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Using epidemiological methods in energy and buildings research to achieve carbon emission targets

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ABSTRACT

Energy demand reduction from buildings is widely recognised as a key component of greenhouse gas abatement strategies. As governments shift towards large-scale sectoral interventions, a far more robust research and evidence base is needed to support the development, implementation, and on-going evaluation of energy demand policy.

The shift to a low carbon built environment will require both a step change in the energy performance of buildings alongside more efficient provision of energy services, and an aggressive decarbonisation of the energy used. Yet the prerequisite data of building stocks needed to support this essential shift in energy performance of buildings are not necessarily available or are inaccessible or incomplete. As more information on building energy use is collected through high frequency sensors and building form analytics become more sophisticated, the analysis methods applied to the myriad and diverse sub-sectors of the building stock 'population' need to be commensurate with the heterogeneity of the building stock.

This paper describes and illustrates the basis of the IEA EBC Annex 70: Building Energy Epidemiology, which draws on the health sciences to posit 'energy epidemiology' as a whole-system approach for empirical research that provides a methodological framework for building physicists, engineers, social scientists, and economists to engage in cross-disciplinary studies. It makes the case that the development and application of an epidemiological approach to investigating energy demand can advance understanding of the inter-related factors for policy guidance and evaluation and provide insights on the mechanisms that influence energy demand. The aim of the IEA EBC Annex 70 is to work in an international collaboration to identify user needs around energy demand in buildings and to establish best practice methods and harmonized formats for data collection, analysis and modelling.

To illustrate this process, we present an example from the UK on the application of energy epidemiological methods to building energy performance in the residential sector. The case study investigates the potential effectiveness of the policy and technical measures proposed by the UK Government.

Policy implementation for broad, deep, and urgent reductions in energy demand from the building sector requires a far better understanding of the underlying relationships between people, energy use, buildings and the environment.

1. Introduction

The International Energy Agency (IEA) have argued that a renewed focus on energy efficiency, including the energy performance of buildings, could half the rate of growth in energy demand and effectively buy time – substantially easing the transition to a low-carbon economy [1]. Recently, the Paris Accord set out a global framework for reducing global emissions to a level that would limit warming to 1.5 °C [2], which means for many high-income countries a carbon reduction of greater than 80% by 2050 from 1990 levels. For the built environment, this offers a formidable challenge. Building operation accounts for about a third of both global final energy consumption, with about half of this due to space heating, cooling, and hot water [3]. Many governments have already identified buildings as a key sector to contribute reductions in energy demand and help attain policy objectives for GHG abatement, alongside priorities for energy security and socioeconomic development, of which the potential for decarbonisation may evolve under rapidly changing circumstances [4]. Investment in buildings in OECD countries has increased by 9% between 2014–2015, despite falling natural gas prices of 10%, alongside the introduction of energy efficiency policies that have continued to increase in terms of improved building codes and standards [5]. In the EU-

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27 countries, all new buildings must be 'nearly zero-energy' by the beginning of 2021 [6] with the contribution from existing buildings seen as crucial to achieving the EU target of 80–95% emissions reductions by 2050 [7]. In the US, the most ambitious targets for lowering energy demand have been set at the state level, for example California aims to reduce energy consumption in existing homes by 40% by 2020 [8].

Mitigating climate change by transforming to a low carbon built environment pose pressing challenges for policymakers. Energy demand reduction from buildings is widely recognised as a key component of greenhouse gas abatement strategies. As governments shift towards large-scale sectoral interventions, a far more robust research and evidence base is needed to support the development, implementation, and on-going evaluation of energy demand policy. This shift to a low carbon built environment will require both a step change in the energy performance of buildings alongside more efficient provision of energy services, and an aggressive decarbonisation of the energy used. Yet at the national and regional setting, the prerequisite data of building stocks needed to support this essential shift in energy performance of buildings is often not available or are inaccessible or incomplete (e.g. energy meter data, physical building information, occupant details, etc. . .). There are a number of countries and settings where energy and building stock data is emerging and accessible (e.g. UK National Energy Efficiency Data-Framework, US DOE's Building Energy Performance Database, South Korea's Building Energy Integrated Database, or Sweden's Energy Performance Certificate Database), or where high-quality surveys are a part of the research landscape (e.g. US DOE's or Residential or Commercial Building Energy Surveys). However, as more information on building energy use is collected through high frequency sensors and building form analytics become more sophisticated, the analysis methods applied to the myriad and diverse sub-sectors of the building stock 'population' need to be commensurate with the heterogeneity of the building stock.

Policies focused on energy demand in buildings are developed in a complex environment of crosscutting multi-objective and interacting issues of climate change, prices and affordability, energy supply, market regulation, and health and wellbeing. To date, however, energy policy has not adequately recognised or been able to respond to this complexity, which has meant that policies have failed to deliver or adequately address many of these complex, socio-technical challenges in a timely manner, e.g. the rollback of the UK's building fabric targets in order to support the now defunct zero carbon building target [9,10]. More broadly, this failure is seen in the mismatch of the nationally determined contributions for the Paris Climate Accord and the needed actions to avoid 2 °C global warming [11]. Energy and building policy is focused at the population scale, but current research is largely carried out at the individual unit level (e.g. building, person, household) and small-scale, driven by single discipline perspectives. Beyond policy, the building industry and technology manufacturers create products that are focused at populations (e.g. national building stock, cities, building typologies). These industries rely on population data to understand their market whilst also carrying out technology field trials to determine product potential. However, the limited availability of detailed empirical data on energy demand in buildings makes it difficult to understand the market potential and impact of widely installed technologies. This has meant that deeper insights into problems around energy demand in buildings, their presence and persistence across the population, are severely limited, which in turn undermines effective policy, product development and deployment. As national sustainable development and decarbonisation plans are developed, government, research and commercial organisations will need better empirical data on building stocks to support intervention programmes, modelling exercises and to evaluate past and predict future practices.

2. An empirically-based transformation

The implications of a low-carbon transformation of the building stock have received growing recognition in terms of the scale of the reduction in energy demand proposed, the scope of change applied across diverse building sub-sectors, and the urgency needed to deliver robust outcomes [12,13]. Yet, the current empirical evidence base for understanding energy demand from buildings remains far from commensurate with the need to support robust implementation and evaluation of these policy measures or to suggest further initiatives [14]. For example, most countries and cities do not have accessible a consistent or frequently updated database on empirically measured energy and building performance for a large scale of their building stock, though some countries like those mentioned above remain exceptions. Initiatives such as the US DOE's Standard Energy Efficiency Data Platform (SEED) and the EU's Building Stock Observatory is designed to help address this by providing a standard data management platform [15].

The energy and buildings research community, therefore, faces an extraordinary challenge that requires a concomitant transformation in the culture and practice of the energy and buildings research [12]. It entails moving beyond research questions that just address technical aspects of energy demand to multidisciplinary studies that aim to disentangle the dynamic and interrelated effects of technical, social, lifestyle, economic and environmental factors that influence occupant behaviour and energy demand [16–19]. Instead, the prevailing approach across much of energy demand research is characterised by piecemeal small-scale studies and fragmented discipline-specific methods that struggle to identify emergent phenomena and unintended consequences of interventions in a complex multi-layered system[20]. This has led to a lack of clarity regarding the validity and applicability of predictions from building energy models in terms of their underlying theoretical limitations [21], for instance the degree they account for behavioural change in heating and cooling. As a consequence, the interpretation of research findings suffers in terms of their scope and generalizability to provide clear guidance for policy makers and industry [12]. Predictive models, whether national and sub-sector/population focused, require robust data to characterise the 'baseline' of energy and services demand – otherwise they are at risk of applying future technologies into socio-technical contexts that are not well defined.

Historically relatively little empirical broad scale evidence has been available to guide both strategic and detailed policy development. If we just consider improving the energy performance of residential buildings or dwellings a number of key questions arise, such as:

- What is the empirical distribution of energy demand of buildings across the population, and how heterogeneous is this demand across sub-groups of dwellings and household types? For instance, interventions are unlikely to provide the same reductions in energy demand for different dwelling types or for buildings occupied by different social groups.
- Do building components perform as expected in situ and under varying environmental conditions and over time, and does the source of any discrepancy lie in properties of building materials, poor installation methods, design flaws, or elsewhere? Building-related efficiency interventions often have lifetimes spanning decades and so if not correctly installed or otherwise fail to perform, are likely to prove difficult to rectify subsequently.
- How does the energy demand of sub-groups respond according to changes in external climatic conditions and socioeconomic