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LIFE COURSE BUILDING EPIDEMIOLOGY: AN ALTERNATIVE APPROACH TO THE COLLECTION AND ANALYSIS OF CARBON EMISSION DATA

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Developing policy for the reduction of the carbon emissions due to buildings requires models for energy usage that incorporate social, behavioural, and environmental factors in addition to the physical properties and technical specifications of the buildings. Marked parallels exist with some of the more intractable public health issues, such as rising levels of obesity. Recently, health researchers have recognized the importance of taking a broader life-course approach to epidemiology in order to examine the degree that long-term health outcomes are set in early life and the extent that these may be mediated or mitigated by subsequent growth and development, as well as by intervention strategies. Life course epidemiology as applied in building science, where energy usage is treated as analogous to poor health outcomes, provides an alternative approach for the construction of causal models that allow for complex interactions between social and technical factors as well as long term effects. It can provide a useful framework for the successful management and analysis of longitudinal studies and may prove particularly effective in identifying the type, timing, and targeting of intervention strategies to produce optimal outcomes in terms of absolute reductions of carbon emissions and resilience of building performance to external stresses, such as those imposed by climate change. An example based on a study in Milton Keynes (London), which is currently in progress, is used to illustrate the way causal models may help elucidate the complex interactions between factors that influence energy usage.

Keywords: Building Performance, Energy, Modelling, Longitudinal Studies.

INTRODUCTION

Faced with the challenges posed by climate change and the UK government objective to reduce CO2 emissions by 60% by 2050 (DEFRA, 2004), researchers have increasingly recognised that accounting for carbon emissions requires a broader approach than is suggested by a purely technical model. The UK Office of National Statistics has estimated the environmental impact of households by region not only due to direct emissions (heating, cooking) but also the contribution from indirect consumption (public transport use, demand for other goods and services)(Francis 2004). In building science, social and behavioural factors typically result in less energy savings than expected from models based on the building's physical properties. For instance, previous investigations into domestic energy use have shown that a significant proportion of energy efficient improvements are taken as improvements in comfort. Over the last 30 years the efficiency of the domestic stock in England has improved by 30%, yet during that period, despite warmer winters, primary energy use

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increased by 27%, mostly as a result of increased heating levels and appliance use (Shorrock & Utley 2003).

Even ‘energy efficiency measures’ themselves can lead to greater energy consumption. In one study of conservatory additions in the UK, two thirds of respondents stated they heated their conservatory directly, whereas a further 24% heated them indirectly through leaving the doors open between the heated house and conservatory or had no doors separating the conservatory from the house (Oreszczyn 1993). Contrary to expectations, the study also found that double glazed conservatories used twice the energy of single glazed conservatories. This may be explained by the difficulty in keeping in single glazed conservatories warm during winter, whereas double glazed conservatories provide a space that with an energy penalty can be maintained to be comfortable all year. Thus they become an extension of the main dwelling with consequent changes in occupancy patterns and energy consumption that were never originally envisaged.

In dealing with similarly complex challenges posed by public health issues, such as rapidly rising levels of obesity, epidemiologists have also had to broaden their methodological approach to disease aetiology to include the effects of social and environmental factors on long term health outcomes. Life course epidemiology has become favoured as an inherently broad and interdisciplinary approach that allows for complex causal models that include interactions between numerous factors at different stages of the life course and influence the onset and progression of adverse health outcomes in later life. It is a methodology that is intended to address ways of identifying the type, timing, and targeting of policy interventions for the most effective impact. This suggests that such a methodological approach may hold potential for building researchers to construct causal models for the analysis of energy data within a socio-technical framework and so identify the optimal measures for reducing the carbon emissions due to the building stock. In the following sections, some of ideas behind this approach are outlined as the basis for a research project using energy consumption data initially collected 16 years ago, with a follow-up survey that is currently in progress.

BACKGROUND

The inclusion of the built environment in epidemiological research dates from at least the 1850’s when various London districts were suffering from outbreaks of cholera. By meticulously mapping the address of victims and their source of drinking water, John Snow showed that the incidence of cholera was related to the water supplies from one particular company and thus gained support for his model that this disease was spread via contaminated water (Snow, 1855; Beaglehole et al. 1995). Crucially, his evidence indicated that water supplies should be improved as a matter of public health policy long before the specific organism responsible for cholera was identified. This founding event for the discipline of epidemiology is commemorated in the built environment of London by the notorious water pump in Broad Street, Soho, responsible for a cholera outbreak in 1854. It still stands today, *sans* handle, near the John Snow pub.

Epidemiology has been defined as ‘the study of the distribution and determinants of health-related states or events in specified populations, and application of this study to the control of health problems’ (Last, 1995). Epidemiology and epidemic both derive from the Greek epidēmos, or ‘prevalence’, with *demos*, meaning ‘people’, at its root.

The discipline developed rapidly through the twentieth century into a major branch of medical science with research primarily focussed on the aetiology and prevention of communicable diseases. More recently, as medical health has improved, studies have encompassed non-communicable and chronic diseases of industrialised nations, as with the influential work on the relationship between smoking and lung cancer (Doll and Hill, 1964). In the process, there has been recognition for the need to address and account for the social and environmental determinants of disease, such as lifestyle and behavioural factors, as well as the role of the built environment (Ben-Shlomo and Kuh 2002).

Recently in building energy research, common interests and opportunities for collaboration with epidemiology have emerged. Warm Front is a UK government funded programme to alleviate fuel poverty, a situation that occurs when inhabitants are unable to afford adequate heating of their home and so risk ill-health. The programme involves energy efficiency refurbishment of dwellings, such as cavity wall insulation, loft insulation, and in some cases efficient heating systems. As part of the Health Impact evaluation of Warm Front initiated in 2001, a large scale survey has determined the extent that these efficiency measures have resulted in both energy savings and warmer internal temperatures (Hong et al. 2005 submitted; Wilkinson, Oreszczyn & Hong 2005 submitted). This research collaboration with epidemiologists illustrates how energy policy can be strengthened, since the analysis can reveal those measures that prove most effective in the field and at the national scale. Subsequent recommendations will be underscored by the additional health benefits that are found with higher internal temperatures.

These points suggest there is scope to move beyond just common interests between these two fields and see if methodological approaches in epidemiology can help progress building energy research, and specifically for the analysis of carbon emission data. Two particular reasons suggest that a reappraisal of methodologies used in built environment research from this perspective would be worthwhile. The imperatives of addressing climate change require that the performance of the existing building stock is addressed, rather than merely the standards of new buildings or small scale interventions. Epidemiology is explicitly defined as being concerned with incidence and distribution of outcomes in the population and in these terms the focus of research would be directed towards the building stock. Secondly, it is important to be mindful that buildings themselves do not cause the bulk of carbon emissions; rather they arise from the process of providing appropriate environments for humans and their activities. Given that the derivation of epidemiology has ‘people’ at its core, it is premised on the inclusion of social and behavioural factors in any models for predicting carbon emissions.

The alarming epidemic of obesity that has emerged as a major public health issue over recent years has striking parallels to the question of carbon emissions. Both concern excess consumption of calories, or energy. In both a complex set of social and environmental influences appear to be at work that, in health terms, seemingly conspires to encourage poor eating habits and a more sedentary lifestyle. These interactions can undermine generic and overly simple health messages. For instance the rising popularity of convenience foods in modern life that often results in the consumption of energy dense foods, itself has resonances in energy research with the way convenience may lead to the acquisition of electric appliances. The built environment is being recognised as having a direct role to play in effective public policy to reduce obesity. For instance, if no provision is made for bicycles then, even if people wish otherwise, they may resort to using their car for the journey to work (and that, in a further neat coincidence, results in both a more sedentary lifestyle *and* increased carbon emissions). Without taking the metaphor too literally, a similar complexity in the interactions between social, behavioural, and environmental factors appear to be at work that makes effective policy to reduce the overall carbon emissions due to buildings (and the activities of people) difficult to formulate.

Obesity levels and related disease risks may also be influenced by environmental exposures that occur much earlier in life, such as dietary patterns developed during childhood. Epidemiologists have long been aware of the problems arising from using cross-sectional studies during adulthood with limited prospective data and where there is little or no latency accounted for between exposure and outcome. This is precisely the kind of methodological issues addressed by life course epidemiology, where comprehensive models can be constructed to describe the development of a particular pathway with respect to a health outcome, or in terms of obesity research, a weight trajectory through life (Ben-Shlomo & Kuh 2002).

Before proceeding further, it is necessary to consider an essential aspect of any epidemiological or statistical study: the choice of unit under investigation. There should be minimal variation in the main outcome measure within the unit; secondly that measurements should not be available at a more refined level. In research on domestic buildings, each dwelling normally defines the unit of study since this often corresponds to one family or occupant, the physical building (with its physical attributes that influence consumption), and energy consumption measurement via meter readings or utility bills. By contrast the non-domestic sector is highly complex and may require a multi-level model in the selection of units, such as buildings and ‘activities within buildings’ (Bruhns et al. 2000; Bruhns, Steadman, & Herring 2000; Steadman, Bruhns, & Gakovic 2000). Moreover a distinction needs to be drawn between the energy directly required for the production of goods and services associated with a particular activity, rather than just providing the appropriate internal conditions. For purposes of illustration here, the sample unit will be taken as corresponding to a single building

LIFE COURSE EPIDEMIOLOGY

Life course epidemiology has been defined as ‘the study of long term effects on later health and disease risk of physical or social exposures during gestation, childhood, adolescence, young adulthood, and later adult life’ (Kuh et al. 2003). It is fundamentally an interdisciplinary approach and incorporates the two main paradigms that have tended to polarise epidemiological research. According to the fetal origins hypothesis, the structure or functioning of body systems may be ‘programmed’ to produce long term effects on disease risk through exposure at critical phases, for instance during the rapid growth and development *in utero*. This was presented as an alternative to the model that focused on how behaviours in adulthood, such as smoking, diet, and exercise, influence health outcomes. Thus the life course approach is based on the premise that various biological and social factors throughout life influence disease in adult life independently, cumulatively, and interactively (Kuh et al. 2003). Implicit in life course epidemiology is the use of longitudinal studies on a cohort of subjects with data at time points that span from birth and even earlier through the life course, or at least until the age range relevant to the health outcome under investigation. In building research this would correspond to having data from as early possible in the design phase, particularly through construction and other critical phases of development, as well as other exposures that may affect the building over time, from changes in building functions and modes of operation though to environmental conditions.

In addition to the use of longitudinal studies, life course epidemiology requires the use of theoretical models to describe the set of exposures and interactions that can lead to distinct pathways through life; specifically those that result in healthy outcomes or are robust in resisting the effects of adverse exposures, compared with those that eventuate in greater disease risk or are vulnerable to external events. Thus, it provides the means to consider identifying multifaceted interventions that can provide long-term protective effects and reduce the risk of poor outcomes. Again, it may be useful to identify the factors that influence the trajectory of a building's energy performance over time; which attributes correlate with resilience or vulnerability in the face of adverse conditions; which interventions might be most effective in changing the trajectory of the building's performance.

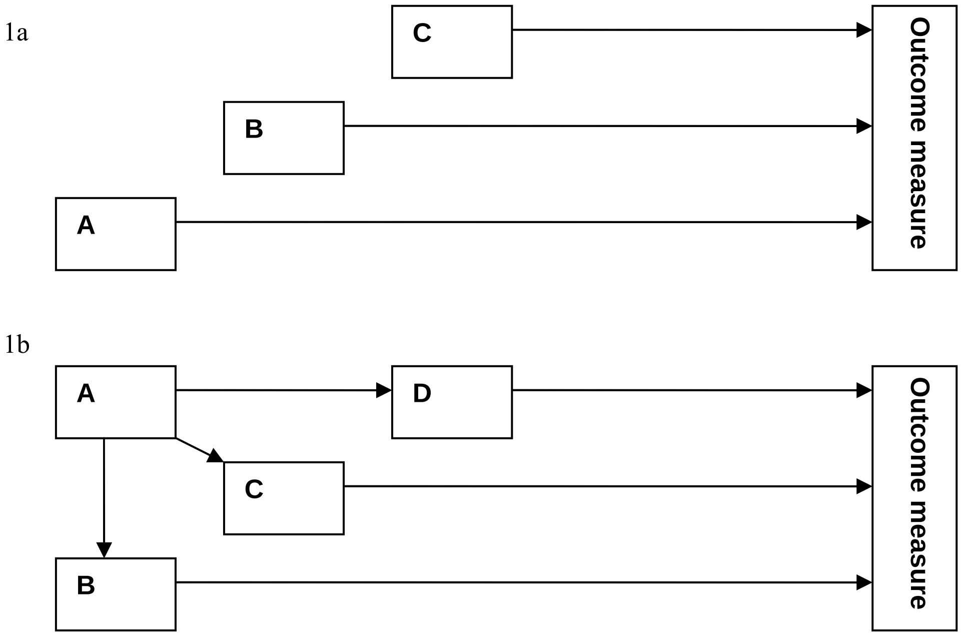

Figure 1 Life course causal models for the *accumulation model* (1a) and the *accumulation model with clustering* (1b) (after Kuh et al. 2004).

Life course epidemiology uses four elemental models of causation, where time is represented along the horizontal axis, which may be combined to form a more complex and comprehensive model. The first shown in Figure 1a describes a situation where cumulative effects may independently cause long term effects. For instance in a scenario for energy consumption in buildings, this may describe the situation where an inefficient HVAC system is installed at construction, followed by sub-standard building maintenance, and a change in building operation (such as in the hours that lighting and heating are required). Figure 1b is referred to as *an accumulation model with risk clustering*, where multiple events occur as a result of a single exposure or event. Thus a period of sub-standard building maintenance may result in deterioration of draught stripping, light shelf reflectivity, and boiler performance, each independently affecting the building's energy consumption. A single exposure may also bring about positive effects on the outcome; thus refurbishment may lead to a series of independent improvements to the building such as cavity insulation, double glazing, and boiler replacement; or new building tenants may produce a change in function from retail to offices, providing an opportunity to introduce an energy conservation program for the employees, and a more responsive management structure to handle occupant feedback on building conditions.

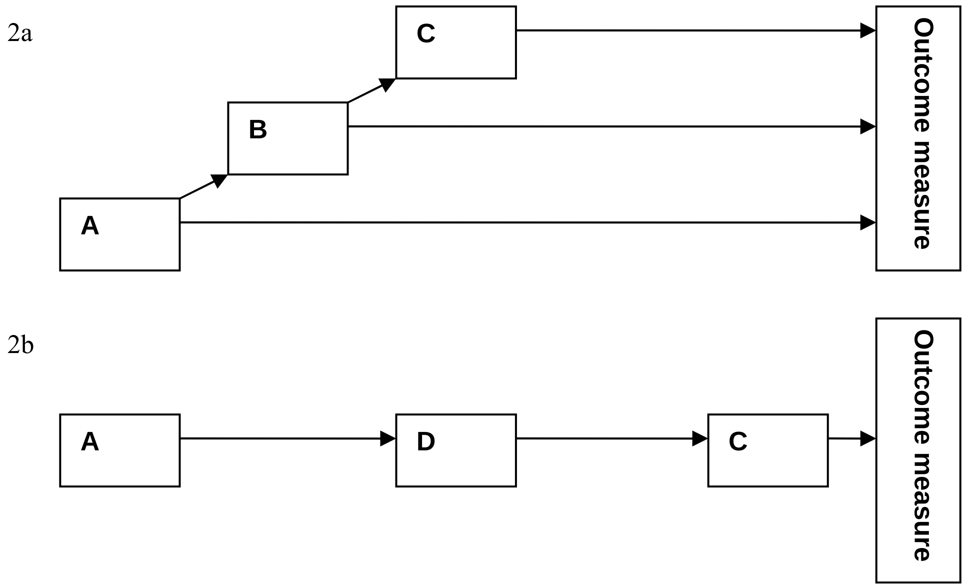

Figure 2 Life course causal models for the *chain of risk model* (2a) and *chain of risk model with a trigger effect* (2b) (after Kuh et al. 2004).

The *chains of risk* model shown in Figure 2a illustrates how each exposure can have an independent effect on the outcome, in addition to increasing the risk of the subsequent exposure. For instance lack of maintenance of draught stripping, in addition to its own effect on the degradation of building energy performance, may lead to inefficient operation of the air conditioning. Such links are probabilistic and introduce the concept of *mediating* and *modifying* factors. The former refers to a risk or protective factor that lies along the causal pathway after an exposure has occurred, so that sub-standard equipment specified in the initial building design may be mediated by the role of building regulations to impose changes or the impact of inefficient plant may be mediated by the occupants behaviour (by for example leaving windows open, leaving computer equipment on, etc.). A modifying factor is a risk or protective factor that has varying degrees of impact according to the level of the modifying factor. Thus increasing economic constraints on construction costs are an example of *antagonism* since they are likely to increasingly compromise the implementation of energy efficiency features. A modifying factor that enhances performance outcomes is termed *synergistic*. The last model in Figure 2b illustrates the situation where earlier exposures have no effect without the *final link in the chain* to precipitate an impact on the outcome. Thus buildings that do not have attributes failing to perform under current conditions, such as reliance on natural ventilation, may suddenly be revealed as being inadequate when exposed to external stress, such as an extreme weather event or higher peak summer temperatures due to climate change.

AN ILLUSTRATIVE EXAMPLE

In 2004 the Engineering and Physical Sciences Research Council (EPSRC), Carbon Trust, and Economic and Social Research Council (ESRC) funded the Carbon Reduction in Buildings (CaRB) project, a major 4 year research project to investigate carbon emissions from both the domestic and non-domestic building stock in the UK. The CaRB project provides a unique opportunity to test and validate a number of approaches for developing socio-technical models for energy usage. By drawing upon energy and social survey data from previous studies, as well as records of plans and refurbishment, it may be possible to form the baseline data for a longitudinal study and initiate a life course epidemiological approach without the delays of initiating a study.

The CaRB project is currently re-examining a study dating from 1989 where hourly energy temperature data was collected over more than 2 years for 160 dwellings located in Milton Keyes Energy Park (MKEP). Of these, 29 houses were monitored in more detail with hourly internal temperature data and a social survey. These dwellings were of conventional residential design for Britain but were constructed to better specification in energy efficiency terms than required by the current building regulations enacted in 1985. For instance the walls had cavity insulation with U values 28-50% lower than required, all had 50mm of polystyrene ground floor insulation, and some had condensing gas boilers installed. Results for the 29 dwellings in the detailed survey indicated a mean annual consumption of 55.9 GJ or 32% less than the national average in 1988 (Edwards 1990).

A follow up study of 18 from the original 29 dwellings in the detailed survey is in progress with temperature measurements in multiple rooms in each house and meter readings and utility bills for energy consumption data. A social survey that replicated many parts of the original questionnaire has also been conducted. While it is premature to present results for trends in internal temperature and energy consumption, it provides a useful illustration of how the causal model used in the life course epidemiological approach can help elucidate some of the factors and interactions that may have influenced energy consumption over the last 16 years.

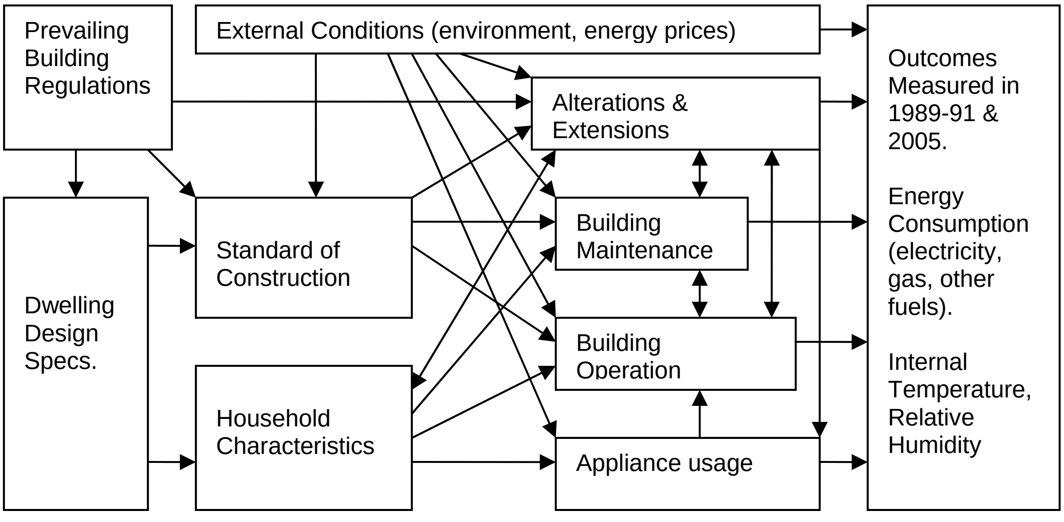

Figure 3: A suggested causal model for determinants of dwelling energy consumption.

The schematic causal model shown in Figure 3 delineates the set of relationships that may be operating in dwellings in the MKEP study. As illustrative of some of these, it can be seen that the mediating effect of building regulations on the energy usage is modified by the standard of construction (compliance, detailed finish, heating system installation, etc.) that in turn is modified by building maintenance and operation (ventilation rates, central heating times, thermostat settings, etc.). The design specifications influence household characteristics (size, age, socioeconomic status, occupancy patterns), which among other factors influence appliance usage (tumble dryer, TV, computer, etc.) and building operation. In addition, appliance usage can affect building operation (e.g. opening windows for the tumble dryer, turning lights on when working at the computer). The relationship between household characteristics and extensions and alterations operates in both directions since the existing household specify its characteristics and the characteristics of new occupants are influenced by the attributes of the dwelling as a whole, including any extensions. Equally an interaction may occur between building operation and building maintenance.

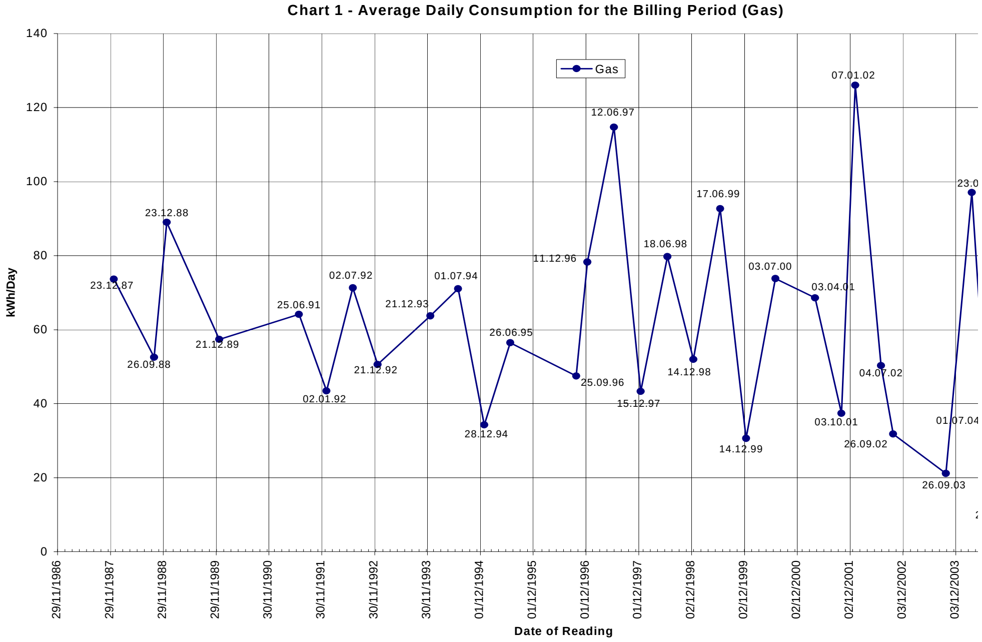

Figure 4: Gas consumption from 1986 to 2003 for one dwelling in the MKEP study.

As an indication of the complexity of possible relationships involved, the chart in Figure 4 contains some early results using billing data for gas consumption over a 17 year period for one dwelling from the MKEP study. It shows a noticeable increase in the variability of gas consumption over the period. Nevertheless, along with the greater dispersion there is also a slight downward trend of consumption. Gas is used for heating and cooking but, considering that in the UK climate cooking uses proportionally much less gas than heating, it is likely that the trend downwards is mostly due to a decrease in heating requirements. Conversely to what would normally be expected, an extension in the floor area (a family room, a bedroom and a porch were added to the original building in Feb.1997) was not followed by an increase in gas consumption. The decrease has therefore to be explained in different ways, most likely by a combination of several different factors such as a decrease in the number of people in the household (currently the children only stay at home for short periods of time) hence all services are less loaded. Also likely to be important are the milder winters that have occurred over the past decade. Analysis of these and other data is ongoing.

CONCLUSION

Developing policy for the reduction of carbon emissions due to buildings requires models that incorporate social, behavioural, and environmental factors in addition to the physical properties and technical specifications of the buildings. The methodology of life course epidemiology, where energy usage is treated as analogous to poor health outcomes, provides an alternative approach for the construction of causal models that allow for complex interactions between factors as well as long term effects. It offers a useful framework for the management and analysis of longitudinal studies. Many statistical techniques have been developed to address the analytical challenges posed by longitudinal studies. These may prove effective in identifying the type, timing, and targeting of intervention strategies to produce optimal outcomes in terms of absolute reductions of carbon emissions and resilience of building performance to external stresses, such as those imposed by climate change. An example study based on an earlier project in Milton Keynes Energy Park is currently in progress. Considerable further research, preferably drawing upon existing datasets as baselines for longitudinal studies, is required to evaluate the approach and test and validate the causal models.

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