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Increased house size can cancel out the effect of improved insulation on overall heating energy requirements

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ABSTRACT

Stand-alone single-family dwellings are the dominant housing type in several countries. The floor-area of the average stand-alone dwelling has been increasing faster than the floor-area of the average apartment/flat/row-house in England, Australia, Canada, the USA and New Zealand. Standalone dwellings have a greater external heat transfer area than multiple family dwellings, for the same floor-area. Larger dwellings require more energy to heat than smaller dwellings insulated to the same level. Although insulation requirements have been increasing, the heating required to maintain newer larger stand-alone dwellings to a constant temperature can be similar to that required to heat older smaller stand-alone dwellings. Building regulations should be future-proofed by considering trends in dwelling size.

1. Introduction

Building standards for new dwellings exist to protect potential purchasers and occupants in both the immediate and distant futures. Durable, fit for purpose dwellings are also useful at a societal level, as assets that endure and do not need to be replaced. Dwellings that are energy efficient will need less fuel and therefore reduce household expenditure and CO_2 emissions to the environment. Houses that can be easily maintained at appropriate temperatures are also healthier for the occupants (Viggers et al., 2013).

The dwellings currently in use are the legacy of previous building regimens; and the dwellings that are built now will become the current era's legacy to the future. Although internationally building regulations can specify requirements for any aspect of dwellings the country's legislators choose, regulations typically focus on building quality including insulation levels, and sometimes specify minimum sizes, though typically not maximum sizes. However maximum sizes have sometimes been specified, for example, in New Zealand there were maximum size limits imposed due to material shortages after World War Two (Ferguson, 1994), and many of those dwellings are still in use.

Countries develop their building energy codes in response to a variety of drivers. These include: international obligations, such as the EU's directive on the energy performance of buildings; a desire to adapt to or mitigate climate change; or to improve energy security (both stated motivating factors behind the European Directive (European Commission, 2010)); to best utilize available materials; to reduce costs to future building occupiers, or to the countries energy distribution system. The codes express the minimum quality considered acceptable at the time the code was enforced.

There is convincing evidence that a dwelling built to high energy efficiency standards will use less energy than a dwelling of similar size built to less stringent standards. In the US Dixon et al. found houses of similar size built to higher standards used less energy despite being heated to a warmer temperatures (Dixon et al., 2010). In Australia Berry et al. found dwellings designed to be highly energy efficient and only slightly larger than the state average for new dwellings used less energy than other nearby new dwellings (Berry et al., 2014), however some of this difference was demonstrably through the use of more efficient appliances. Somewhat similarly Ambrose (Ambrose et al., 2013) found highly rated dwellings used less heating energy than lower rated dwellings despite maintaining warmer temperatures, although the trends in dwelling size by rating for this sample suggested that there might have been inclusion biases.

Builders, especially developers in market economies, who build to on-sell, can be focussed on finances and marketability (Forlee, 2015). If

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good quality thermal design is not required by legislation or believed by developers to be valued by buyers then the builders will typically focus on other aspects of the dwelling, such as size or number of rooms. A study of builders in England found that legislation and government policy were far more significant as drivers toward low energy homes than financial/cultural forces as builders did not see customer demand or clear signposting indicating that they would recoup any additional costs (Osmani and O'Reilly, 2009). A study of Dutch builders reported low demand by buyers for energy efficient homes including one company's internal research that only 2% of buyers were willing to pay more to buy an energy efficient home, but the majority of home buyers prioritized other aspects including the number of rooms (Pinkse and Dommisse, 2009). Ambrose, in Australia, reported builders double-glazing some but not all windows in a dwelling in order to achieve the minimum allowable energy efficiency (Ambrose et al., 2013).

A number of authors have noted both increasing dwelling size, and the likely energy consequences of such large dwellings. Withers and Vieira (2015) when modelling energy use in Florida found a smaller difference between modern and older homes than expected, then explained the discrepancy by older homes having been retrofitted. Palmer (2012) looking at energy use in Melbourne over 50 years thought that a combination of factors including larger dwelling size and reduced occupancy had caused per-capita energy use to remain largely constant. Inversely, the occupants of large dwellings, built to replace older smaller dwellings, noted that the energy bills were comparable (Wiesel et al., 2013). An analysis of house size increase in Victoria, Australia (Clune et al., 2012) estimated that only 62% of potential emission reductions from moving to an increased thermal performance requirement between 2003 and 2009 were realised, as the efficiency gains were counteracted by the increased conditioning requirements of increased dwelling floor area. Brecha et al. (2011) considering US data, thought it likely that increased energy efficiency of dwellings was not offsetting the substantial increases in size. Huang et al. (2015) noted a worldwide trade-off between dwelling size and energy consumption if the atmosphere is to be kept below 450 CO_{2eq}.

Energy use data from the English Housing Survey and the follow-up Energy Survey have suggested one of the biggest drivers of household energy use factors is the physical state of the building, dominated by floor area (Huebner et al., 2015). Considering representative dwellings in Northern Ireland, Yohanis et al. (2008) found stand-alone dwellings used more electricity than terraced dwellings, and larger dwellings used more electricity than smaller ones. These results are unsurprising as, other things being equal, the heat transfer will be proportional to the exposed surface area of the dwelling and stand-alone dwellings by definition have larger areas of exposed surfaces. In cool climates this corresponds to greater heat loss.

The thermal efficiency of dwellings exists at a nexus of these concerns. People in dwellings in which it is difficult to maintain an appropriate temperature are more likely to experience ill-health, and may require more energy in their attempt to maintain appropriate temperatures – conversely retrofitting of insulation can both reduce energy bills and reduce ill-health (Chapman et al., 2009; Howden-Chapman et al., 2007). In order to reduce anthropogenic climate change the use of fossil fuels (including for home heating) should be minimized. Dwellings typically survive for decades, and decisions locked into the building envelope at the time of construction will continue to have effects until a renovation removes them, these building envelope decisions have a longer life than many of the appliances that the dwelling will hold.

The overall question the paper is focussed on is “What effect has the increase in dwelling size, in Western countries, over the last 40 or 50 years, despite the improvement in building code and energy efficiency standards, had on the overall energy required to heat homes” To answer this, the paper has three sections. First, the evidence for change in dwelling size in several English-speaking countries is examined and this is supplemented with evidence about change in the dominant dwelling type over time. In the second section, New Zealand is used as a case study for examining the impact of changes in both the size and insulation requirements for stand-alone houses on projected dwelling heating energy use. In the final section the policy implications of the work are discussed.

2. Changes in dwelling size and type

This section examines the extent of changes in size and type of dwellings in several countries. It includes both single stand-alone dwellings and other dwelling types.

2.1. Method

Data from a range of official and semi-official statistics were accessed. The datasets had to contain both a measure of dwelling floor area and year of construction. Data sources were sought for both time series of completed dwellings collected during the process of dwelling approval and/or construction, and cross-sectional surveys at one time-point of the age of dwellings currently (or recently) in use. Any type of floor area measurement was considered (whether external, internal gross, internal net area, or other measures). Although each country uses its own vernacular for both the dwelling design and the description of their conformation, in this analysis, where possible, the dwelling types have been divided into “stand-alone” or “detached” houses, “semi-detached and row houses”, and “apartments or flats”.

2.2. Data-sources

2.2.1. England

The English Housing Survey includes a physical inspection of about 6200 dwellings annually; over a two year cycle they are a representative sample of housing stock across the country. Although for most outputs the dwelling ages are grouped into large categories, estimated years of construction are also available. Here, confidentialised microdata were used and the estimated years of construction grouped into decades (Department for Communities and Local Government, 2014). The dwelling floor area was measured by surveyors, and is “total dwelling area” – although this is not further defined, it seems likely that this is the gross internal area of the dwelling (therefore, excludes the floor area occupied by the external walls, but includes the floor area of internal staircases and internal walls).

2.2.2. Australia

The Building Activity Survey in Australia reports on the number of completed dwellings in Australia every year. A periodic analysis of this dataset reports the floor area of residential dwellings, with the floor area defined by the external perimeter of the building walls (Australian Bureau of Statistics, 2013). This dataset was obtained dating back to 1984 (Becker), however it subdivided dwellings only into stand-alone and other.

2.2.3. Canada

In 2011 Statistics Canada and Natural Resources Canada together conducted a “Survey of Household Energy Use”, the data were occupant reported through a two phase process by either computer-assisted telephone interview or the follow-up mailed questionnaire. The data on heated area were occupant reported in categories of approximately 44 m2 (500 ft2) but excluded basements and garages. Data reference: (Government of Canada, 2014).

2.2.4. United States

Three data sources are used from the United States: the American Housing Survey (AHS), the US Survey of Construction (SoC) and the Residential Energy Consumption Survey (RECS).