Energy-Pollution Nexus for Urban Buildings

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Since the first oil crisis in 1974, economic reasons placed energy saving among the top priorities in most industrialised countries. In the decades that followed, another, equally strong driver for energy saving emerged: climate change caused by anthropogenic emissions, a large fraction of which result from energy generation. Intrinsically linked to energy consumption and its related emissions is another problem: indoor air quality. City dwellers in industrialised nations spend over 90\% of their time indoors and exposure to indoor pollutants contributes to \(\sim 2.6\%\) of global burden of disease and nearly 2 million premature deaths per year\textsuperscript{1}. Changing climate conditions, together with human expectations of comfortable thermal conditions, elevates building energy requirements for heating, cooling, lighting and the use of other electrical equipment. We believe that these changes elicit a need to understand the nexus between energy consumption and its consequent impact on indoor air quality in urban buildings. In our opinion the key questions are how energy consumption is distributed between different building services, and how the resulting pollution affects indoor air quality. The energy-pollution nexus has clearly been identified in qualitative terms; however the quantification of such a nexus to derive emissions or concentrations per unit energy consumption is still weak, inconclusive and requires forward thinking. Of course, various aspects of energy consumption and indoor air quality have been studied in detail separately, but in-depth, integrated studies of the energy-pollution nexus are hard to come by. We argue that such studies could be instrumental in providing sustainable solutions to maintain the trade-off between the energy efficiency of buildings and acceptable levels of air pollution for healthy living.

We now understand that the lion’s share of total generated energy is consumed by modern urban buildings, with both commercial and residential buildings being the culprits. These buildings cover only 0.2\% of land worldwide, but account for 30–40\% energy use and \(\sim 8\%\) of total greenhouse gas emissions\textsuperscript{2}. Half of the world’s population was living in urban areas in 2010, which is expected to grow to \(\sim 61\%\) by 2035. By 2020, primary energy use by emerging economic nations is expected to surpass its use in developed countries\textsuperscript{3}. Over the past 30 years per capita consumption of primary energy has grown at a much faster rate (17.5\%) than the population, with projected increase in building energy use of \(\sim 34\%\) in the next 20 years\textsuperscript{4}.  

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Of particular significance is the growth in energy consumption for heating, ventilation and air-conditioning (HVAC) systems. In developed countries, HVAC systems account for about half of the energy use in buildings and 1/5 of total energy use\(^3\). This energy is mainly generated by power plants situated away from urban areas, thus adding to general ambient air pollution. This pollution penetrates indoors, and in naturally ventilated buildings, concentrations of outdoor-generated PM\(_{10}\) and PM\(_{2.5}\) reach between 50-100% of their outdoor levels. We believe that to establish a quantitative link between energy consumption and indoor air pollution for naturally ventilated buildings, the following existing data could be utilised: the contribution of power plant emissions to the overall atmospheric pollution, the fraction consumed by buildings and the established I/O ratios for such buildings. In contrast, much less outdoor pollution penetrates into the mechanically ventilated buildings through the HVAC system. Nevertheless, outdoor air is the main pollution source for such buildings, and in our view, some assessment of the relationship between energy and indoor pollution would be feasible.

Also of significance in our opinion is the energy consumed by building appliances. This energy is also generated by the power plants that add to ambient pollutant loads, but the appliances themselves make a direct contribution to indoor pollutant concentrations. Data on this aspect of energy consumption is sparse, but extensive energy losses are expected due to the practice of continuously powering many appliances, even when they are not in use.

Another issue is pollution generated inside the buildings by indoor sources. These sources could be energy consuming, like vacuum cleaners, printers or other type of electric motors. The sources could also be the use of consumer products that do not require electrical energy (e.g. fresheners, paints, incense, tobacco). Modern buildings are intentionally designed to be airtight, to minimise loss of energy. This airtightness affects the air-exchange rate (i.e. breathability) of buildings and hence controls the indoor air quality and build-up of harmful pollutants, such as carbon monoxide, total volatile organic compounds (VOCs) as well as coarse, fine and ultrafine particles. In addition, air tightening may also lead to the growth of mold and bacteria, as well as fungal staining (blackening) on the building’s interior walls and roofs\(^4\). Blackening affects the buildings aesthetics and calls for regular refurbishment, which is linked with the emission of semi-VOCs, which in turn elevates the number concentration of particles that induce condensation, thereby contributing to further blackening. Reduced air exchange rates due to new insulation standards further exacerbate this process and changes in relative humidity and temperature can disturb indoor chemistry to form harmful pollutants\(^5\). The commonly applied measure to counter this issue is the operation of dehumidifiers. Their use not only leads to additional energy consumption, but also production of toxic pollutants, such as nanoparticles related to electric motor operation.

While optimal energy use is the key for sustainable building operation, maintaining the quality of indoor air to acceptable standards is equally important from a health perspective. We put forward that the right combination of energy efficient building designs, energy saving technologies, informed behavioural choices and optimisation based on local climatic conditions can lead to substantial reductions in energy consumption and hence, pollutant emissions within the buildings. Use of appropriate materials (e.g. hygroscopically active to moderate indoor
humidity), preventive and remedial actions, such as controlling emission sources, the removal of indoor emissions by ventilation and cleaning the air with filters could improve indoor air quality. In summary, we firmly believe that there is an immediate need to understand the energy–pollution nexus for urban buildings to support the future development of resilient and sustainable conurbations and urban communities.

References: