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OPINION

Research priorities in the decarbonisation of buildings

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Abstract

Research challenges and key gaps in knowledge to achieve decarbonisation of buildings are discussed.

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1. Introduction

In the operation of buildings, energy-related greenhouse gas emissions arise from burning fossil fuels; both directly for heating, hot water and cooking, and indirectly to produce district heat supplies and grid-supplied electricity. Emissions vary depending on building energy uses, the mix of energy and fuels used and the extent of decarbonised energy supplied to a building.

2. Building renovation

Existing buildings, which constitute the majority of the stock, can be renovated to incur low heat losses, heat more efficiently and directly harness solar energy. However, renovations often need to satisfy multiple expectations beyond decarbonisation. These can include smaller energy bills; better thermal comfort, internal air quality and access to daylight; and increased property values. To achieve these successfully requires research to identify optimal interventions and construction practices. To reduce renovations costs, research is required on how to make "one-stop-shop" renovation services effective for consumers and the use of non-invasive building fabric diagnostics, for example infrared thermography, to eliminate overcosts from remedying unforeseen defects. Decarbonising heritage buildings with unique and legally protected attributes remains a major research challenge, as is the resilience of both refurbished and new buildings and energy systems to the impacts of climate change.

For existing buildings with very poor energy performance, affordable decarbonisation is probably unachievable solely by either energy demand reduction or replacing fossil fuel supplies with renewables [1]. An optimal building renovation thus entails reducing building energy demand with that thus-smaller demand then being met from decarbonised electricity and/or heat supplies. Further research is required on techniques to optimise this combination, as well as on the reliability of the databases of multple individual building certification assessments that are extrapolated to describe the energy performances of entire building stocks.

3. Embodied carbon

In addition to emissions incurred operating buildings, emissions are also embodied in building materials and components when fossil fuels are in their manufacture. The embodied carbon in a refurbished building depends on the depth of renovation and how much wood, repurposed previously-used building components and recycled materials have displaced use of steel, concrete and bricks. The more carbon embodied in renovation materials, the longer it takes for cumulative lower operational emissions to offset them. Reconciling reusing, repurposing, and recycling materials and designing for disassembly with constructing robust and healthy buildings requires considerable research as does decarbonising cement, glass and steel production as the continued use of these materials will, to some extent, be inevitable.

4. Interior environment

"Adaptive facades" alter their characteristics to lessen heating and cooling requirements. Innovative adaptive building envelope materials and facade components have been developed that improve energy efficiency and occupant comfort, however their adoption has been limited. The lack of standard procedures to characterise their performance has impeded predicting operational performance at the design stage, successful operational realisation of benefits and predictive maintenance planning [2]. To achieve synergy between façade and building services systems, cyberphysical control strategies that augment passive thermophysical responses to weather and occupancy merit further research [3].

Daylight is both important for human health [4] and displaces electric lighting during the day. Research on daylighting, on benefits of views from windows and energy-efficient window technologies continue to be a priority [5].

Good indoor air quality is critical to healthy indoor environments. Focusing on school buildings, pupils breathe more air for their weight than adults, so are sensitive to heat, cold and moisture. Healthy school environments may thus reduce absence and enhance learning [6], but large pupil sample-size studies of the effects of internal environmental conditions in school buildings close to transport routes and industrial areas remain necessary.

5. Heat pumps, district heating and thermal energy storage

District heating and cooling is particularly attractive in urban areas with high building densities. Current operating temperatures in district heating networks fulfil requirements for Legionella-safe domestic hot water. A transition to renewable energy based district heating networks, requires heating systems in buildings that can provide comfort and hot water hygienically at lower temperatures.

The best mix of low-carbon heating and thermal energy storage varied significantly depending patterns of heat demand and the availability of renewable generation [7]. In most European countries heat pumps thus do not require back-up heating. However, more research is required on heat pumps and heat storage to achieve acceptable heating where and when temperatures fall far below 0˚C for significant periods [8]. With the introduction of a heat pump, the consequent need, if any, for additional insulation, mechanical ventilation and fan coils to replace existing radiators varies for different climates, buildings and occupancy patterns. These relationships need further research so that predicted outcomes lie with desired ranges.

6. Electrification, PV electricity generation and electricity storage

Photovoltaics on buildings not only reduces annual emissions from a building but via self-consumption of the generated electricity enables certainty on energy costs and security of supply. This may be particularly useful in climates where cooling is required for comfort in summer. Energy storage will become increasingly important as the fraction of variable renewable electricity generation from wind and solar generation on the grid increases. Electricity can be stored in batteries or as low temperature heat in water tanks. Using stationary batteries in buildings and/or mobile batteries in electric vehicles may permit a wider use of demand response and prosumer participation in electricity markets. More research is need to help electricity distribution system operators manage grid connections where there is large-scale adoption of distributed renewables and active prosumers [9]. Research is also required on how to improve the transmission and distribution of energy to cities from often remote large-scale renewable energy resources. Further research is need on technologies to capture data on energy consumption at appropriate granularity whist maintain personal data security.

7. Social policy

Low incomes, private tenancies, other social inequalities and poor quality buildings combine to create the difficult problem people in energy poverty in hard-to-decarbonize homes. [10] that remains a critical area of cross-cutting research. Income inequality is often the primary reason for energy poverty, so addressing social policies alongside energy policy becomes crucial. Research is needed to determine if, and how, public investment in renovations for energy-poor households may be a preferable option with no unforeseen consequences to providing long-term social welfare support to pay high energy bills. At the opposite end of the consumption spectrum, more research is required to determine the cultural and behavioural changes required for effective long-lasting demand reduction in countries with high domestic energy consumption, such as the USA.

8. Conclusion

An extensive report containing advice for policy makers on how to the European Union (EU) could achieve its goal of reducing carbon emissions to net zero by 2050. was published in 2021 by the European Academies Science Advisory Council [11]. This paper summarises a selection of key associated research challenges.

Energy efficiency is not the prime function of buildings; rather they must primarily ensure a healthy, comfortable and safe set of amenities and services are provided whilst incurring minimal energy use. So, for applications to individual buildings, health and well-being must be kept to the fore in all research on building decarbonisation. At national scales, policy research needs to define and underpin adaptation of institutional and financial systems to enable large-scale investment in decarbonised energy infrastructures.

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