 0.8 W/m²K has been achieved we can now examine how we can offset the total CO₂ emissions for the space heating, hot water and 30% fixed internal low energy lighting requirements as defined by the DER calculation. This will involve trying a variety of different primary and secondary heating systems and types of renewable technologies.

Unlike lv. 1 through 4 of the CSH where the primary concern is achieving a fixed percentage improvement over the TER for a CSH lv. 5 or 6 dwelling it is best to adopt a heating system which achieves the lowest absolute CO₂ emissions, as opposed to achieving the best percentage improvement over the DER.

The table 4 provides a breakdown of the total CO₂ emissions for the dwelling types provided within table 3 according to the heating system specified. The HLP for these examples has been fixed at 0.8 W/m²K, this therefore represents the worst case scenario acceptable for CSH lv. 6, with the renewable technology contributions being reduce somewhat for dwellings with better HLP values.

As can be seen in table 4, where mains gas is available there is little benefit between either specifying individual boilers or community heating (with or without CHP). However, the benefit of community heating is highly reliant upon the efficiency of the plant. Heating and hot water systems based on biomass provide a large reduction in total CO₂ emissions, and the benefit of biomass CHP is larger than that of a gas CHP unit because of the smaller CO₂ emissions achieved when generating electricity.

Heat pumps achieve similar levels of CO₂ emissions as gas based systems, with independent oil boilers and electric panel heating system being viable, but requiring larger amounts of renewable technologies to offset the higher CO₂ emissions.

The use of electric heating may be of advantage to Hanson however, as the resultant saving in specification could be used to specify renewable technologies such as solar hot water or private wire arrangement with community wind farms.

Solid fuel systems have not been considered within these scenarios as the resulting CO₂ emissions are too onerous.
In all cases the HLP has been fixed at 0.8 W/m²K

<table>
<thead>
<tr>
<th>Dwelling type</th>
<th>Mains Gas</th>
<th>Biomass</th>
<th>Grid electricity</th>
<th>Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A-rated Condensing boiler</td>
<td>Automatic feed boiler</td>
<td>Ground Source Heat Pump¹</td>
<td>A-rated Condensing boiler</td>
</tr>
<tr>
<td></td>
<td>Space Heating</td>
<td>Hot Water</td>
<td>Electricity</td>
<td>Total</td>
</tr>
<tr>
<td>Detached bungalow</td>
<td>213</td>
<td>594</td>
<td>339</td>
<td>1188</td>
</tr>
<tr>
<td>Detached house</td>
<td>369</td>
<td>713</td>
<td>554</td>
<td>1386</td>
</tr>
<tr>
<td>Semi-detached</td>
<td>299</td>
<td>645</td>
<td>434</td>
<td>1378</td>
</tr>
<tr>
<td>End-terrace</td>
<td>265</td>
<td>612</td>
<td>461</td>
<td>1328</td>
</tr>
<tr>
<td>Mid-terrace</td>
<td>268</td>
<td>612</td>
<td>461</td>
<td>1281</td>
</tr>
<tr>
<td>3 Storey townhouse (narrow frontage)</td>
<td>454</td>
<td>736</td>
<td>501</td>
<td>1586</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dwelling type</th>
<th>Community heating</th>
<th>Community heating</th>
<th>Panel heaters</th>
<th>Panel heaters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Space Heating</td>
<td>Hot Water</td>
<td>Electricity</td>
<td>Total</td>
</tr>
<tr>
<td>Detached bungalow</td>
<td>292</td>
<td>642</td>
<td>264</td>
<td>1135</td>
</tr>
<tr>
<td>Detached house</td>
<td>395</td>
<td>774</td>
<td>430</td>
<td>1599</td>
</tr>
<tr>
<td>Semi-detached</td>
<td>318</td>
<td>721</td>
<td>360</td>
<td>1399</td>
</tr>
<tr>
<td>End-terrace</td>
<td>281</td>
<td>686</td>
<td>327</td>
<td>1297</td>
</tr>
<tr>
<td>Mid-terrace</td>
<td>385</td>
<td>765</td>
<td>327</td>
<td>1297</td>
</tr>
<tr>
<td>3 Storey townhouse (narrow frontage)</td>
<td>491</td>
<td>852</td>
<td>527</td>
<td>1846</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dwelling type</th>
<th>Community heating with CHP</th>
<th>Community heating with CHP²</th>
<th>Panel heaters</th>
<th>Panel heaters²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Space Heating</td>
<td>Hot Water</td>
<td>Electricity</td>
<td>Total</td>
</tr>
<tr>
<td>Detached bungalow</td>
<td>184</td>
<td>517</td>
<td>264</td>
<td>985</td>
</tr>
<tr>
<td>Detached house</td>
<td>219</td>
<td>624</td>
<td>430</td>
<td>1373</td>
</tr>
<tr>
<td>Semi-detached</td>
<td>256</td>
<td>580</td>
<td>360</td>
<td>1196</td>
</tr>
<tr>
<td>End-terrace</td>
<td>227</td>
<td>527</td>
<td>327</td>
<td>1108</td>
</tr>
<tr>
<td>Mid-terrace</td>
<td>229</td>
<td>552</td>
<td>327</td>
<td>1108</td>
</tr>
<tr>
<td>3 Storey townhouse (narrow frontage)</td>
<td>396</td>
<td>662</td>
<td>527</td>
<td>1585</td>
</tr>
<tr>
<td>Flat (exposed ground or roof)</td>
<td>484</td>
<td>707</td>
<td>527</td>
<td>1605</td>
</tr>
<tr>
<td>Flat (mid-floor)</td>
<td>184</td>
<td>497</td>
<td>264</td>
<td>945</td>
</tr>
</tbody>
</table>

¹Biomass has an emissions factor of nearly zero (0.025 kg/CO₂ kWh), the factor is not zero because the CO₂ emitted in felling, processing and transporting the material needs to be accounted for. Biomass products should also be from a sustainable local source.

²Within SAP calculations it is possible to achieve negative CO₂ emissions for the heat generated by a biomass CHP unit. This occurs because the SAP calculation needs to work out the CO₂ factor for use in calculating the CO₂ emissions from the CHP unit. Because the biomass emission factor (0.025 kg/CO₂ kWh) is already close to zero when subtracting the CO₂ savings made by displacing electricity from the national grid (0.568 kg/CO₂ kWh) the resulting figure is negative. However the resulting emissions are not negative of course and the SAP calculator treats any negative emissions as zero within the total.

Table 4: Total annual CO₂ emissions according to heating and hot water system choice per dwelling type

If require the DER values can be calculated from the above figures by dividing the total CO₂ emissions by the total floor area of the dwellings as provided in table 3.

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From table 4 it is possible to estimate the typical range of remaining CO\textsubscript{2} emissions which will need to be offset to achieve CSH lv 5 (i.e. a 100% improvement over the DER).

Table 5: range of CO\textsubscript{2} emissions

<table>
<thead>
<tr>
<th></th>
<th>Space heating</th>
<th>Hot Water</th>
<th>Electricity</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Gas</td>
<td>184</td>
<td>491</td>
<td>497</td>
<td>822</td>
</tr>
<tr>
<td>Biomass</td>
<td>0</td>
<td>67</td>
<td>0</td>
<td>106</td>
</tr>
<tr>
<td>Electric (HP)</td>
<td>190</td>
<td>410</td>
<td>472</td>
<td>672</td>
</tr>
<tr>
<td>Electric (resistance)</td>
<td>418</td>
<td>899</td>
<td>917</td>
<td>1322</td>
</tr>
<tr>
<td>Oil</td>
<td>281</td>
<td>615</td>
<td>713</td>
<td>984</td>
</tr>
</tbody>
</table>

Within table 5 it can be seen that the range electricity requirements are relatively similar, however the space heating and hot water requirements vary considerably depending upon the fuel and system choice.

Choosing a heating and hot water system that has the lowest overall range of CO\textsubscript{2} emissions offers Hanson the opportunity to reduce expenditure on renewable technologies – once the space heating and hot water system has been chosen the only way Hanson can decrease the space heating requirements is to further reduce the HLP, and for the water heating requirements by specifying solar hot water panels.

**C) Achieving a 100% improvement over the DER**

Once a HLP of 0.8 W/m\textsuperscript{2}K or better has been achieved renewable technologies must be used if the goal of a 100% reduction in the Dwelling Emission Rate CO\textsubscript{2} emissions is to be achieved.

**Solar hot water (SHW)**

A correctly sized SHW systems sited within approximately 45° of due south can provide a significant contribution in offsetting hot water demand and associated CO\textsubscript{2} emissions. A typical domestic solar water heating system will be able to save 1,000–2,000kWh per year, which equates to approximately 50 per cent of a household’s annual domestic hot water needs. However the benefit of a SHW system depends upon the fuel it is offsetting.

Table 6: benefit of SHW depending upon the hot water demand, panel aperture size and the fuel being offset.

<table>
<thead>
<tr>
<th></th>
<th>Minimum Hot Water CO\textsubscript{2} emissions</th>
<th>Maximum Hot Water CO\textsubscript{2} emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zero</td>
<td>3m2</td>
</tr>
<tr>
<td>Gas</td>
<td>497</td>
<td>349</td>
</tr>
<tr>
<td>Biomass</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Electric (HP)</td>
<td>472</td>
<td>361</td>
</tr>
<tr>
<td>Electric (resistance)</td>
<td>917</td>
<td>619</td>
</tr>
</tbody>
</table>

Note: the above table uses SAP defaults for SHW, if a developer has information on the actual performance of the SHW system a larger benefit can be achieved.
As can be seen in table 6 a SHW system with an aperture area of 3m$^2$ to 6m$^2$ has a large impact on reducing CO$_2$ emissions due to the production of hot water, a SHW system larger than this offers little tangible benefit to an individual dwelling as all of the hot water generated cannot be utilised effectively. What can also be seen in table 6 is that specifying a SHW system offers little or no CO$_2$ saving when the heating and hot water is provided by a biomass system – this makes perfect sense because biomass is essentially zero carbon, so offsetting a nearly zero carbon source with a zero carbon source provides little or no saving. SHW systems should not be overlooked entirely for biomass based heating and hot water systems however because a SHW will have a financial benefit for the occupants as wood pellets, for example, are more expensive than mains gas. A SHW system could also mean that the use of a biomass system can be minimised during the summer.

Based upon the scenarios provided in table 6, assuming that Hanson specifies SHW in all circumstances, we can apply the typical CO$_2$ savings made by specifying a 3 m$^2$ SHW panel to the total CO$_2$ emissions calculated within table 4. The renewable technologies available to offset the remaining CO$_2$ emissions are Photo-Voltaics (PV) and wind turbines (micro or community wind). Whilst in theory there are other renewable energy sources which could be utilised these are the only technologies which, subject to planning constraints, are readily adoptable via a private wire arrangement and given credit for within SAP.

<table>
<thead>
<tr>
<th>Collector type</th>
<th>Area (m$^2$)</th>
<th>Total installed cost (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat-plate</td>
<td>3</td>
<td>2,000-3,000</td>
</tr>
<tr>
<td>Evacuated tube</td>
<td>3</td>
<td>3,000-5,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Typical CO$_2$ savings achieved for a 3m$^2$ SHW panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
</tr>
<tr>
<td>Biomass</td>
</tr>
<tr>
<td>Electricity (HP)</td>
</tr>
<tr>
<td>Electric (resistance)</td>
</tr>
<tr>
<td>Oil</td>
</tr>
</tbody>
</table>

Using table 7 it is now possible to estimate (using assumptions on site location etc…) the amount of PV or wind turbines required to offset the remaining CO$_2$ emissions.

It is possible for Hanson to calculate an estimate of the required amounts of renewable technologies using the savings CO$_2$ figures provided in table 8 to achieve a 100% reduction in the CO$_2$ emissions per dwelling type provided in table 7.

3 Please read ‘Solar water heating systems’ (CE131) from www.energysavingtrust.org.uk for further guidance
### Table 8: Typical renewable energy systems and CO₂ savings

<table>
<thead>
<tr>
<th>Renewable system</th>
<th>CO₂ saving (kg/CO₂/yr)</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Module of PV</td>
<td>95</td>
<td>• Based upon a typical high performance 1.5m x 0.8m PV module with a peak output of 200 Watts peak⁴.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• South facing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Little or no over-shading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Mounted at a pitch of 30⁰</td>
</tr>
<tr>
<td>Small scale roof mounted wind turbine</td>
<td></td>
<td>• Blade diameter 1.75m</td>
</tr>
<tr>
<td>Manufactures rated output of 1.25kW</td>
<td>Dense Urban 73kg</td>
<td>• The local annual average windspeed is 5 m/s or more.⁵</td>
</tr>
<tr>
<td></td>
<td>Low-rise / Sub-urban</td>
<td>• Hub height above building is 10m (Dense urban), 6m (low-rise/sub-urban) and 12m rural.</td>
</tr>
<tr>
<td></td>
<td>126kg</td>
<td>• No part of the turbine blade dips below the level of the ridge of the roof;</td>
</tr>
<tr>
<td></td>
<td>Rural 418kg</td>
<td>• There are no obstructions significantly larger than the building within a radius of 10 times the building height.</td>
</tr>
<tr>
<td>Mast Mounted wind turbine</td>
<td>Low-rise / Sub-urban</td>
<td>• Blade diameter 3.5m</td>
</tr>
<tr>
<td>Manufactures rated output of 2.5 kW</td>
<td>503kg</td>
<td>• Hub height is fixed at 12m (dense urban example not provided in this scenario)</td>
</tr>
<tr>
<td></td>
<td>Rural 1672kg</td>
<td>• All other assumptions as per small scale roof mounted wind turbine</td>
</tr>
<tr>
<td>Mast Mounted wind turbine</td>
<td>Low-rise / Sub-urban</td>
<td>• Blade diameter 5.5m</td>
</tr>
<tr>
<td>Manufactures rated output of 6 kW</td>
<td>1242kg</td>
<td>• Hub height is fixed at 15m (dense urban example not provided in this scenario)</td>
</tr>
<tr>
<td></td>
<td>Rural 4130kg</td>
<td>• All other assumptions as per provided 2.5 kW example.</td>
</tr>
</tbody>
</table>

Using the figures provided in table 8 if we look at the detached house example fitted with a mains gas A-rated condensing boiler a PV array of 2.07 kWp would be required to offset the remaining 981 kgCO₂/yr and achieve a 100% improvement over the DER (total CO₂ emissions divided by the typical CO₂ saving per module). This equates to over 10m² of roof area being required, excluding fixtures for the PV modules and the SHW system.

It can also be noted that where it is possible to use mast mounted wind turbines, such as in sub-urban or rural situations, they are capable of offsetting large amounts of the CO₂ emissions – a single larger wind turbine potentially being able to offset the CO₂ emissions for one, or more, dwellings. Conversely, the benefit of smaller scale wind turbines is reduced in dense urban environments.

---

⁴ At the time of writing the best commercially available PV panel, of similar size, has panel conversion efficiency of 19.3% and delivers up to 310 Watts peak.

⁵ An approximate figure for your location can be checked on the BERR website [http://www.berr.gov.uk/energy/sources/renewables/explained/wind/page16085.html](http://www.berr.gov.uk/energy/sources/renewables/explained/wind/page16085.html)
For both PV and wind turbine systems, grants and a list of approved suppliers and products is available on [www.lowcarbonbuildings.org.uk](http://www.lowcarbonbuildings.org.uk)

### Wind Turbines

The power available from the wind is related to the cube of the speed. In practice, this means that a 20% increase in wind strength will almost double the power available. It is therefore very important to maximise the incident wind on the turbine blades. Wind speed increases with height and even small increases in turbine height can produce significant improvements in performance.

Furthermore, two sites with the same annual average wind speeds may not produce the same amount of energy. Wind strength varies with the seasons, from day to day and even with time of day. So the wind speed distribution - that is to say, frequency and duration of different wind strengths - will affect output. The site with the greater range, i.e. more high speeds matched by lower speeds over the course of the year, will in fact generate more energy because of the cubic relationship between wind speed and power.

The Energy Saving Trust provides the following guidance on it’s website:

#### Roof mounted

Commercially available small scale wind turbines are generally more suited to rural areas due to siting and planning issues, as well as the higher average wind speeds more readily available.

These cost from £1,500. The amount of energy and carbon that roof top micro wind turbines save depends on several things including size, location, wind speed, nearby buildings and the local landscape. At the moment there is not enough data from existing wind turbine installations to provide a figure of how much energy and carbon could typically be saved. The Energy Saving Trust is monitoring up to 100 wind turbine installations; the results of this activity will help to provide further information for householders and developers considering this technology.

#### Mast mounted

Larger systems in the region of 2.5kW to 6kW would cost between £10,000 - £25,000 installed. These costs are inclusive of the turbine, mast, inverters, battery storage (if required) and installation; however it’s important to remember that costs always vary depending on location and the size and type of system.

Turbines can have a life of up to 20 years but require service checks every few years to ensure they work efficiently. For battery storage systems, typical battery life is around 6-10 years, depending on the type, so batteries may have to be replaced at some point in the system’s life.

### Photo-Voltaics (PV)

PV is perhaps the most suitable of all renewable energy technologies for widespread use in urban environments.

Because electricity is generated at the point of use, the energy loss and costs associated with transmission and distribution are avoided. There are however some important considerations regarding their selection and integration into urban areas. The main consideration being that there is usually a limited amount of space available for mounting PV modules.

In situations where roof space is a premium mono or polycrystalline modules have the advantage over amorphous silicon because, being more efficient, less surface area is required to provide the same output.
Conversely, amorphous/thin film modules can be deposited on a wide range of rigid and flexible substrates, making them ideal for integration into new-build dwellings.

A key advantage of PV in the urban environment is their potential to be integrated into the fabric of the building. No extra land space is required and the visual aesthetics of a building can be altered – either to be unobtrusive, or to give a clear indication of ‘green’ credentials.

The Energy Saving Trust provides the following guidance on its website:

**Costs**

The installed cost of a typical PV array for a dwelling is still relatively high. The total cost will vary significantly according to the module type, the application and the overall efficiency of the system.

A typical 1kWp (kilowatt peak) polycrystalline PV array would cost between £4,000 to £6,000.

A system of this size would be sufficient to supply the majority of the base load (the electricity required to run appliances and processes that are in constant use) for a typical UK dwelling, however a larger array size will be required to achieve CSH lv. 5 and 6 for most dwelling types.

Many PV installations, particularly in urban areas, will require regular cleaning to remove dust accumulation. In extreme cases, dust accumulation can cause power reduction of up to 10 per cent. At low angles of tilt, debris could be trapped which could lead to shading of part of the array. However systems can be designed and located so that they can ‘self-clean’ when it is raining. This can normally be achieved if the array tilt is at least 15 degrees.
Stage 2: Achieving CSH lv 6 ‘True Zero Carbon

In addition to achieving a 100% improvement over the DER and a HLP of 0.8 W/m²K a ‘true zero carbon’ home must also have net zero carbon dioxide emissions from use of appliances in the homes (i.e. on average over a year).

A) Offsetting the CO₂ emissions from cooking and appliances

Due to the lack of available SAP software at the time of writing, Code Assessors are supplied with an MS Excel Spreadsheet to calculate the additional CO₂ emissions due to cooking and appliances. The equation used to calculate this is provided within the Code technical guidance document – the equation is a function of the total floor area and estimated number of occupants (based on the floor area) – as a result dwellings with smaller floor areas have lower renewable energy requirements to achieve CSH lv. 6.

Table 8 provides a summary of the CO₂ emissions due to cooking and appliances which need to be offset in addition to the total CO₂ emissions calculated in accordance with the DER methodology (note however that where developers have specified greater than 30% low energy lighting they may take benefit for this within the Code lv.6 calculations).

<table>
<thead>
<tr>
<th>TFA</th>
<th>Number of Occupants assumed</th>
<th>Total CO₂ emissions due to cooking and appliances per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detached bungalow</td>
<td>67</td>
<td>2.35</td>
</tr>
<tr>
<td>Detached house</td>
<td>104</td>
<td>2.80</td>
</tr>
<tr>
<td>Semi-detached</td>
<td>88</td>
<td>2.71</td>
</tr>
<tr>
<td>End-terrace</td>
<td>79</td>
<td>2.60</td>
</tr>
<tr>
<td>Mid-terrace</td>
<td>79</td>
<td>2.60</td>
</tr>
<tr>
<td>3 Storey townhouse (narrow frontage)</td>
<td>118</td>
<td>2.83</td>
</tr>
<tr>
<td>Flat (exposed ground or roof)</td>
<td>61</td>
<td>2.18</td>
</tr>
<tr>
<td>Flat (mid-floor)</td>
<td>61</td>
<td>2.18</td>
</tr>
</tbody>
</table>

The CO₂ emissions provided above can be offset using PV, wind turbines or other renewable energy technologies as detailed in table 7. Using table 7 a PV an array of between 2 kWp or 10 PV module (Flat) and 2.8 kWp or 14 PV modules (3-storey townhouse) would be required in addition to the renewable technologies specified to achieve a 100% improvement over the DER to achieve CSH lv. 6.
Summary

- The Hanson Quickbuild system is more than capable of achieving CSH lv 6 for semi-detached and end-terrace dwellings (typically U-values of 0.15 or better and high performance double glazing), however detached dwellings need exceptional fabric performance to achieve a HLP of 0.8 W/m²K (typically U-values of 0.10 W/m²K or better with high performance triple glazing). The Hanson Quickbuild system does not meet this elemental requirement.

- With mid-terraced dwellings and flats are able to achieve a HLP of 0.8 W/m²K with relatively common practice U-values, thus the Hanson Quickbuild system is suited to these scenarios, although MVHR is required to enable this.

- The use of Whole House Mechanical Ventilation with Heat Recovery (MVHR) is essential for almost all dwelling types to achieve a HLP of 0.8W/m²K – ventilation losses when specifying natural ventilation are too high to overcome in almost all instances by specifying improved fabric performance. Selecting a SAP Appendix Q MVHR system provides additional benefit.

- Carefully considering fuel choice can have a major impact upon the amount of CO₂ – where available biomass offers a large improvement in CO₂ emissions, however there are practical issues in it’s use.

- The amount of CO₂ emitted from a dwelling is context sensitive, thus different dwelling types require different approaches. For example, as a proportion of total CO₂ emissions flats have lower space heating emissions but have higher emissions due to water heating – it makes sense to concentrate on the larger emissions sources.

- Whilst the provision of mechanical cooling is not accounted for within building regulations CO₂ calculations (although minimum performance requirement still apply) it is within the CSH. Designing out the need for mechanical cooling⁶ will make achieving a CSH target easier. Hanson products make good use of thermal mass thus helping to achieve this aim.

- Solar hot water provides sizable CO₂ savings and is highly recommended in all circumstances, although it’s CO₂ benefit when specifying heating and hot water systems using biomass is negligible, it does help to reduce the running costs and reduces the requirement to run the biomass system during the summer months.

And finally,

- The amount of renewable technologies required to achieve CSH lv. 5 and 6 varies considerably according to the fuel type used and dwelling type. However, assuming that solar hot water is provided Hanson should typically expect a PV array consisting of
  
  - between 2 (flat, biomass) to 26 (3-storey town house, panel heaters) PV modules to achieve CSH level 5, **PLUS**
  
  - an additional 10 (flat) to 14 (3-storey town house) PV modules being required to offset the CO₂ emissions due to cooking and appliances to achieve CSH lv.6

⁶ Please see the Energy Saving Trust Publication ‘Reducing overheating a designers guide’ (CE129)

[www.energysavingtrust.org/housingbuildings/](http://www.energysavingtrust.org/housingbuildings/)
• Wind turbines can be used to meet this requirement, with larger mast mounted turbines in sub-urban or rural locations provided the best benefit.
APPENDIX 8

Compressive strength of thin joint glued brick prisms

1 Introduction
Three sets of thin joint glued brick prisms were tested for their compression strength. The purpose of the testing was to establish which of three mortar thicknesses in the bed joint would yield the highest compressive strength, when used for glued brickwork walling.

2 Methods of construction
Three sets of thin joint glued brick prisms were constructed by Hanson Brick and delivered to Oxford Brookes University for compression testing (see picture 1). Each set consisted of five prisms, and each prism was built with six stack-bonded bricks. One set of prisms had 3 mm thick bed joint, the other set had 5 mm thick bed joint, and the final set had 10 mm thick bed joint. The thin joint mortar used for all 15 prisms was Ankerplast type B. However, the colour of Ankerplast mortar used for 5 and 10 mm thick bed joints was darker in colour compared to that used for 3 mm thick joint beds. In addition, the 3 mm thick mortar was recessed from the front faces of the prisms where it was used.

3 Method of testing
The prism specimens were tested in a compression test rig in the Structures Laboratory, Oxford Brookes University (see picture 2). Each of the prisms to be tested for compression strength was inserted in the centre of the base platen of the test rig, and in order to ensure that the applied load was evenly distributed on the areas of prism in contact with the upper and lower platens of the machine, plywood plates were inserted between the bottom and top of the prism and the machine’s upper and lower platens. A compression load was applied to the prism. In the first $\frac{1}{3}$ part of the test, a faster load rate was applied. In the second $\frac{2}{3}$ part of the test, a slower load rate was applied, i.e. 28 kN/min. The average load rate for the overall test was approximately 33 kN/min.

Picture 1: Three sets of thin joint brickwork prisms; 1A: prisms with 10 mm thick bed joints, 1B: prisms with 5 mm thick bed joints, 1C: prisms with 3 mm thick joint

Picture 2: A thin joint brickwork prism in the compression test rig before it was crushed
4 Results
The individual failure load relating to each prism and the mean stress relating to each set of prisms are given in the following table. According to this table, the 3mm thick bed joint prisms performed better in terms of compressive strength, as their mean stress was the highest, i.e. 17.5 N/mm$^2$, in comparison to the 5mm and 10mm thick bed joint sets of prisms. The mean stresses for the latter were not significantly different and were respectively, 15.4 N/mm$^2$ and 14.3 N/mm$^2$. It should be noted that the 10mm and 5mm thick bed joint bed prisms usually failed immediately after they had cracked. Whereas the 3mm thick bed joint prisms usually took longer time to fail after they had cracked. Failure modes of some of the prisms are given in picture 3, 4, 5 and 6.

Picture 3: Common failure mode of thin joint brickwork prisms with 10mm thick bed joints

Picture 4: Common failure mode of thin joint brickwork prisms with 5mm thick bed joints

Picture 5: Common failure mode of thin joint brickwork prisms with 3mm thick bed joints (View of front face)

Picture 6: Common failure mode of thin joint brickwork prisms with 3mm thick bed joints (View of back and side faces of early prism)
## COMPRESSION TEST ON THIN JOINT GLUED BRICK PRISMS

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<thead>
<tr>
<th>REF. NO.</th>
<th>DATE CAST</th>
<th>AGE DAYS</th>
<th>MORTAR THICKNESS</th>
<th>MASS KG</th>
<th>THEORETICAL DIMENSIONS</th>
<th>ACTUAL DIMENSIONS (mm)</th>
<th>TEST DATE</th>
<th>RATE KN/min</th>
<th>LOAD KN</th>
<th>MEAN LOAD</th>
<th>STRESS N/mm²</th>
<th>MEAN STRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>10mm</td>
<td>17</td>
<td>215 102.5 440</td>
<td>219 106 441</td>
<td>07/08/03 33</td>
<td>370</td>
<td>15.9</td>
<td>14.3</td>
<td>17</td>
<td>15.7</td>
<td>15.63</td>
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</tr>
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<td>2A</td>
<td>10mm</td>
<td>17</td>
<td>215 102.5 440</td>
<td>219 105 440</td>
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<td>15.7</td>
<td>12.5</td>
<td>17</td>
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<td>3A</td>
<td>10mm</td>
<td>16</td>
<td>215 102.5 440</td>
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</tr>
<tr>
<td>4A</td>
<td>10mm</td>
<td>17</td>
<td>215 102.5 440</td>
<td>219 106 440</td>
<td>07/08/03 33</td>
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<td>14.8</td>
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<td>21</td>
<td>14.8</td>
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<td>219 105 419</td>
<td>07/08/03 33</td>
<td>405</td>
<td>17.6</td>
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<td>07/08/03 33</td>
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<td>425</td>
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</table>
Hanson QuickBuild Prefabricated Panel System

The performance of prefabricated stone used in conjunction with high strength adhesives

1. Background and reference to correspondence from Axis Architects

2. Aims and Objectives

3. Construction of trial panels by Hanson Building systems
   a. Trial sample panel
   b. Buildability
   c. Workmanship
   d. Lifting and handling
   e. Properties of stone and adhesive
   f. Lateral load and flexural strength of wallets
   g. Cyclic frost testing

4. Conclusions and recommendations
1. **Background to evaluation and reference to queries raised relating to performance.**

Correspondence received in June 2008 from Architectural practice, Axis, expressed concern over the use of “epoxy mortar” in conjunction with natural stone masonry as opposed to use of lime mortars.

Specific concerns relate to

- Strength of adhesive mortar
- Mortar type and composition
- Compatibility of mortar / stone for durability
- Compatibility of mortar / stone for strength

2. **Aims and Objectives**

The aim of this report is to address those concerns raised in section 1(Above) ie to evaluate the performance of masonry and its material properties when using the Hanson QuickBuild adhesive system in conjunction with natural stones.

To this end Hanson Building Systems carried out a number of preliminary construction trials and tests :-

a. Construction of trial sample panel  
b. Buildability  
c. Workmanship  
d. Handling and transportation  
e. Physical properties of materials  
f. Lateral loading and flexural strength of wallets  
g. Cyclic frost tests.

Notes :-

These tests were carried out using stone samples from Stancliffe Stone.

Since all stone types have unique properties, it will be necessary to evaluate performance for each type specified as and when required.
3. Construction of trial panels by Hanson Building systems

a. Construction of trial sample panel

Samples of red and yellow sandstone were received in order to make a trial panel 6m long x 1.2m high.

Stone samples came from Stancliffe Stone.

b. Buildability

Standard Hanson QuickBuild mortar type B was used for the fabrication of stone panels. This was delivered by means of a gun and pump system with perpend and bed joint thickness of 10mm.

A single panel was constructed in approximately 1 working day. Additionally a number of wallettes were constructed in preparation for the lateral load test.

Techniques for setting out and handling of the stone units were found to be similar to traditional masonry. However, a level of expertise is required for applying the specialist adhesive.

All joints were pointed using the Hanson adhesive.
c. Workmanship

When using Hanson QuickBuild adhesives, colour and texture will be restricted to a specific range. However it is possible to use the adhesive as a primary bonding mortar and subsequently place a traditional mortar to achieve a desired finish.

d. Handling and transportation

Trial panels were lifted by means of lifting beam and two, 5 tonne capacity straps which were slung underneath the walls. Future panels will be lifted using our specialist perpend lifting frame.

No damage or cracking was recorded as a result of the lifting and handling process.

Panels are typically transported in batches of 4no. on a flat bed trailer lorry.

e. Physical properties of materials - stone

Tests were carried out on pieces of both the buff and the red stone previously used in the flexural strength wallette panels.

Results are as follows:

Buff stone;

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>53.6 N/mm²</td>
</tr>
<tr>
<td>Normalised strength</td>
<td>62.1 N/mm²</td>
</tr>
<tr>
<td>I.R.W.A.</td>
<td>0.4 kg/m²/min</td>
</tr>
<tr>
<td>24 hour water absorption</td>
<td>4.3%</td>
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<tr>
<td>Net density</td>
<td>2250 kg/m³</td>
</tr>
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</table>

Red stone;

<table>
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<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>39.6 N/mm²</td>
</tr>
<tr>
<td>Normalised strength</td>
<td>54.6 N/mm²</td>
</tr>
<tr>
<td>I.R.W.A.</td>
<td>2.6 kg/m²/min</td>
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<tr>
<td>24 hour water absorption</td>
<td>5.3%</td>
</tr>
<tr>
<td>Net density</td>
<td>2120 kg/m³</td>
</tr>
</tbody>
</table>

The tests were carried out on one specimen of each type, hence the results can only be taken as an approximate guide to the material properties which can be obtained from the manufacturer.

The normalised compressive strengths were calculated as the specimens were high in relation to their width (particularly the piece of red stone - c.100mm wide and 214mm high).
f. Physical proerties of materials – Adhesive mortar

Hanson QuickBuild high performance mortars comprise cement, sand and additives which allow:

- Rapid initial setting
- Increased final strength compared to traditional mortars
- Increased flexural strength
- Increased compressive strength
- Durability - resistance to cyclic freeze/thaw damage.

There are 3 basic mix types which cater for differences in the masonry suction rate and allow for optimum performance and ease of laying.

g. Lateral load and flexural strength of wallets.

Wallette testing in accordance with the brickwork test.

*Ref – BS EN 1052 :1999 for full test description.*

Mean flexural strength = 0.25N/mm²
(bending parallel to bed joints)

Characteristic strength $f_{xx}$ = 0.15N/mm²
(bending parallel to bed joints)

h. Cyclic frost test

Frost testing procedure was carried out in accordance with the standard clay brickwork cyclic frost test procedure.


The standard test for clay brickwork involves the construction of a masonry panel which forms one wall of the frost cabinet. This is subjected to repeated saturation, freezing and thawing. For brickwork to be deemed “frost resistant” it must survive at least 100 cycles of freeze / thaw. On visual inspection there must be no chipping, spalling or disintegration of either the bricks or the mortar.

For this specific test samples of stonework were used which had already been subjected to the flexural strength testing (and therefore already load tested to destruction).

Inspection of a samples showed no breakdown of material. There was also no damage observed between the stone / mortar interface.
Images show masonry samples upon removal from the freeze / thaw frost cabinet.

a. Construction and handling of masonry panels in terms of structural integrity and appearance was acceptable.

b. Flexural strength for the particular samples was adequate. Correct handling showed panels to be as strong as those built in clay brickwork. Flexural strength will vary depending on the stone type.

c. Durability / freeze thaw test – this was more severe than the standard test since the specific samples were exposed on all sides rather than on just the front face. No damage or degradation were recorded.

d. Compatibility of stone / adhesive mortar – Exposure to excessive saturation did not indicate any problems between the adhesive and stone interface nor any breakdown or degradation of stone at the adhesive joint.

It is anticipated that all stone materials would be tested by the manufacturers for compliance with the relevant Codes and Standards for stone masonry.

For the Hanson QuickBuild walling system it is standard practice to test any materials ie masonry (including natural stone, reconstituted stone, clay brick, aggregate block, aircocrete block) and adhesive mortars, which have not been previously been used to ensure integrity, suitability and fitness for purpose for a specific project requirement.

In the case of natural stone, due to the very high variation in properties such testing will always be carried out for first time use.
CONTENTS

FOREWORD....................................................................................................................iv
EXECUTIVE SUMMARY ...............................................................................................v

1 INTRODUCTION ..........................................................................................................1
  1.1 Introduction ...........................................................................................................1
  1.2 Research methodology and programme .............................................................1
    1.2.1 Literature review .......................................................................................1
    1.2.2 Steering Group formation ......................................................................2
    1.2.3 Information review ..................................................................................2
    1.2.4 Testwork schedule and review ................................................................2
    1.2.5 Peer review ...............................................................................................2
    1.2.6 Dissemination .............................................................................................3

2 THIN-JOINT GLUED BRICKWORK ........................................................................3
  2.1 Background to the technology ...........................................................................3
  2.2 Advantages ...........................................................................................................4
    2.2.1 Strength ......................................................................................................4
    2.2.2 Potential for prefabrication ......................................................................4
    2.2.3 Appearance and aesthetics ......................................................................4
    2.2.4 Durability ..................................................................................................5
  2.3 Introduction of the technology to the UK ..............................................................5

3 EXAMPLES OF EUROPEAN BUILDINGS WITH THIN-JOINT GLUED
   BRICKWORK ...........................................................................................................5
  3.1 Crawford Art Gallery in Cork, Ireland ..................................................................5
  3.2 Kuiper Bouwgroep office block, Arnhem, The Netherlands ..............................6
  3.3 Heysel Stadium (now King Baudoin Stadium), Brussels, Belgium ....................7

4 UK EXAMPLE OF BUILDING WITH THIN-JOINT GLUED BRICKWORK ...........7
  4.1 School of Architecture & Planning, University of the West of England ..........7

5 BUILDING CODES AND TECHNICAL REPORTS WITH RELEVANCE TO THIN-
   JOINT GLUED BRICKWORK ..............................................................................9
  5.1 The United Kingdom ............................................................................................9
  5.2 Europe ..................................................................................................................9
  5.3 Belgium ...............................................................................................................11
  5.4 Germany .............................................................................................................11
  5.5 Australia ............................................................................................................11
  5.6 The Netherlands ................................................................................................12
    5.6.1 Reports 1 and 2 .......................................................................................12
    5.6.2 Report 3 ....................................................................................................12
    5.6.3 Report 4 ....................................................................................................12
  5.7 Further reports .....................................................................................................13

6 MATERIALS AND STRUCTURAL DESIGN ..............................................................13
  6.1 Thin-joint mortar – particle size distribution .......................................................13
  6.2 Thin-joint mortar ..................................................................................................13
  6.3 Water penetration ...............................................................................................14
  6.4 Frost resistance ....................................................................................................14
  6.5 Compressive strengths ......................................................................................14
  6.6 Flexural Strengths .............................................................................................15
  6.7 Movement Joints ................................................................................................16
  6.8 Wall Ties ..............................................................................................................16
  6.9 Lintels ..................................................................................................................18

7 SITE PRACTICE ........................................................................................................19
  7.1 Introduction ..........................................................................................................19
  7.2 Results ..................................................................................................................19
    7.2.1 Machine reliability ....................................................................................19
    7.2.2 Power supply .............................................................................................19
7.2.3 Transportation of equipment around site and working access ..........20
7.2.4 Glue setting times and cold weather working ..................................20
7.2.5 Protection of brickwork materials and equipment during construction .20
7.2.6 Different brick types ........................................................................21
7.2.7 Treatment of perpend joints ..............................................................21
7.2.8 Attitudes and work practice of site operatives ......................................21
7.2.9 Interfacing with other trades ..............................................................22
7.3 Conclusions ............................................................................................22
8 CONSTRUCTION DETAILING AND ARCHITECTURAL ISSUES .....................22
  8.1 Appearance ...........................................................................................22
  8.2 Control of dimensions ..........................................................................23
  8.3 Movement joints ...................................................................................23
  8.4 Damp-proof courses ............................................................................23
  8.5 Weepholes ............................................................................................23
  8.6 Jointing and pointing ............................................................................23
  8.7 Ties .........................................................................................................23
  8.8 Coursing ................................................................................................23
  8.9 Frames ...................................................................................................24
  8.10 Site practice ........................................................................................24
9 Prefabricated brickwork panels .................................................................24
  9.1 Introduction ...........................................................................................24
  9.2 Advantages ...........................................................................................24
  9.3 Issues to consider with prefabricated brickwork panels .........................25
10 CONCLUSIONS AND ISSUES ARISING .......................................................26
  10.1 Thin-joint glued brickwork ...................................................................26
  10.2 EuroCode 6 ........................................................................................27
  10.3 Standards and tests ............................................................................27
    10.3.1 Thin-joint mortar ...........................................................................27
    10.3.2 Water penetration ..........................................................................28
    10.3.3 Frost resistance ............................................................................28
    10.3.4 Compressive strengths ...................................................................28
    10.3.5 Flexural strength tests ...................................................................28
    10.3.6 Movement joints ...........................................................................29
  10.4 Wall ties ................................................................................................29
  10.5 Site practice ........................................................................................29
  10.6 Construction detailing and architectural issues ......................................30
  10.7 Prefabrication ......................................................................................30
  10.8 The next steps .....................................................................................30
  10.9 Further research and development ......................................................30
APPENDIX 1
APPENDIX 2
APPENDIX 3
APPENDIX 4
APPENDIX 5
APPENDIX 6
APPENDIX 7
APPENDIX 8
APPENDIX 9
BIBLIGRAPHY
FOREWORD

This report was prepared by Dr Bousmaha Baiche and Dr Nicholas Walliman of the Technology Group, Oxford Institute for Sustainable Development, Department of Architecture, School of the Built Environment, Oxford Brookes University, with data compiled by the project partners. The work leading to the report was carried out under a contract to DTI as part of the 2001 Partners in Innovation (PII) programme.

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Website

This report and other information can be seen on:

www.thinjointbrickwork.co.uk
EXECUTIVE SUMMARY

This report is submitted in accordance with the requirements of the fourth project milestone of the DTI PII project, ref. F-01-UOXB2: Thin-Joint Glued Brickwork. It is based on the work of the steering group and has been developed from previous drafts of the consultation document. Prior to the final report, a workshop was held for construction specialists, to disseminate the research findings, and get expert feedback from peers.

The research has produced essential background, experimental and practical information about thin-joint brickwork, sufficient to inform construction professionals how to apply this technique in the UK. The content of the report is summarised below:

• Thin-joint glued brickwork is used increasingly in mainland Europe. Only one building project in the UK is known to have used this technique. This is briefly reviewed, as are some notable buildings abroad. The characteristics and advantages of thin-joint glued brickwork are described.

• The working practices and tests used so far in the countries applying this technique refer directly to the national codes of the respective countries. Some of them are briefly discussed and a list of publications is provided. Caution is required in transferring test results and codes to the UK.

• EuroCode 6: Design of Masonry Structures (PrEN 1996-1-1) is now issued for formal vote and is well passed the development stage. It contains sections relating to brickwork using ‘thin layer mortar’. These are discussed in relation to UK standards, in particular the difficulties invoked by the limitation to maximum 3mm thick joints. An increase to at least 4mm is recommended. The term ‘thin-joint’ is used in this report to distinguish it from the restrictive EuroCode 6 ‘thin layer’ definition.

• Tests were carried out on thin-joint mortar, brick couplets, prisms, wallets and panels, at Oxford Brookes University, the Hanson Laboratory at Stewartby and at CERAM. Compared with conventional brick construction, these tests indicated enhanced mortar compressive strength, faster setting times, enhanced panel compressive and flexural strength. In most cases these occurred only under certain conditions. Frost resistance depends on the quality of the bricks and water penetration is affected by mortar curing and adhesion as well a brick quality.

• Available and potentially suitable wall ties were investigated and tested for compression and tension. The thinness of the joints and the non-alignment of bed joints provide particular challenges. Two tie types are deemed suitable for UK conditions. Further action on production and testing is suggested.

• Issues relating to site practice, when building with thin-joint glued brickwork, are discussed, pointing out the differences and difficulties encountered, compared with those of traditional brick construction techniques. Specific training and an adjustment of work practices will be required when this technique is used.

• A short section on detailing and architectural issues deals with appearance, dimensioning, pointing, expansion joints and other constructional issues.

• The suitability of thin-joint techniques for brickwork prefabrication was examined. Tests carried out by Hanson demonstrated the potential advantages of using this form of construction for production, lifting and transportation.

• A summary of the workshop session is given, together with a list of major points raised by the delegates.


1 INTRODUCTION

1.1 Introduction

This is the third draft of the final report which will inform the construction industry about the potential uses of thin-joint glued brickwork in the United Kingdom.

This research project is sponsored by the Department of Trade and Industry as part of the 2001 Partners in Innovation (PII) programme, with contributions from industrial partners, including Hanson Brick, the Brick Development Association, Ibstock Brick and Mander Structural Design.

The main objectives of this research are to anglicise design guidance relating to thin-joint glued brickwork in use in mainland Europe. Whilst there is considerable interest in thin-joint glued brickwork amongst UK specifiers, uptake of the technology is inhibited by a lack of design guidance. This research collates and extends the body of information and presents it in a form for use by architects, engineers, contractors, brick producers and other stakeholders in the UK construction industry. The project deals only with ‘pre-competitive’ issues, and therefore benefits from the collaboration of a broad cross-section of UK brick manufacturers.

Brickwork is the most common external cladding material in the UK. Whilst it accounts for in excess of 90% of all domestic construction, the sector is under pressure, owing to a shortage of skilled bricklayers, rising costs (principally as a result of decreased competition for work) and difficulties in maintaining quality. Thin-joint glued brickwork is an alternative to conventional brickwork. The technique has the potential to significantly alleviate skill and cost problems. It is a more automated process than conventional bricklaying, can increase productivity and quality, and is proving popular in mainland Europe. Considerable research has been carried out in European countries, particularly The Netherlands and Belgium.

The main outputs of the project are this report, issued by Oxford Brookes University and the project partners with guidance and recommendations for the effective use of thin-joint glued brickwork in the UK, an information pamphlet for wide distribution, a website, and journal articles and papers.

1.2 Research methodology and programme

The research was carried out in collaboration with architects, structural engineers, approval authorities, brick producers, and other stakeholders in the UK construction industry. The methodology was based on techniques used previously for similar projects, refined and adapted in collaboration with construction experts within the Postgraduate Research School of Oxford Brookes University. The research programme has had six stages. These are described below.

1.2.1 Literature review

This was undertaken by the research assistant from the start of the research programme and, in order to ensure currency of the database, the process was continued until the project was complete. The literature review has involved collation and review of relevant research projects carried out in mainland Europe, and collection of information on selected projects.
1.2.2 Steering Group formation

A steering group was formed at the beginning of the project, comprising nominated representatives of all participant partners: Hanson Brick, the Brick Development Association, Ibstock Brick, Mander Structural Design and Oxford Brookes University. The group was open to any parties who were identified by the participants as possessing material expertise.

The steering group held its first meeting on 23rd September 2002 at Oxford Brookes University. Subsequent meetings were held on a regular basis, mostly at Oxford Brookes University. All these meetings discussed the current progress of the project and produced recommendations and directions.

1.2.3 Information review

The steering group oversaw a process of review of existing design codes and information gathered during the literature search, and consultation with sectors of the construction industry. It generated draft design guidance for the use of thin-joint brickwork, which includes sections on structural design, materials, site practice, construction detailing and specification.

1.2.4 Testwork schedule and review

A series of tests was carried out within the resources of the project. Full testing, as required to form the basis of official codes, was not possible within the scope of this research project. The aim of the tests undertaken was to produce indicative results to form a basis for general recommendations. An account of the test results and their implications are given in this report. Below is a summary of the testing procedures that have been carried out.

- Compressive strength of mortar cube tests by OBU
- Water penetration tests by Hanson/CERAM
- Freeze/thaw tests by Hanson/CERAM
- Wall tie tests by CERAM based on BS DD140: Part 1 1986, method of test for mortar joint and timber frame connections
- Further tests on different wall ties by CERAM
- Flexural tests on wallettes at OBU
- Compressive tests of brickwork prisms at OBU
- Compressive tests of wall ties at OBU

1.2.5 Peer review

A workshop was held at the Brick Development Association (BDA) on June 10th 2003, involving about 40 leading stakeholders in the construction industry to both inform them about the research involved, and to gain feedback and expressions of interest. Details of the issues raised and discussed in relation to thin-joint brickwork technology, are included in Appendix 1.

This final document has been prepared after being peer-reviewed by several experts from both academia and the industry. The final draft was sent to 5 experts for their written comments, which were considered by the steering group and incorporated as necessary into the final report.
1.2.6 Dissemination

In order to inform more on the research of this project, an information brochure has been produced for wide distribution within the construction industry. In addition, this final report, with appropriate interpretation and recommendations, is being presented as a culmination of the project. It is published by Oxford Brookes University and is available directly from the University. The findings from the project will also be written up in paper and/or article form and submitted for publication in relevant journals such as the Architects’ Journal, Building Design, Brick Bulletin, and the journals of relevant professional institutions, including RIBA (Royal Institute of British Architects), IStructE (Institution of Structural Engineers) and ICE (Institution of Civil Engineers), to ensure that the availability of the design guidance is well advertised.Copies of the report will be sent to appropriate standards institutions, including BSI, and offered to the BDA (Brick Development Association) for issue to members.

A website has been set up, containing the information in a user friendly format, with links to a range of relevant sites, including those of the participants and contributors to this research project. The website address is [www.thinjointbrickwork.co.uk](http://www.thinjointbrickwork.co.uk).

2 THIN-JOINT GLUED BRICKWORK

2.1 Background to the technology

The technology originated more than 10 years ago in The Netherlands. The technique relies on joints which are formed using a glue mortar. This has a high percentage of cement, very fine inert additives and specially formulated polymers. It is applied by using specially developed hand-held pumped nozzles that usually dispense two parallel beads of material along the horizontal bed joints and on the perpends prior to the bricks being laid. Many metres of bed joint adhesive can be laid in a rapid single operation, the nozzle dispensing relatively accurate quantities of mortar. Working conditions, speed of construction and overall quality are generally considered better than those of traditional mortar.

![Method of application of thin-joint mortar on the horizontal bed joints at the new School of Architecture at the UWE, Bristol (Courtesy of Ankerplast)](image)

Since glued joints are stronger than traditional mortar and cure more quickly (approximately 30 minutes), they allow bigger lifts to be constructed. This further benefits the speed and productivity of the technology.

Thin-joint glued brickwork is appropriate for a wide range of building types, from domestic construction, particularly where several dwellings are constructed on the
same site, allowing equipment to be used efficiently, to large commercial and civil engineering projects such as the Heysel (now King Baudoin) stadium in Belgium. Here the technology was used successfully to construct 20m high external walls. At present there is only one known building in the UK where thin-joint glued brickwork system is used, the new School of Architecture and Planning building at the University of the West of England. The latter has involved three of the project partners (Oxford Brookes University, Hanson Brick and Mander Structural Design). A similar scale project has also recently been constructed in Eire, where Eric van Egeraat Architects have used the technology for an extension to a gallery in Cork. These examples of buildings where thin-joint glued brickwork has been used will be explored further in section 3.

2.2 Advantages

A short summary of key advantages of thin-joint glued brickwork is given below. It includes, strength, potential for prefabrication, appearance and aesthetics, and durability.

2.2.1 Strength

The compressive, flexural and tensile strengths of thin-layer mortars are higher than that of common mortars. However, this is offset against a reduced bed width. The increased bond strength and stiffness means that lintels can often be omitted, and facilitates the simple use of un-reinforced stack bonding. Wind posts and other forms of panel reinforcement can potentially be dispensed with, further reducing costs.

2.2.2 Potential for prefabrication

Thin-joint glued brickwork can be used to form prefabricated panels, either in a factory environment, and then transported and craned into position, or at the construction site. Prefabrication is particularly useful for congested city centre sites, buildings with rapid construction programmes and when there is shortage of local bricklayers.

2.2.3 Appearance and aesthetics

Thin-joint glued brickwork has appealing aesthetic qualities. Initial feedback from UK architects has been particularly positive. Traditionally, the mortar joint between brickwork is 10mm thick. In contrast, mortar thickness in thin-joint brickwork is only 3 to 6mm, though EuroCode 6 defines thin layer joints as joints made with thin layer mortars ‘not less than 1mm nor more than 3mm thick’. This definition raises several issues relating to the specification of wall ties, of the aggregate size of thin-joint mortar and brick size tolerances. It is felt by this working group that the 3mm maximum joint thickness restriction is prohibitive and should be relaxed to 4 mm or possibly 5mm. Consequently, this report uses the term ‘thin-joint’ to distinguish it from the restrictive EuroCode ‘thin layer’ definition.

In thin-joint brickwork both the beds and perpends are less visible. The colour of finished walls therefore tends to be stronger, and similar to traditional gauged brickwork. The technology also gives considerable scope for novel bond patterns. The enhanced strength of the brickwork makes possible the creation of curved and slanting walls without the need for props during construction and without additional structural support.
2.2.4 Durability

The permeability of glue mortar is less than that of common mortars. This, together with the thinness of the joints, tends to prevent water penetration through the mortar zone. Tests have established that water penetration is dependent on the quality of the brick rather than that of the joints. The reduced permeability may mean that water is less likely to escape from cavities; however, this can be overcome by increasing the number of weepholes.

2.3 Introduction of the technology to the UK

Thin-joint glued brickwork was used for the first time in the UK at the new School of Architecture and Planning, University of the West of England in Bristol. The project has been reported in various magazine articles and is discussed further in Section 4.

Thin-joint mortar for masonry, however, is not new to the UK. For example, Thermalite, Durox and H+H Celcon have been using the technique with their respective block systems, using thin-joint mortar developed specially for their aircrete blocks (e.g. Celfix).

3 EXAMPLES OF EUROPEAN BUILDINGS WITH THIN-JOINT GLUED BRICKWORK

Thin-joint glued brickwork is more popular in mainland Europe than in the United Kingdom. The following examples are only a few amongst several buildings in Europe where the technology has been applied. Examples described briefly below are: Crawford Art Gallery in Cork, Ireland; Kuiper Bouwgroep Head Office, Arnhem, The Netherlands; and Heysel Stadium (now King Baudoin Stadium), Brussels, Belgium.

3.1 Crawford Art Gallery in Cork, Ireland

Erick van Egeraat, the Dutch avant-garde Rotterdam-based architect, was selected from amongst 60 architects from around the world (shortlisted to just five, four of which were Irish) by Cork’s municipal art gallery to design a contemporary extension for the museum. The existing museum is a mixture of parts, each illustrating a piece of regional history. Originally a customs house built in 1724, it was renovated and extended in 1884 when the wealthy Crawford family converted it into an art school and gallery.

The awkward footprint – the gallery is almost triangular in plan with no common angles or parallel walls – required a more considered response than a standard white cube. The extension occupies an infill that was once a dilapidated yard at the rear of the existing buildings. For the addition to the Crawford Art Gallery, Erick van Egeraat used brick in a new, novel way, wrapping the two existing portions in an undulating curve of matching brick. The architect adopted the thin-joint mortar system in which bricks are glued together, creating a superior bond, to achieve the aesthetic intention. This method of construction also ensured a quick-drying, gravity-defying bond, enabling the brick to be laid at an angle without the use of props.

His refreshing approach to the exterior is said to have helped to express the complex history of brick-clad pieces as a time line, each built approximately 100 years apart. Inside, the building is claimed to make good on its promise from outside, with curved walls and ceiling planes shaped to bring natural light into the two floors of galleries.
3.2 Kuiper Bouwgroep office block, Arnhem, The Netherlands

The Dutch architect Ger Kengen, from the architects office Arnhemse Factor Architecten bv in Arnhem (The Netherlands), was commissioned to design a representative office for the construction firm Kuiper Bowgroep, taking account of multiple constraints including accessibility, multifunctionality of the building, ergonomy and environmental integration.

The Westervoortsedjik in Arnhem constituted for Kuiper Bowgroep an ideal site for the firm’s new buildings. The site, having a size of 3500 m$^2$, is located between the centre of Arnhem and the road junction of Velperbroek. The concept suggested an office block with a cubic form, and a long workshop located next to the storage space.

The glued envelope of the office block gives the building a good impression of industrial robustness. The robustness of the building is also apparent in the use of massive, red and burnt Kuhfuss bricks, which are block-tinted. The gracefulness of the building lies, however, in its system of brick stacking, which matches harmoniously the cedar timber, aluminium and glass used. A refined technique of brick gluing is used only for the bed joints; the perpends are generally open, un-mortared to ensure an optimum ventilation to the building.
3.3 Heysel Stadium (now King Baudoin Stadium), Brussels, Belgium

The renovation of the old Heysel Stadium (now King Baudoin Stadium) in Belgium constitutes a step forward in the technology of glued brickwork not only in Belgium but in the entire world. The project by the Flemish architect Bob Van Reeth raised a number of controversies about aesthetics and construction technology. However, with this project, Bob Van Reeth became the inspiration for many other architects and, thanks to him, glued brickwork technology has experienced rapid expansion.

Before 1995, i.e. before the renovation of King Baudoin Stadium, gluing of construction elements was reserved only for limestone and aircrete building blocks. It was not until 1997 that Belgium undertook to do something to inform itself on the glued brickwork system. Although it was a worthy move, the initiatives lacked scientific foundation. The need for tested methods, design techniques, and standards and norms were felt. Belgium, like other European countries, lacked appropriate standards and norms relating to glued brickwork systems.

4 UK EXAMPLE OF BUILDING WITH THIN-JOINT GLUED BRICKWORK

4.1 School of Architecture & Planning, University of the West of England

Thin-joint glued brickwork construction was used for the first time in the UK at the new School of Architecture and Planning at the UWE. The building is a teaching facility and itself forms an interactive learning tool for the students. It incorporates a number of unique features, including straw bale cladding and thin-joint glued brickwork construction.

Thin-joint brickwork construction was proposed for the project from inception, with a fall back option of using traditional masonry. Hanson, the brick supplier, undertook a number of presentations to both the client and the tendering contractors, explaining various aspects of thin-joint glued brickwork. Willmott Dixon became the successful contractor and work commenced on site in September 2001.

The building is comparatively simple, with an exposed steel frame and precast concrete floors. The north and south elevations of the building have full height glazing panels which negate any horizontal spanning of the masonry. At the early stages of the project, it became apparent that the masonry panels would not be adequate to span vertically between floors without wind posts. Steel wind posts were therefore introduced to the cavities. The east and west elevations of the building
have solid masonry panels without windows, and in these instances the masonry spans both vertically and horizontally without the need for wind posts.

The particular brick type chosen by the architect was tested with thin-joint mortar at Oxford Brookes University to determine flexural strengths, both perpendicular and parallel to the bed joints. Wallette panels were constructed and tested to failure. Flexural strengths were determined about both axes, and these parameters were used for the design of the brickwork. The results did not show any significant increase in the flexural strength of thin-joint brickwork compared to traditional brickwork. The reason for this was not clear at the time, but recent testing at OBU has led to the conclusion that this was due to reduced bed width.

In Belgium, thin-joint brickwork is used with various brick modules and with a bed joint of typically 3mm. The courses of the inner and outer leaves of masonry therefore do not level up, and the wall tie is designed to be bent between the two bed joints. The crank in the wall tie varies, depending upon the coursing, and the wall tie is of a thin gauge stainless steel. The wall tie used in Belgium has not been tested to the draft British Standard DD140, and discussions were held with Ancon CCL Ltd in the UK about a possible wall tie for the UWE project. Ancon CCL Ltd proposed a traditional wall tie with a vertically slotted channel to the inner leaf, into which a 2mm thick tie was inserted. The vertically slotted channel allows for inconsistencies in coursing between the two leaves. The wall tie was tested by Ceram and was found to comply with DD140 for a type 2 wall tie.

In the UK, virtually all building products are coursed on a standard brick/block module, resulting in a series of standard sizes which readily interlock. With the use of thin-joint brickwork at UWE, the bed joint was only about 4mm thick, so overall brickwork panel heights and widths were not of a standard module. The architect on the UWE project therefore had to carry out a more detailed coordination exercise of panel sizes to ensure dimensional fit.

Wilmott Dixon’s bricklayers travelled to Hanson’s Belgium factory where they were trained in the use of thin-joint brickwork. A mortar machine was made available for the project. However, the non-availability of spare parts and servicing initially slowed production. In order to increase production, a further machine was introduced and a UK service centre was established. Also, once the learning curve of the first brickwork panels had been overcome, production greatly increased. The brickwork progressed rapidly, and proved to be a great success.

It was interesting to note that although this was so, there was initially a general sense of reluctance to use thin-joint brickwork by many parties involved. This was probably
due to the fact that it was unknown and perceived as a possible risk. However, once the masonry started to progress, these concerns diminished.

5 BUILDING CODES AND TECHNICAL REPORTS WITH RELEVANCE TO THIN-JOINT GLUED BRICKWORK

A brief review of building codes in other countries revealed a paucity of direct references to specific codes relating to thin-joint glued brickwork, although, for example, some references are made to thin-joint masonry within the general masonry codes in Australia, the Netherlands and Germany. However, there are a series of technical reports on aspects of thin-joint construction, mostly emanating from the Netherlands.

5.1 The United Kingdom

The use of thin-joint glued joint technology for lightweight concrete blockwork has become widely accepted in the UK during the last few years. The technique has been commonly used in Germany and other European countries for many years, and pioneered in this country by Aerated Concrete as long as 17 years ago. Now reference is made to ENV 1996.1.1, the structural EuroCode on masonry with regard to strength and stability. It is also possible to design lightweight concrete blockwork to BS 5628:Part 1:1992 by using mortar designation (iii), where tests for the product have been carried out in accordance with the standard.

The Building Research Establishment has produced a Good Building Guide (GBG58) entitled ‘Thin layer mortar masonry’ that limits itself to the describing of its application to aerated blockwork. It must be noted that there are significant differences between using bricks rather than blocks with this system; a direct transfer of the experiences of thin-joint blockwork to brickwork should not be undertaken.

5.2 Europe

EuroCode 6: Design of masonry structures, is well passed the development stage. Discussions have been held with Peter Watt of the Brick Development Association, who was a member of the UK delegation to CEN/TC250/SC6 meetings when the drafts were discussed.

According to a letter from Peter Watt in response to an enquiry from the research team (see Appendix 2), thin-layer masonry is addressed by the EuroCode being
developed under the title prEN 1996–1-1; this has now reached what is termed a second 34 draft status. This means that final text and technical details of content have now been agreed by CEN/TC 250/SC6 and the document is being prepared by the project team CEN/TC250/SC6/PT1 for formal vote. Such a vote is likely to take place this summer (2004), depending upon how quickly CEN progresses the pre-vote preparatory work. Basically, technical argument and development of the prEN has finished.

Most thin-joint masonry development work has been undertaken in the Netherlands, Denmark, Belgium and the ‘Germanic’ speaking countries. The current design information on prEN 1996-1-1 is based on this continental experience. The UK has had little influence on the EC6 thin-joint masonry design data/equations/limiting criteria.

Thin-joint glued masonry is defined as having a joint thickness of not more than 3mm. The limitation of the joint to 3mm was a point discussed by SC6 for some considerable while before a final decision was established. Basically, once the joint exceeds 3mm, the enhancement of compressive strength given by up to 3mm joint reduces. A 4-5mm joint has a potentially lower effective compressive strength associated with it.

The aggregate size limitation in EN 998-2 for mortars is ‘up to 2mm particle size’. This does not preclude specification of smaller aggregate sizes if there is a problem of wall tie embedment. Smaller joint width masonry might pose greater difficulties in respect of finding commercially suitable aggregates in the UK.

The issue of masonry unit tolerance is critical. On the continent ‘precision units’ are often used, particularly in the ‘Germanic’ countries, and these have very close tolerances on height of unit in order to allow thin-joint mortars to be used successfully. Often, in these countries, they do not fill cross-joints but use tongue and groove jointing, for example. If clay brick is used in the UK, context then size/tolerance selection will be the key to success. Many British made clay bricks will not be suitable for use with this method, even with 4-5mm joints (unless size selection is undertaken).

Peter Watt believes that in order to continue the development of the methodology of thin-joint work or adjust the joint width, it is necessary for the basic design data, particularly for compressive strength, flexural strength and bond strength, to be properly developed. At the moment, the UK would be likely to lose any argument it made to SC6 to change the thin-joint requirement from 3mm to 4-5mm. According to Peter Watt, in the UK there is a lack of the data bank to justify any such submission, and the prEN is now at too advanced a stage to make such a change this time round. He suggests that another option is to contact the Royal Dutch Clay Brick Association in the Netherlands with a view to enabling collaborative research work, as they have been closely associated with the methodology for over ten years.

For compressive strength design, he adds that if the joint thickness goes above 3mm, "standard" 10mm joint gauging fk values can be used as default.

But flexural strengths must be developed for the joint thickness that are ultimately chosen for use, and these values must have integrity in terms of potential BS 5628: Part 1 inclusion. This means a large testing programme with variants if other test results are not available from elsewhere. EC6 uses the UK flexural strength design methodology of yield lines, but will contain no flexural strength values (characteristic resistances such as those given in BS 5628: Part 1, Table 3), as these cannot be
agreed on a European wide basis for such inclusion. Many of the continentals do not believe in need for flexural strength design because they use wide, heavy masonry units for the inner leaf construction that are inherently stiff. The lack BS 5628 flexural strength characteristic values and any relationship with water absorption or net density for classification of \( f_{kx} \) could restrict the use of thin-joint masonry in the UK. However, the BS 5628: Part 1 Table 3 \( f_{kx} \) values will effectively be put in the EC6 UK National Annex, but specific figures for thin-joint are still needed as currently there are none.

Peter Watt intimates that there are three "problem" matters that must be resolved as priorities, namely:

1. The lack of commercially available wall ties (and ones that allow easy coursing with blockwork)
2. The lack of BS 5628 flexural strength characteristic values, and any relationship of such values to water absorption or net density for classification of \( f_{kx} \)
3. Tolerance of practical fired clay units and squareness tolerance (the latter is not a BS 3921 requirement). In order to achieve consistent thin-joint work, this has to be addressed.

In addition, this project group felt that the limitation to a 3mm joint was extremely restrictive, both from the point of view of achieving the required tolerances in the bricks, and in fitting the wall ties. The group recommends that the 3mm maximum should be increased to 4mm or even 5mm. This view is supported by the TNO Report 94-CON-R1532 commissioned by the Royal Association of Dutch Clay Brick Manufacturers (see Appendix 3).

5.3 Belgium

The titles of two papers, one on reinforced glued brickwork, the other one on flexural tests on reinforced glued brickwork are included in the Bibliography. Of some importance are the Belgian national guidelines for the production of glue mortars for clay bricks, calcium silicate bricks, concrete blocks and aerated blocks, BRL-1005, produced in 1999. The reported outcomes of some of the tests are of interest.

5.4 Germany

Investigations to find out whether the DIN codes have any relevant application in glued brickwork construction found no direct reference useful for this study. However, one research paper on Ankerfix mortar has been listed - Forschungsgemeinschaft Eisenhütten- schlecken e.v. (1998) Prüfung and Mörtel “Ankerfix PVM Typ C” nach DIN-1053, Prüfbericht nr. 1998/369, Germany: FE.

5.5 Australia

The AS3700 Masonry Code allows for ‘thin bed’ joints, ‘which are used in some systems with very accurately made bricks or blocks. It also allows for hollow block masonry units, which are not a common form but are occasionally manufactured in clay masonry, and for cored units, which are normal bricks with holes through them’ (Clay Brick and Paver Institute - HTTP://www.brickby design.com).

The code refers to joint thicknesses, finishing, and specifies tolerances.
5.6 The Netherlands

A list of technical reports on aspects of thin-joint glued brickwork were reviewed. All were in Dutch, apart from one in English. Copies of four reports were obtained and summaries prepared in English to assess their importance and usefulness for this project. It was hoped that some specific codes relating to glued brickwork might have been developed on the basis of these studies. This proved not to be the case. There is, however, reference to the Dutch codes on brick and masonry work and the relationship these can have with the new method of building brickwork.

5.6.1 Reports 1 and 2

Although two of the reports, i.e. Nos. 1 and 2 (in Appendix 3) consider the structural properties of thin-joint glued brickwork, the tests and calculations refer exclusively to the Dutch codes and conventions. This makes it difficult to apply the results directly in the British context, as the bases for experiment and calculation are significantly different. It is therefore necessary to conduct parallel tests conforming to British norms and codes in order to establish compliance with British practice.

5.6.2 Report 3

One of the reports, i.e. No. 3 (in Appendix 3) records the results of experiments on moisture transmittance and water penetration through brickwork panels. The conclusions reached about the properties of thin-joint glued brickwork are interesting and prove to be of relevance to the British context. The main conclusions are as follows:

- Frost, soot and mould growth are not significantly harmful influences.
- Generally, water transmittance of glue mortar is significantly less than of conventional mortar.
- Due to excessive air entrainment or insufficient hydration, the water transmittance may be increased above that of conventional mortar, leading to rising damp through the mortar joints.
- Water penetration of brick panels constructed with closed perpends occurs through the brick rather than the joints, even in extreme conditions.
- The effects of pressure release on water penetration of brick panels constructed with open perpends requires further testing.

5.6.3 Report 4

This report is in English and reports on the compressive strength of clay brickwork with thin-joint mortar (see Appendix 3). The main objective of the research was to establish design values for the compressive strength of this kind of construction that could be used for the Dutch Code of practice (EN 1052-1) and also for (EC-6).

The main conclusions were:

- The demand for the maximum thickness of thin layer mortars in EuroCode 6 (3 mm) should be extended to at least 4 mm for fired clay bricks
- The compressive strength parallel to the bed joints is higher than that perpendicular to the bed joints.
- Tensile peak stresses, due to the stiff mortar, are the main cause of failure perpendicular to the bed joint. A less stiff joint might improve the compressive strength perpendicular to the bed joints.
Because of the relatively high slenderness of the specimens, the results for strength perpendicular to the bed joints might be conservative when used in the context of EC-6 and the new version of EN 1052-1.

It was not possible to find meaningful values for the parameters of the EC-6 formula for the compressive strength, due to the influence of the tensile strength of the bricks on the compressive behaviour and the limited combinations of materials tested.

In general, it can be stated that fired clay masonry with thin-joint mortars is a new material to which current experience does not apply.

5.7 Further reports

The titles of a set of reports from the Netherlands and other countries are included in the Bibliography. The subjects include: “The constructive possibilities of glued brickwork” (July 1991); “Flexural strength of prefabricated, glued and reinforced walls” (Sept 1997); a sequel to the Report 2 described above – “Moisture movement through glued brickwork constructed with open perpends” (April 1999); and several structural tests reports on reinforced glued brickwork samples (July, October and December 1999). These reports have not been analysed in detail. Copies of these reports can be obtained from their authors.

The kind assistance of Marcel Ruben of Ankerplast in obtaining these references is acknowledged. For further details about Ankerplast and Omnicol, he can be contacted at Nijverheidsstraat 14, 2381 Weelde, Belgium, tel. 00 32 1465 6285.

6 MATERIALS AND STRUCTURAL DESIGN

6.1 Thin-joint mortar – particle size distribution

EuroCode 6 limits aggregate size to 2mm, which seems a large aggregate size if there is to be aggregate above and below a wall tie in a 3mm joint thickness. Ankerplast mortar was tested at Oxford Brookes University for particle size distribution using a sieve analysis. The Ankerplast mortar has a maximum particle size of 1mm and on the UWE project there were no reported problems with the size of the aggregate (see Appendix 4).

6.2 Thin-joint mortar

The Ankerplast mortar Class B used in thin-joint brickwork was tested at Oxford Brookes University for compressive strength. Details of the tests are attached in Appendix 5. Ankerplast mortar is available in three classes, A, B and C, each designed for different water absorption and suction properties of the bricks. The Celfix mortar used on the thin-joint blockwork was also tested, and compressive strengths for the two mortars are shown overleaf and compared against traditional mortars.

The Ankerplast mortar has an initial higher strength gain and the 28 day strengths are comparable, both averaging approximately 21N/mm². With a traditional mortar designation (iii) 1:1:6, in laboratory conditions a mean 28 day strength of 3.6 N/mm² would be expected, increasing to 16N/mm² for a mortar designation (i) (Table 1 of BS 5628). The strength of the Ankerplast mortar is considerably in excess of traditional mortars and in some cases could be stronger than some bricks. If the mortar is stronger than the brick and cracking does occur, it is likely that the cracking is...
through the bricks rather than the mortar joints.

<table>
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<th>Mean compressive strength (N/mm²)</th>
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<tr>
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<td>25</td>
<td>21.15</td>
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<td>30</td>
<td>24.3</td>
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</table>

6.3 Water penetration

Five brickwork panels built with different brick types were tested for water penetration at the Hanson Laboratory at Stewartby, Bedford in February 2003. The tests results were inconclusive due to problems with mortar adhesion and gaps in the mortar joints (see Appendix 6). Anecdotal evidence suggests that water penetration is a problem at the intersection of bed and perpend joints. Extensive test work in Holland has provided interesting conclusions, summarised in section 5.6.2 and Appendix 6. Tests showed that the joints could be less permeable to water than the bricks themselves if the glue-mortar is properly cured.

6.4 Frost resistance

Five brickwork panels of different brick types were made to be subjected to freeze/thaw tests at the Hanson Laboratory. One panel was broken during transport, the remaining were tested. Two panels survived the test. The two panels that failed showed both multiple brick failures and bed joint failures. It is thought likely that the brick failures contributed to the mortar failures (see Appendix 6). For freeze/thaw testing of thin-joint panels, it appears essential to use bricks that are fully frost-resistant, as failure of the bricks can lead to failure of the brick/mortar bond.

The thin-joint construction process gives a recessed joint at the front of the panel, which leads to particularly severe conditions in the frost test. Thus, if bricks are not fully frost-resistant it is likely that failure will occur. To remove any risk of such problems in ‘on site’ situations, it is essential to use only frost-resistant bricks in all exterior thin-joint brickwork. Further testing is required to investigate whether expansion from freezing in the thin recessed joint can lead to debonding.

6.5 Compressive strengths

A series of thin-joint brickwork compressive tests were carried out at OBU for three different bed joint thicknesses, 3mm, 5mm and 10mm. Details of the tests are attached in Appendix 8. For a 10mm thick joint, the mean compressive strength was 14.3 N/mm² increasing to 15.4 N/mm² for a 5mm joint and 17.5 N/mm² for a 3mm thick joint. The testing shows an increase in strength as the joint thickness reduced, which
is to be expected.

EuroCode 6 defines thin layer mortars as “not less than 1mm nor more than 3mm thick”. Both TNO in Holland and this project’s working group believe the maximum 3mm thickness is prohibitive and should be increased to at least 4mm or even 5mm. This has been raised with Peter Watt (from the BDA) who sits on the EuroCode committee. Evidently, this was debated at length by the committee. An increase in joint width reduces compressive strength, as is confirmed by the above testing. However, it was felt by some Europeans that the reduction in compressive strength was prohibitive, and as a result the 3mm joint thickness has remained. Commonly, however, in the UK brickwork is used as a cladding material to a steel or concrete frame, and compressive strength is not generally an issue. Should an engineer wish to use a 4 or 5mm bed joint thickness the allowable compressive loads have to be reduced from the 3mm thickness figure. The reduced compressive loads are not deemed to be prohibitive for the use of thin layer masonry in the UK.

6.6 Flexural Strengths

Flexural strength tests were carried out at OBU in 2001 for the New School of Architecture and Planning at the University of the West of England. The average flexural strengths were 1.9N/mm\(^2\) perpendicular to the bed joints, and 0.54N/mm\(^2\) parallel to the bed joints. These figures compare favourably with those of a designation (i) mortar in Table 3 of BS5628, i.e. respectively 1.5N/mm\(^2\) and 0.5N/mm\(^2\). However, they do not exhibit greatly enhanced flexural strengths, considering the strength of the mortar.

The reason why the flexural strength was lower than anticipated was examined further, and three sets of flexural tests were undertaken at OBU in 2003, but with differing bed joint configurations (see Appendix 7). One set of wallettes had the adhesive mortar applied to the full width of the horizontal bed joints, while the second set had two beads of adhesive mortar applied to the centre of the horizontal bed joints. The third set of wallettes had two beads of adhesive applied to the rear of the brick.

The test results parallel to bed joints give a flexural strength of 1.29N/mm\(^2\) for a full bed width of adhesive, compared to 0.53N/mm\(^2\) for two glue beads to the centre and 0.78N/mm\(^2\) for two glue beads to the rear. An identical test was also carried out with a traditional designation (iii) mortar for the full bed width for comparison purposes and the average bending stress was 0.58N/mm\(^2\). The results for two beads to the centre are just less than a conventional designation (iii) mortar by 0.05N/mm\(^2\), which is approximately a 10% reduction. The results cannot be directly compared against the tests carried out for the School of Architecture and Planning, as the bricks were of a different size and hole configuration.

It is interesting to note that the flexural strength doubles for a full bed joint application of adhesive compared to the two central beads. The reason for this is probably the increased section modulus (Z). With two beads applied to the centre, it is difficult to determine the exact width of the mortar bed, due to the variable squashing of the mortar and the various holes. However, the mortar bed generally averages 65-70mm. Section modulus (Z) is defined as \(bd^2/6\) and the difference in 70 squared compared to 100 squared is a factor of 2, which explains the doubling in flexural strength of the full bed width of adhesive mortar compared to that of the two beads of mortar to the centre. To gain the full benefit of thin-joint glued brickwork, more research is needed on how to achieve a full bed-width of mortar without staining the face of the bricks.
The reason for the increase in flexural strength in the case of joints with two beads to the rear is probably due to the layout of the holes in the brick. The brick used has two rows of five holes, and with two central beads much of the mortar falls within the holes. However, with two beads applied to the rear, the beads fit in between the holes, resulting in added flexural strength. It is interesting to note how the hole layout has a considerable effect – each different hole layout will give differing flexural strengths. It should be noted that due to the need for parallel bonding surfaces, frogged bricks are not suitable for this type of bonding.

A further set of similar tests were carried out perpendicular to the bed joints (see Appendix 7). The two beads to the centre gave an average bending stress of 1.43N/mm\(^2\) compared to a figure for traditional construction of 1.4N/mm\(^2\). Two beads to the rear showed an increase to 1.67 N/mm\(^2\) and it is not clear why this is so, being even higher than the full bed width figure of 1.59N/mm\(^2\). Flexure perpendicular to the bed joints involves interaction with both the perpendicular joints in bend and the parallel bed joints in shear, and this is probably why there is no significant increase in strength with a full bed width.

The above preliminary work gives an initial indication of flexural strengths and it is apparent that thin layer mortar flexural strengths are not dissimilar to that of a designation (iii) conventional mortar.

Upon discussing flexural strengths with our European counterparts, it became evident that on the continent the majority of the flexural strength is provided by the inner leaf, and the external leaf is treated merely as a rain shield. In Belgium the inner leaf is often constructed of clay blockwork of such thickness as to be considerably stiffer than the outer leaf. Hence the flexural strength of the outer leaf is not as critical as in UK design, where both leaves share the load carrying almost equally. This situation will be addressed by EuroCode 6 in the future.

### 6.7 Movement Joints

The high strength of the mortar is less accommodating for movement, and the recommendation for movement joints in Belgium is typically 2/3 the frequency of that used for traditional brickwork. However, more recent buildings have increased the frequency to that of traditional brickwork.

### 6.8 Wall Ties

The very thin-joint and the difference in coursing heights of the outer and inner leafs of cavity walls restrict the choice of wall ties. There is concern that the thinness required of wall ties to fit the 3mm joint, together with the varying length of span across the cavity due to bridging between bed joints, could have a detrimental effect on the structural integrity of the cavity wall. Extensive testing will be required to ascertain values for the compressive and tensional strengths across the cavity wall, and the pullout values of the embedded sections. A full testing programme does not lie within the remit of this research project, but some indicative tests were carried out at CERAM and OBU. Special stainless steel wall ties have been developed in Belgium for thin-joint
masonry. These are thin stainless steel strips that have flattened ends to build into the wall and a rolled tube central section to bridge the cavity. In Belgium the wall ties are bent up and down to accommodate the different coursing between the two leaves. This often results in thin strips of tie in the cavity, and it is difficult to understand how the ties do not buckle, especially when they are inclined.

The wall tie developed in Belgium

The Belgian wall ties were tested in tension pull out by CERAM in accordance with DD140: Part1: 1986; Wall Ties Method of Test for Mortar Joint and Timber Frame Connections (see Appendix 9). The results show that anchorage bond is generally good and the wall ties comply with a Type 2 tie for pull out.

The main concern, however, is the transfer of compression forces from the outer to the inner leaf, particularly as the thin foil is often exposed in the cavity. Further wall tie couplets were constructed at OBU and tested for compression in accordance with DD140: Part1: 1986; Wall Ties Method of Test for Mortar Joint and Timber Frame Connections. Four sets of wall tie couplets, with three different types of wall tie (one thin horizontal, one slightly thin and cranked diagonally, and the other one was the Ancon Fastrack channel & tie) and with varying cavity widths, were tested (see pictures). The results show that the Ancon Fastrack channel & tie which failed at around 1300 N, complying with a Type 2 tie for compression, performed far better than the other two types of wall tie (see results in Appendix 9). This means that there is at least a potential wall tie that can be used with thin-joint glued brickwork.

Wall tie couplet with thin horizontal wall tie  Wall tie couplet with Ancon Fastrack channel & tie  Wall tie couplet with relatively thin cranked diagonally wall tie

Thin-joint wall ties for use with timber frame construction are available from a number of manufacturers.
Ties suitable for use with brick and block construction are available from Ancon Building Products and also Powerplace Ltd although they may also be available from other manufacturers.

Ties similar to the ‘Fastrack’ short channel strip were found to be adaptable for use regardless of the size of the block used to form the inner leaf. The Fastrack Channel is built into the inner leaf of blockwork ready to take an Ancon SD28 or similar tie for the outer leaf. This two-part tie thus accommodates the different levels in the bed joints. This method of construction also avoids the dangers of projecting ties. ‘Fastrack’ ties are available in different lengths to suit various cavity widths.

Wall ties tests were carried out on Ancon ‘Fastrack’ Channels and Ties in 2001 for the UWE project in Bristol, using galvanised steel bar wall ties 2mm-thick. These ties met the strength requirement of Type 2 tie to DD140. Ancon is currently developing the tie further, to reduce manufacturing costs.

### 6.9 Lintels

There is a potential opportunity to omit lintels and rely solely on the masonry. Evidently, this has been done in Holland and Belgium but the research team has not seen any specific details.

The BRC was contacted regarding reinforcement for thin-joint masonry. It currently rolls a 4mm galvanised bar down to 1.5mm thick, but the steel becomes ductile and is used only for crack control. The galvanised bar cannot be used in the outer leaf, but BRC is developing a stainless steel brickforce system for the outer leaf. The bars need to be staggered at laps to ensure fit within the 3mm joint thickness. The brickforce system has potential, but further work, including full scale testing, is required.
There is, however, no reason why the standard lintel products on the market could not be used for thin-joint brickwork, albeit confirmation should be sought from the manufacturer.

7 SITE PRACTICE

7.1 Introduction

The objective was to assess the practical issues encountered by operatives on site in building clay masonry walling with a thin-joint glued brickwork system. Discussions were held with UK contractors with experience of glued brickwork and contact was made with manufacturers and distributors of glue materials and equipment.

The topics for investigation covered the performance and use of the mortar machine, use and storage of materials and recommended working practices. A questionnaire was produced and forwarded to contractors and manufacturers. Where possible, ‘face to face’ meetings were arranged.

7.2 Results

The response to all enquiries was very poor. There appear to be only two contractors in the UK with site experience of glued brickwork, one of whom was unavailable for the meeting and failed to complete the questionnaire. The results below are therefore based principally on the experience of Hanson’s experimental work in this area, which includes building brick panels under a wide range of conditions. In addition, discussion with experts in Holland provided useful insights.

7.2.1 Machine reliability

Apparent reliability problems have been encountered, partly due to rapid wear experienced on certain machine parts. Currently the application equipment is only available in a 220v version. Stepping the voltage down to 110v to satisfy Health and Safety requirements creates instability and hence increased downtime.

7.2.2 Power supply

Long cables are vulnerable to damage, and therefore become a health and safety issue. In some cases it may be preferable to consider the on site use of suitably powerful generating equipment. Although there is no direct experience of this in the UK, it has been used successfully by pointing specialists. This could reduce the length of power cabling but would introduce a generator refuelling requirement.

While this is still contentious with the Health and Safety management of UK sites, there are a number of practical precautions that can be taken which ensure safe running of the machine.

• All cabling should be armoured
• Use only 12 volt electrical wiring for the gun head, which runs from the machine to the gun head.
• Fit earth leakage circuit breakers.
• Fit a guarded lid cover to the machine over the hopper area. When this is lifted the machine automatically cuts out.
• Fit a pressure gauge to the machine with clearly indicated recommended safe
working pressures.
• Fit a pressure release valve.

7.2.3 Transportation of equipment around site and working access

The pump is generally transported both horizontally and vertically around a site by forklift truck. Other methods of transport such as hoists may be suitable.

Current evidence suggests optimum pipe runs to be in the region of 8 metres horizontally, giving a working span of around 15 metres without moving the pump. No evidence was available on maximum vertical runs; it is common to move the pump on a ‘lift by lift’ basis.

The use of thin-joint glued brickwork means that the pump for the glue gun may have to be used on scaffolding. Conventional scaffolding is not generally wide enough to allow easy personal movement around the pump. One solution has been to place the pump in material loading areas. However, this may create other problems in movement of materials such as bricks. To be carried out effectively, the scaffolding should be specifically designed to not only accommodate the pump, but also allow easy use of the gun employed to apply the mortar glue.

7.2.4 Glue setting times and cold weather working

Glue mortar setting times will depend upon the water content of the mix and the air temperature. Glue will start to set in a matter of minutes with a very thin “skin” forming at the surface which can be broken by applying a brick unit to the bed with a gentle pressure.

Bagged glue mortar has a shelf life after which its use is not recommended, as its performance characteristics, including strength, will be reduced.

As with traditional masonry, work should not be carried out when frost is evident. In periods of cold, it may be necessary to store the bagged powder in heated conditions and to use warm water in the mixing process.

7.2.5 Protection of brickwork materials and equipment during construction

As with conventional brickwork, masonry should be protected at the end of the day and during periods of rain. The diagram below shows a typical method:

Brick to weight polythene

Bricks should be stored in line with usual guidelines. Bagged thin-joint glue should be stored as bagged cement. Stored correctly, the bagged powder has a shelf life of
up to 12 months.

The pump and gun should be kept protected during periods of extreme temperature and not positioned in direct sunlight when in use, to reduce the risk of glue mortar hardening in the machine.

7.2.6 Different brick types

UK experience appears to be mainly with solid brick, or perforated brick which can be treated in a similar manner, i.e. jointing material applied as if the brick was solid. Frogged bricks are not suitable for this type of bonding due to the increased mortar requirement in order to fill the frog, leading to slower laying rates and increased material usage, with a corresponding effect on the project costs.

7.2.7 Treatment of perpend joints

In Europe perpend joints are often left open and this again confirms that there is little reliance on the flexural strength perpendicular to the bed joints. In the UK, with cavity walls comprising two 'high performance' leaves, there is often a requirement for bending perpendicular to the bed joints and hence the joints are filled.

The most common method of applying glue to the header end of the brick is by trowel. An alternative method is to line up a row of bricks on end, all adjacent to each other, before laying. The glue gun is then struck down the brick ends ensuring that each individual unit has an equal amount of glue. Each brick is then taken from the row with the mortar still attached to one end, and laid onto the brickwork bed, which already has the bed adhesive in place.

7.2.8 Attitudes and work practice of site operatives

Generally, site operatives found the new technology interesting to use because it was different and new, despite frustrations with machine reliability, cleaning, etc, which tended to slow down the work rate. Although the use of the glue laying machine minimises the need for trowel skills when forming both bed and perpend joints, an experienced bricklayer will still produce the best quality finish.

One contractor considered the use of a scoop, similar to the type used in thin-jointed lightweight blockwork systems, to be more appropriate, but this leads to greater variations in bed joint width and slower working rates.

Accuracy in setting out, a high quality finish and a high laying rate will only be attained by efficient and enthusiastic bricklaying gangs. A one plus one team can provide the highest output, and in recent work by Hanson a laying rate of between one and one and a half square metres per hour has been achieved, depending upon the type and format of clay unit.

In spite of the need for the traditional skills as outlined above, bricklaying with a glue gun requires a different approach and a routine in both the working day and the gun maintenance. Problems encountered by the gun servicing team were almost always attributed to user error rather than electrical or mechanical failure. Indeed the simplicity of the gun and mixer design ensure that it is easily maintained with only minimal knowledge. The most common defects are:

- Failure to adequately clean machinery at the end of a working day
- Leaving the gun with adhesive being agitated in the mixer but in a static position
in the pipe causing solidification of material

- Incorrect water content for the given weather conditions
- Using the wrong gun nozzle for the particular brick perforation format
- Leaving a gun during a tea break

Manufacturers’ recommendations are to place the gun in a bucket of water to prevent hardening during short breaks. After the break, the mortar inside the delivery pipe should be pumped away and discarded. However, evidence from contractors suggests that it is better to empty and clean the machine in order to ensure that the glue mortar does not set in the delivery pipe. At the end of the working day, the machine should be thoroughly cleaned. Pressure washing has proved to be an efficient and effective method.

A daily routine will soon ensure that problems are eradicated and a standard set of spare components is always made available for rapid exchange of parts maintaining continuity. Rapid wear on components will occur if such components are not cleaned properly.

7.2.9 Interfacing with other trades

No serious problems were reported.

7.3 Conclusions

This joint glued brickwork can be used effectively to produce brick masonry with an interesting appearance. If it is to be widely used, factors such as power supply access, scaffolding, etc need to be considered at an early stage. A 110v machine with adequate safety features should be developed in order to make the concept more acceptable from a Health and Safety point of view.

The difference in working practices necessitated by this method should be recognised and suitable training given. Failure to do this will lead to problems on site and unwarranted disenchantment with the method.

8 CONSTRUCTION DETAILING AND ARCHITECTURAL ISSUES

8.1 Appearance

The absence of pointing in thin-joint brickwork means that the appearance of the work is unlike that of conventional brickwork. It is best described as a ‘clay facing’, because the colours and texture of the bricks are the only component of the wall.

There are many different ways of using this brickwork to achieve different effects.

The use of bricks with a tight size tolerance aligned vertically and horizontally in stack-bonding gives a tile-like appearance, whilst stock bricks with looser size tolerance and irregular outline combine to form a wall rich in texture.

It is possible to mix bricks of different sizes and to make a wall by laying bricks as soldiers and stretchers because, unlike conventional brickwork, it is not essential to maintain a bonding pattern.

It is comparatively easy to introduce surface modelling into a wall because the mortar
makes it easy to lay the bricks at different angles or to alter the plane of the work by recessing or advancing the face of the brickwork.

Thin-joint glued brickwork will give talented designers an opportunity to be innovative in their use of bricks, creating original and exciting ‘clay façades’.

8.2 Control of dimensions

The conventional 10 mm mortar joint has sufficient tolerance to accommodate bricks which fall within the dimensional requirements of BS 3921. A thin-joint mortar system has less tolerance and the designer needs to select bricks that have dimensional tolerances suitable for the proposed work, e.g. close tolerance for stack-bonding, wider tolerance for conventional bonding. Trials have shown that thin-join mortar system has sufficient tolerance to accommodate stock bricks laid in the conventional manner, with every fifth perpend lined through.

The overall dimensions of a thin-joint wall should be calculated vertically by using brick height plus 4 mm, and horizontally by using brick length plus 4 mm.

8.3 Movement joints

8 mm are to be allowed for a vertical movement joint, and the requirements for BS 5628 should be followed with respect to frequency.

8.4 Damp-proof courses

6 mm are to be allowed for the horizontal DPC, which should be sandwiched between 2 layers of thin-bed mortar.

8.5 Weepholes

Weepholes are to be formed in perpends by omitting the mortar; frequency to be as BS 5628 requires, but generally every 1.2 metres.

8.6 Jointing and pointing

No requirement, but it should be noted that the mortar should be kept at least 8 mm back from the external face of face work. The perpends are best filled by applying mortar to the ends of the bricks prior to laying. Anecdotal evidence about water penetration using thin-joint materials suggests there is likely to be water ingress at the junctions between bed and perpend joints. This is probably more linked to workmanship than materials and thus requires particular attention.

8.7 Ties

See 6.5 about wall ties. Availability of different suitable types should improve over time if manufacturers see a developing market for them.

8.8 Coursing

Conventional masonry in the UK is set out so that every third horizontal brick course-lines through with a horizontal block joint. To do this, the vertical dimensions of bricks and blocks assume a 10mm mortar bed. Thin-joint glued brickwork is based on a much thinner mortar bed. This means that conventional brick and block dimensions do not allow the mortar beds on either side of the cavity to be aligned. This creates a
number of issues because:

- Conventional wall ties laid in the bed joints usually cannot be installed horizontally.
- The difference in mortar bed thickness may result in cutting blocks at the heads and sills of windows, doors, etc.
- There is the problem of how to turn bricks around corners whilst maintaining modules. With thin-joint courses and standard UK brick setting out equations such as ‘3 long faces approximately equals 2 short faces plus 2 long faces’, no longer holds true. The designer will have to detail the setting out of the brickwork to take account of the actual dimensions.

Some manufacturers already produce blocks to suit this new coursing specification.

8.9 Frames

Frames are built in as the work proceeds, or a template is provided to give 5 mm tolerance for fixing finished work.

8.10 Site practice

Conventional practice for bricklaying in cold and hot weather should be followed. It should be noted that all newly laid work requires protection from rain and frost.

9 Prefabricated brickwork panels

9.1 Introduction

One of the main advantages of the thin-joint system is its suitability for prefabrication - either in a factory environment or on site. Panels of variable size and shape may be constructed by bricklayers in a factory or site factory away from their final location, then transported and craned into position. The prefabrication of thin-joint brickwork panels is enhanced by the high bond and quick dry properties of the thin-joint mortar.

9.2 Advantages

The main advantages that the thin-joint glued brickwork system provides for prefabrication include:

- High quality / consistency in workmanship
- A way to combat skill shortages, particularly of skilled bricklayers through the repetitive nature of work in a factory and close quality control
- A panel production process which is independent of weather conditions
- Reduced wastage
- Tighter control of panel manufacture
- Faster on site construction
- Reduction in on site trades
- Reduction in on site supervision time
- High degree of versatility with respect to other structural systems
- Thin-joint glued brickwork attains much quicker early strength. This, together with enhanced tensile strength makes it particularly suitable for prefabrication.

Prefabricated panel brickwork made with thin-joint adhesives generally attains a
higher strength than traditional cement/sand mortars – and a much faster setting time. With elements ready to move in less than 72 hours, the residual strength exceeds that of traditional brickwork.

9.3 Issues to consider with prefabricated brickwork panels

Key areas to consider in terms of the prefabrication design process include the necessity of:

- Panels of a manageable shape and size. As with all masonry, the key to efficient design lies not only in the structural adequacy of the components but also in the detailing. Where possible, elements should be of a size which allows for manageable transport and this may be enhanced by the use of appropriate edge detailing to control working dimensions.

- Attention must be given to temporary support during construction, design for lifting – either by crane or fork lift, and design to allow for safe transportation. Design for transport & lifting is more critical than design for final panel location. Bed joint reinforcement provides extra strength. The Health and Safety issues should be addressed when lifting and transporting panels.

- Appropriate fixing and connection systems with respect to the superstructure. Fixing details are critical when considering the overall stability of the building. The interaction between panels and the beams and columns to which they may transfer load back to the superstructure requires careful consideration.
From a practical point of view, it is advisable not to exceed one-storey high panels with prefabricated construction. This not only improves on-site handling techniques, but also keeps temporary works to a minimum.

The complete versatility of the thin-joint adhesive system is such that for a given project it may be feasible to utilise all three methods of construction, i.e.

- Factory built component – for small repetitious elements
- Prefabricated panels made in-situ – where larger panels may make heavy, long distance transportation inappropriate
- In-situ construction – where complex shapes and details would be better constructed as work proceeds.

Initial prefabrication is based upon manual bricklaying processes. However, where panel quantities become high, it is envisaged that automatic bricklaying techniques (already in use for glued blockwork in Europe) will be developed here in the UK.

The simplicity with which prefabrication or in-situ processes may be interchanged to suit the design requirements make thin-joint glued brickwork a serious option for the façade solution both for cladding and structural components.

10 CONCLUSIONS AND ISSUES ARISING

10.1 Thin-joint glued brickwork

Examples of successful building projects using thin-joint glued brickwork abroad and, to a limited extent in this country, indicate that the technique is a feasible alternative to conventional brickwork construction. Current knowledge is sufficient for thin-joint glued brickwork to be successfully used to exploit its particular properties in future building projects in the UK.

This report is a major contribution towards providing technical and practical information required by designers and constructors in the UK. This will inform the architects, engineers and specifiers who currently have poor awareness and understanding of thin-joint glued brickwork, and provide them with sufficient data in
order to employ this building technique with confidence. Wide dissemination of this guidance will be achieved through the professional press, dedicated industry publications, academic journals and a website.

There is, inevitably, need for additional research and testing. A greater use of this building technique will be encouraged by additional specific official design guidance and codes relating directly to thin-joint glued brickwork construction.

10.2 EuroCode 6

EuroCode 6: Design of masonry structures (EN 1996-1-1) is now issued for formal vote. In its references to thin-joint masonry, it uses the terminology ‘thin layer mortar’, a term which is used in this report only in connection with EuroCode 6. In this code, thin layer glued masonry is defined as having a joint thickness of between 1mm and 3mm. It appears that the 3mm maximum joint dimension was probably derived from thin-joint blockwork practice, rather than thin-joint brickwork. The members of this project believe that the limitation to a maximum of 3mm joint thickness is unnecessarily restrictive.

The extremely thin-joint will make unusually high demands on the brick dimensional tolerances. It will also invoke problems in the development of a range of suitable wall ties. The latter will have to be so thin as to make the achievement of the necessary structural strength, particularly in compression, difficult.

The researchers noted that, in the projects visited in Holland, the joints achieved in practice were not less than 4mm thick, and often even thicker. Despite a recommendation by a 1994 TNO technical report from the Netherlands that the thin-joint dimension for fired clay bricks should be increased to at least 4mm in the EuroCode 6, the 3mm maximum joint thickness has been retained. The advanced stage of the code drafting means that there is little chance of this being revised in the short term.

Despite this, the members of this project strongly recommend that the EuroCode 6 be changed to allow the joints of thin-joint brickwork to be at least a maximum of 4mm thick, and better still, 5mm.

10.3 Standards and tests

The technical codes and tests employed so far in the countries for using thin-joint brickwork refer directly to the national codes of the respective countries. Great caution is required in transferring test results and codes to the UK, due to different experimental and test procedures. Therefore, a series of preliminary tests were carried out on two types of glue mortar and on sample couplets,wallettes and panels of glued brickwork. The results can be used only as indicative, as full test procedures could not be carried out within the framework of this research project. The tests did, however, show some interesting results.

10.3.1 Thin-joint mortar

Ankerplast mortar was tested for particle size, which proved small enough to comply with EuroCode 6. Compressive strength tests on Ankerplast and Cellfix (used for thin-joint blockwork) mortars showed that the mean compressive strengths of these mortars were in excess of those of conventional 1:0-¼:3 cement:lime:sand mortar mix.
At present, there are no UK manufacturers of glue mortar suitable for thin-joint brickwork, although one manufacturer has shown interest. Ankerplast mortar is manufactured in Holland.

10.3.2 Water penetration

Tests in Holland indicated that the water permeability of the thin-joints can be less than that of bricks themselves. Tests carried out here as part of this project led to poor performance due to anomalies in mortar adhesion and gaps in the mortar. Bricks with a sandy finish should be avoided as these tend to inhibit good mortar adhesion. This underlines the importance of the correct choice of bricks and types of mortar.

10.3.3 Frost resistance

It should be noted that the full-bed joint and flush pointing conditions required by current Standard Frost Tests are not strictly applicable to thin-joint construction.

Failure in frost resistance tests was most likely due to brick failure; that in turn led to mortar failure. The externally recessed bed joint led to particularly severe conditions in the freeze/thaw tests. This leads to the conclusion that frost-resistant bricks should always be used in thin-joint brickwork. The use, where possible, of external flush joints is recommended. Brick manufacturers should be consulted about the suitability of their brick types.

10.3.4 Compressive strengths

Compressive tests showed that strength increased as the joint thickness reduced (i.e. from 14.3N/mm² for a 10mm thick joint to 17.5N/mm² for a 3mm thick joint). The compressive strength of brickwork is not generally a crucial factor in brickwork construction. Despite this, the EuroCode committee argue that the reduction in strength for joints thicker than 3mm was prohibitive, hence their insistence on maximum 3mm joints.

In practice, the use of bed joints thicker than 3mm, with their lower allowable compressive loads, should not provide any obstacle to thin-joint brickwork construction.

10.3.5 Flexural strength tests

Tests showed that the position and width of the mortar beads in the bed joints had a major influence on the flexural strength of brick panels. Flexural strength increased with the increase of the section modulus (Z). For example, a full 100mm wide bed of mortar was twice as strong in flexure as a 65-70mm wide bed of mortar in the centre of the brick joint produced by two mortar beads. The quality of the workmanship and consistency of the joint thickness also had significant influence. Considerably higher strengths than those of traditional brickwork can be achieved, but this is dependent on the use of full bed joints, or perhaps five beads of mortar spread equally across the bed.

Although the flexural tests generally appeared to conform to the standards of designation (iii) mortar, it is recommended that, until official testing to provide specific guidance is carried out, individual tests should be done on a project specific basis, or conservative values should be adopted.
10.3.6 Movement joints

In Europe the recommendation for movement joints is typically 2/3 the frequency of traditional brickwork. However, joint centres have recently been increased to the frequency of traditional masonry. Traditional movement joints have 10-12m spacing.

10.4 Wall ties

The majority of available wall ties are not suitable for use with thin-joint masonry, due to their thickness and the need to span between bed joints at different levels. However, several suitable designs of wall ties were selected and investigated, including a tie imported from Belgium, widely used in continental thin-joint masonry construction.

Tests were carried out in tension and compression on a range of UK and continental wall ties. Pull-out tests confirmed that the performance of thin gauge ties was satisfactory. Compression tests to DD140 demonstrated that thin ties (including those from Belgium) were not strong enough and deformed quickly. Two UK designs were acceptable, a channel based design by Ancon and a design aimed at timber framed construction that already has the necessary test results and is in common use for conventional brick-faced timber construction.

It is notable that European practice seems to be less concerned about the compressive strength of wall ties than that in the UK. Perhaps the configuration of the wall leafs allows this.

A small number of UK metal manufacturers are actively engaged or interested in investigating an appropriate design and production of specialist wall ties for use in thin-joint masonry. Further action by these wall tie manufacturers should be encouraged.

10.5 Site practice

Investigation into aspects of site practice that need to be considered if thin-joint glued brickwork is to be widely used showed that factors such as power supply, access, scaffolding, working practices and conditions, etc. need early stage investigation. A 110v machine is recommended, in order to make the concept more acceptable from Health and Safety perspective.

Specific training and an adjustment of work practices will be required. More specific guidelines should be developed as a result of the findings of this research.

There was a suggestion to use a scoop, similar to the type used in thin-jointed lightweight blockwork systems, as more appropriate, but this would lead to greater variations in bed joint width and slower working rates. A better long-term solution would be improvements in the pumping system.

The issue of the EuroCode 6 stipulation of a maximum 3mm bed joint is significant here, as it poses really serious challenges to practical application. The 2mm allowable grain size in the mortar could further complicate matters. Normal UK brick size tolerances will make it almost impossible to achieve this standard. Even more standardised brick sizes in Europe have not led to <3mm joints, according to observations of built examples. It seems that a thicker joint of 4-5mm should not cause any problems so long as the requisite performance data is taken into account.
10.6 Construction detailing and architectural issues

The appearance created by use of different types of brick and different bonds was investigated through observation of a number of glued brick sample panels produced by Hanson at Waingroves Brickworks. The medium sized test glued brickwork panels were on display at Hanson Workshop in Ripley. There appeared to be plenty of scope and opportunity for designers to be innovative in their use of bricks, creating original and exciting 'clay façades'.

Dimensional control is more difficult, due to the smaller joint tolerances. The designer will need to select bricks that have dimensional tolerances suitable for the proposed work, e.g. close tolerance for stack-bonding, wider tolerance for conventional bonding.

Recommendations for construction practicalities such as movements joints, damp proof course, weepholes, jointing and pointing, coursing, and frames, are given, taking into consideration appropriate British Standards.

The prefabrication of panels and elements using thin-joint glued brickwork appears to be a promising aspect of this technique, and could overcome some of the problems associated with the prefabrication of brickwork.

10.7 Prefabrication

Thin-joint glued brickwork promises to provide solutions to the major problems in the production of prefabricated masonry panels. Semi-automated brick laying (using the mortar pump) speeds up laying times and reduces the need for bricklaying skills, and full automation is feasible for large quantities. High quality and consistency are achievable. Faster mortar setting time enables a more efficient production process. Enhanced panel strength compared with traditional construction simplifies lifting and transportation. There is a choice of off-site, on-site and in-situ construction, providing the necessary flexibility to match individual requirements.

10.8 The next steps

The successful completion of this research project has resulted in the production of a comprehensive review of the issues involved in design and building with thin-joint glued brickwork. The technical and practical information provided in this report is sufficient for designers and builders to begin to use this technique in projects in the UK.

Beyond this research project, there is now an urgent need for a comprehensive series of tests on weathering, compression, flexure and other aspects of thin-joint brickwork, to be carried out by independent bodies according to British Standards. These will provide a solid base for the adoption of thin-joint brickwork as a standard form of construction.

This final report will be published and the dissemination stage of the project will be undertaken, including the production of technical, trade/professional magazine and journal articles, the production of a website, and distribution of the information pamphlet.

10.9 Further research and development

Further work is required to explore the following aspects of thin-joint glued brickwork.
Tests should be carried out to the full requirements of the relevant codes in order to establish authoritative data upon which to base accurate and safe codes of practice. The factors which affect glued brickwork are many and varied, so a very wide programme of testing work is necessary over several years.

- Compressive and flexural tests with various joint thicknesses and configurations
- Development of BS 5628 flexural strength characteristics, and the relationship of such values to water absorption or net density for classification of f_kx
- Water penetration tests of a wide range of different types of mortars and bricks on larger panels
- Freeze/thaw tests, exploring not only effects of using different brick types but also of different external joint finishes e.g. flush, recessed.
- Investigate the practical tolerances of fired clay units, including squareness tolerance (not a BS 3921 requirement), in order to achieve consistent thin-joint brickwork
- Tests on movement of brick panels in relation to contraction and expansion in order to produce better design guidelines for movement joint frequency
- Wall tie tests on a range of ties in different relative bed joint levels of the wall leafs. Development of new ties.
- Tests on UK produced thin-joint mortar produced specifically for thin-joint brickwork
- Exploration in the use of glued brickwork as lintels
- Development of techniques to provide a full bed width of mortar without staining the front face of the bricks in order to achieve the full potential of the glue mortar. This might involve new mortar application nozzle design or brick shape.
- Development of a reliable site mortar pump operating on 110v which complies with the requirements of the H&S Executive
- Production of standard construction details and the possible use of specially sized concrete blocks for inner leafs to enable compatible coursing. The interface between the brickwork and standard components such as lintels, sills etc. should also be investigated.
- Prefabrication. A wide range of designs and prototypes should be tested to explore the potential for prefabrication of brickwork wall panels and components. Health and Safety issues will also need to be addressed to convince the H&S Executive that unreinforced masonry panels of this form are consistent in their properties, with respect to tensile strength, to enable safe carnage during transport and construction.
- Development of training materials for construction managers to promote good site practice in the production of thin-joint glued brickwork.
Energy

The Hanson EcoHouse™ and Hanson QuickBuild™ walling system

The development of prefabricated masonry walls using traditional materials and incorporating vacuum insulated panels.

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Theme 3: Industry needs and case studies

Abstract
The Hanson EcoHouse™ constructed for the BRE Offsite 2007 exhibition demonstrates the latest developments in off-site masonry construction, thermal mass and natural ventilation. The objective was to construct a domestic dwelling using prefabricated components including pre cast concrete flooring systems and prefabricated masonry cavity walls constructed using traditional brickwork / blockwork.

The project proved to be a success achieving a high quality finish, rapid construction, energy efficiency, structural integrity and an attainment of Code for Sustainable Homes Level 4. The prefabricated walling system is known as Hanson QuickBuild™. Walls using the QuickBuild™ system may be single or cavity construction – including partial or full fill insulation - and may incorporate clay brick, stone, aggregate or aircrrete blocks.

Further development work is currently addressing alternative insulation systems in order to overcome the trend towards increasing overall wall thickness. It is in this situation that there is potentially an excellent opportunity for vacuum insulated panels to be included in prefabricated walls.

Key words: prefabrication, masonry, thin joint, cavity wall, Code for Sustainable Homes

1. THE HANSON ECOHOUSE™

Designed as a three-bed detached dwelling, the Hanson EcoHouse™ shows all the benefits of off-site fabrication, that together with thermal mass and natural ventilation assist in the development of a building system targeting the zero carbon houses of the future. In addition, it shows how quickly and easily a liveable and saleable property can be constructed.

Constructed using masonry panels manufactured off site in a controlled factory environment, it brings together the benefits of high quality and speed of construction with virtually no site wastage. The process is also less susceptible to weather delays compared to on-site construction.
Designed to meet the combined challenges of off-site construction and the impact of climate change, this concept house has been constructed using the unique Hanson QuickBuild™ walling system.

1.1 Hanson QuickBuild™ System - Development of prefabricated masonry walls

Walls constructed using thin joint adhesive technology have been an established building technique in Europe for several decades. However the system has seen virtually no use in the UK with the exception of a number of important projects which have been developed by Hanson Building Systems in conjunction with evaluation and testing programmes both within the company, and externally with Oxford Brookes (Dti funded project), Kingston and Surrey Universities.

Completed projects include two university buildings (UWE in Bristol and University of Hertfordshire, Hatfield),

Fig 2 – Dept of Architecture and planning, University of West Of England

Fig 3 – New Digital Laboratory University of Hertfordshire

two private house developments, one of which was a Brick Development Association (BDA) award winning project for it's innovative spine wall construction and an Arts Centre in Luton. However, all projects involved single skin clay brickwork and have been constructed by in-situ techniques where bricklayers have used a pump and gun system to apply the special proprietary adhesive – generally known as “glue mortar”

Fig 4 – private development in Thaxted, Essex –structural spine wall in thin joint brick masonry

Fig 5 – private development in Thaxted, Essex
Following a period of further trials and testing of prefabricated panels built in both clay brickwork and aggregate blockwork Hanson built prefabricated dense concrete blockwork cavity walls for the ground floor construction of a two storey house – known as the Hanson House - for BRE Offsite 2005. Previous development and testing work had demonstrated that glued aggregate blockwork is particularly strong and robust achieving up to twice the standard flexural strength of traditional masonry. The method of construction employed involved traditional bricklayers working with thin joint mortars using trowel and scoop techniques the likes of which are already well established on site. However all of the walls were built in a factory environment.

In terms of structural design, the main consideration is not the integrity of panels once in place, rather the handling, lifting, transportation and further craning into position. In the event this proved most successful and paved the way for a full brick / block cavity construction.

1.2 Development of the Hanson EcoHouse™ – BRE Offsite 2007

Architects for the the EcoHouse™ built for BRE Offsite 2007 were TP Bennetts. Their design concept was based on the shape and format of a traditional kiln with consideration given to three key areas, namely :-

Thermal mass.
Masonry construction has high thermal mass. This inherent feature enables the dwelling to store heat and remain cooler for longer than lightweight structures meeting the needs of climate change and keeping buildings cool in an energy efficient environment.

Natural ventilation
The design of the EcoHouse™ was based on a brick kiln (appropriate to one of the largest clay facing brick manufacturers). A ventilating roof lantern is used to give light and to enhance the natural air currents, so maximising the energy conservation potential.

Flexible design
Masonry panels manufactured off site in a controlled factory environment provide total flexibility in the design of dwellings. The system has been designed to meet the needs of housebuilders and is applicable across a wide range of housing options.

Fig 6 Design concept for the Hanson EcoHouse™
The project is particularly important as it provides the first example of prefabricated cavity walls comprising 102mm clay Hanson facing brickwork outer leaf, 100mm aircrete Thermalite blockwork inner leaf and a partial fill cavity comprising 100mm Kingspan rigid insulation and a 50mm air space.

The two storey dwelling comprises walls that are 2.4m in height by up to 9m in length. Panels were both plain and with openings (both doors and windows) and on site construction time approximated to one storey per day. The ground floor also included a number of internal walls which were constructed in aggregate concrete blockwork.

Clay brickwork was constructed using the polyjet pump and gun system. The blockwork inner leaves and the internal dense blockwork leaves were built by use of a scoop. All three masonry types incorporated an appropriate glue mortar.

This is the first time that prefabricated masonry cavity walls have been constructed using the brick / aircrete materials. Prefabricated aircrete walls have been trialled by Hanson Thermalite but there were some concerns relating to their use in cavity wall panels of the dimensions used for the EcoHouse. Stack bonded brickwork, although desirable as an architectural requirement, also demonstrates the strength properties of the wall particularly showing off the residual strength during transportation and handling by crane.

The key properties of the finished walls include higher flexural strength for both brick and block (up to twice the strength of traditional masonry), increased vertical strength and an increase in resistance to rain penetration of the outer leaf due to the continuous consistent mortar jointing.

The thin fully adhered joints also contributed to an air tightness which is superior to that achieved with traditional masonry (4.9m³/m²/hr).

In addition, the wall construction quality is very high, waste is minimal and restricted to the factory environment and the system does allow for any combination of bricks / blocks and for any brickwork bond without a loss of strength.

One particular benefit which came out only during the transportation and erection process was the flexibility of the panels. Normally masonry is regarded as being very brittle and it is somewhat unforgiving of even minor deformation which is manifested as cracking. In the EcoHouse™ walls vertical deflections of up to 40mm were recorded without signs of
cracking. This was due in part to the inclusion of bed joint reinforcement (flat bar profile equivalent to 4mm diameter) which was used to minimise transportation damage.

Although both leaves of the cavity wall were connected by Helifix stainless steel spiral wall ties (5mm diameter, 250mm length), there was notable movement of one leaf relative to the other which was actually beneficial during the location and placement on site.

Accuracy in construction was also a significant plus point with dimensional tolerances not exceeding + / - 5mm on the diagonal of a 9m x 2.4m long panel. Typical deviations in length and height were 2-3mm. This was in part to be expected since all masonry was set out with metal profiles ensuring that, as with any standard masonry, all key dimensions were adhered to even if some variation within joints occurred.

The strength, versatility and ease of buildability of the thin joint adhesive masonry system will certainly allow for the continued use of traditional materials in a variety of building types, albeit with radical departure from traditional methods of construction.

1.3 Structural design concept for the Hanson EcoHouse™

The house is constructed as an “upside down” house ie. three bedrooms and a bathroom down stairs with a large open plan space on the first floor which provides kitchen, dining and living areas. The roof provides a lofty space for natural ventilation through an opening light at the top.

The ground floor is constructed using the Jetfloor beam and insulation block system whilst the first floor incorporates prestressed hollowcore units.

In terms of structural design of the masonry, procedures as outlined in BS5628 Parts 1 and 2 were followed wherever possible. Masonry characteristic strength values used in calculations were based upon tests carried out in accordance with the relevant appendices for that Code. Ground floor walls presented no problem due to the arrangement of internal masonry. However at first floor level, since there are no internal walls all panels had to span vertically between the steel framed roof structure and the first floor. To work successfully as a masonry solution as far as wind loading is concerned this requires the increased strength properties of the thin joint adhesive system, self weight of the roof structure and appropriate restraint at the eaves and floor level.

All materials were manufactured to an approved quality system, regular materials testing was carried out throughout the construction process and workmanship was carried out under regular supervision. Consequently a partial safety factor $\gamma_m = 2.5$ was employed in design calculations which gives an improvement on a “standard” or normal construction which uses a $\gamma_m$ of 3.5.

The wide cavity (150mm) coupled with thin bed joints presented a challenge when ensuring an appropriate strength of wall tie which would be accommodated in the construction format. Joints in brickwork were 6mm and in blockwork approximately 2mm.

The superior strength facilitated by the use of thin joint mortars enabled the wall tie spacing to be limited to 900mm c/c both vertically and horizontally even with the use of a stack bonded brickwork.
The ground floor / first floor detail was dealt with by the introduction of a steel channel (edge beam) which although desired by the architect for visual purposes, did allow for a break in continuity of the external masonry and again ensured that any manufacturing inaccuracies could be dealt with by the detail.

The stack bonded brickwork enabled corner details to be dealt with aesthetically by use of a standard vertical movement joint comprising readily compressible filler and a mastic finish. Joint thicknesses were detailed as 20mm to allow for dimensional variation of panels but these were shown to be more than adequate for the construction accuracy that was achieved.

Fig 9 Completed Hanson EcoHouse™ – Code level 4

2. DESIGNING TO THE CODE FOR SUSTAINABLE HOMES (CSH)

At the time when the original Hanson House concept was being put together, the Code For Sustainable Homes had only just been proposed and this proved to be somewhat challenging when carrying out a code assessment which would give an acceptable evaluation for the building.

The CSH is an environmental assessment method for rating and certifying the performance of new homes. It is split into 9 categories, each category being weighted in order of its environmental impact importance.

- Energy and CO2 Emissions
- Water
- Materials
- Surface Water Run-off
- Waste
- Pollution
- Health & Well-being
- Management
- Ecology

The code highlights 6 categories (ratings) which classify energy saving / efficiency of a building in its particular environment. Most current construction types would attain Code Level 3 whilst a zero carbon building is required to be at Code Level 6.

Government timescales dictate that all new build homes attain level 3 by 2010, level 4 by 2013 and level 6 by 2016 for private sector work. Public sector buildings need to attain level 4 and level 5 by 2010 and 2013 respectively.

The Hanson House achieved a realistic Code level 4.

Initial design requirements in terms of environmental comfort were based on the thermal mass concept which exploits the density of the construction materials (ie concrete and brick for both floors and walls) to provide a cool structure on hot days as the building
materials absorb the heat. This heat is then slowly released during cooler conditions. In simple terms the peaks and troughs in temperature changes over a day/night cycle are not as severe as for other structures which do not possess high thermal mass.

The walls of the house achieved a U value = 0.18W/m²K, an acceptable figure in terms of the wall performance but this highlights an issue which is of some concern ie the ever increasing width of the cavity in order to maintain such low values.

3. DEVELOPMENT OF CAVITY WALLS – COMPOSITION AND REDUCING U VALUES.

A brick / block cavity wall has proven to be a popular efficient form of construction, versatile in terms of finishes and properties. However the traditional cavity wall comprised no more than a 103mm brick outer leaf, 50mm air space and a 100mm iner leaf plus 12mm plaster finish. This gave an overall thickness of 265. Cavity walls require both leaves to be connected with wall ties at sufficient frequency and of sufficient strength to allow both leaves to act integrally when resisting the loads to which they may be subjected. Generally speaking a cavity should not exceed 150mm in thickness as this not only compromises the integrity, but will increase the size, frequency and cost of stainless steel ties which will have to be of the order of 250mm long. Additionally the plan area of a building is compromised by increasing wall thicknesses – either by reducing the living space or increasing the overall building footprint. This will inevitably mean that fewer houses are constructed in an effort to improve building performance.

The following table illustrates the changes that have occurred from the early 1970’s potentially up to 2016 in terms of U values, wall composition and overall thicknesses giving a specific example of mineral wool as the insulation.

It must be noted that improvements in materials ie in insulation types and block masonry materials have helped to keep walls to a minimum thickness but clearly the modern day wall is almost double its original thickness.

<table>
<thead>
<tr>
<th>Wall thickness (mm)</th>
<th>Year</th>
<th>U value</th>
<th>construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>265</td>
<td>Pre 1976</td>
<td>1.5</td>
<td>103mm brick, 50mm cavity 100mm block, mineral wool thickness shown below</td>
</tr>
<tr>
<td>305</td>
<td>1978</td>
<td>0.6</td>
<td>40</td>
</tr>
<tr>
<td>325</td>
<td>1991</td>
<td>0.45</td>
<td>60</td>
</tr>
<tr>
<td>349</td>
<td>2002</td>
<td>0.35</td>
<td>85</td>
</tr>
<tr>
<td>425</td>
<td>Current design request</td>
<td>0.2</td>
<td>160</td>
</tr>
</tbody>
</table>

Some examples of walling solutions offered by Hanson are illustrated. Note how the overall wall thickness increases as the U value is reduced. A U-value of between 0.15 and 0.27 W/m²K for external walls will be appropriate to meet future requirements through to 2016.
## Table 2

### Cavity Walls

#### Brick / Block / Partial Fill

<table>
<thead>
<tr>
<th>U-value (W/m²K)</th>
<th>0.15</th>
<th>0.18</th>
<th>0.20</th>
<th>0.22</th>
<th>0.25</th>
<th>0.27</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall thickness</td>
<td>375mm</td>
<td>332mm</td>
<td>320mm</td>
<td>310mm</td>
<td>300mm</td>
<td>292mm</td>
</tr>
<tr>
<td>Insulation thickness</td>
<td>125mm</td>
<td>82mm</td>
<td>70mm</td>
<td>60mm</td>
<td>50mm</td>
<td>42mm</td>
</tr>
</tbody>
</table>

| Brick / 50mm air gap / P U board (λ = 0.023) / Inner leaf - 100mm Fenlite block / dry lining |
| U-value (W/m²K) | 0.15 | 0.18 | 0.20 | 0.22 | 0.25 | 0.27 |
| Wall thickness  | 385mm| 345mm| 332mm| 322mm| 310mm| 305mm|
| Insulation thickness | 135mm| 95mm | 82mm | 72mm | 60mm | 55mm |

#### Brick / Block / Full Fill

<table>
<thead>
<tr>
<th>U-value (W/m²K)</th>
<th>0.15</th>
<th>0.18</th>
<th>0.20</th>
<th>0.22</th>
<th>0.25</th>
<th>0.27</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall thickness</td>
<td>400mm</td>
<td>340mm</td>
<td>325mm</td>
<td>315mm</td>
<td>300mm</td>
<td>285mm</td>
</tr>
<tr>
<td>Insulation thickness</td>
<td>200mm</td>
<td>140mm</td>
<td>125mm</td>
<td>115mm</td>
<td>100mm</td>
<td>85mm</td>
</tr>
</tbody>
</table>

| Brick / mineral wool (λ = 0.032) / Inner leaf - 100mm Fenlite block / dry lining |
| U-value (W/m²K) | 0.15 | 0.18 | 0.20 | 0.22 | 0.25 | 0.27 |
| Wall thickness  | 400mm| 375mm| 340mm| 325mm| 315mm| 300mm|
| Insulation thickness | 200mm| 175mm| 140mm| 125mm| 115mm| 100mm |
### Table 2 (cont’d)

#### Block / Block / Partial Fill

<table>
<thead>
<tr>
<th>Render / Outer leaf - 100mm Thermalite Hi Strength 7 block (aircrete) / 50mm air gap / P U board ($\lambda = 0.023$) / Inner leaf - 100mm Thermalite Turbo block (aircrete) / dry lining</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U-value (W/m$^2$K)</strong></td>
</tr>
<tr>
<td><strong>Wall thickness</strong></td>
</tr>
<tr>
<td><strong>Insulation thickness</strong></td>
</tr>
</tbody>
</table>

#### Block / Block / Full Fill

<table>
<thead>
<tr>
<th>Render / Outer leaf - 100mm Fenlite block / 50mm air gap / P U board ($\lambda = 0.023$) / Inner leaf - 100mm Fenlite block / dry lining</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U-value (W/m$^2$K)</strong></td>
</tr>
<tr>
<td><strong>Wall thickness</strong></td>
</tr>
<tr>
<td><strong>Insulation thickness</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Render / Outer leaf - 100mm Ultralite block / mineral wool ($\lambda = 0.032$) / Inner leaf - 100mm Ultralite block / dry lining</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U-value (W/m$^2$K)</strong></td>
</tr>
<tr>
<td><strong>Wall thickness</strong></td>
</tr>
<tr>
<td><strong>Insulation thickness</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Render / Outer leaf - 100mm Ultralite block / mineral wool ($\lambda = 0.032$) / Inner leaf - 100mm Ultralite block / dry lining</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U-value (W/m$^2$K)</strong></td>
</tr>
<tr>
<td><strong>Wall thickness</strong></td>
</tr>
<tr>
<td><strong>Insulation thickness</strong></td>
</tr>
</tbody>
</table>

### Thermal mass

The benefits of thermal mass are easily demonstrated simply by visiting a selection of demonstration projects which all lay claim to achievement of energy efficiency and attainment of Code levels in excess of 4. Any structure built of a dense material will keep the internal temperature of the building at a more stable level i.e. the heating up and cooling down time due for example to high external temperatures is less severe due to the temperatures storage capacity of the material. Clearly masonry presents an ideal solution when exploiting the benefit of thermal mass.
5. POTENTIAL BENEFITSOF VACUUM INSULATED PANELS

There is clearly a benefit in using masonry cavity walls although structural integrity and thermal performance need to be addressed.

The issues highlighted above provide a clear invitation to VIP manufacturers to address development of a panel system which might be incorporated into the cavity wall. This might enable walls to be constructed in a format that has not been possible for over 30 years ie the 265mm (or less!) system where the vacuum panel may be encased.

Prefabricated masonry walls could certainly benefit from such a system since the wall tie issue would not be so critical. Prefabrication might also suit vacuum panels as construction and handling are carried out in a factory controlled manor.

A wall with a “sensible” cavity width will be better for structural performance, with less demands on the wall ties.

6. THE CHALLENGE TO VACUUM INSULATION PANEL MANUFACTURERS

1. Design a vacuum panel which is sufficiently thin to be accommodated in a 50mm cavity wall. Designers demand ever lower U values which require more insulation and / or insulated dry lining systems. The cavity wall has increased from a traditional width of 275mm (102 brick, 100 block and 75 fill or partial fill) up to in excess of 350mm which includes a 150mm partial fill cavity. Thicker cavity walls use more valuable land space.

2. Provide a vacuum panel with sufficient resilience / robustness that it cannot be punctured. Alternatively place a panel within wall cavity in such a manner as to avoid puncture by external fixings.

3. Determine size of panel in order to allow simple cavity wall construction without the need to avoid wall ties. Insulation bats are generally co-ordinated in size to fit in between wall tie spacing.

4. Details of connections between adjacent vacuum panels are critical. How will the panel efficiency be affected by joints?

5. Traditional cavity walls - and the Hanson prefabricated QuickBuild wall - use clay brickwork external cladding with a 60 year guarantee in accordance with the Building Regulations. This refers specifically to durability and structural integrity. A vacuum insulated panel must have a relatively long life / low maintenance if it is to be considered.

6. How long will the vacuum panel last – how often and by what technique will the vacuum panel require servicing.

7. If the panel itself is more expensive than traditional insulation, it will be very important to have cost comparative information against traditional walls, ie not only material but also savings in build area, construction time and long term running costs.
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