Energy and Buildings 108 (2015) 433–440

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Review and evaluation of using household metered energy data for rating of building thermal efficiency of existing buildings

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ARTICLE INFO

Article history:
Received 21 January 2015
Received in revised form 3 September 2015
Accepted 11 September 2015
Available online 12 September 2015

Keywords:
Monitored energy use
Home energy rating
Housing energy disclosure

ABSTRACT

This paper investigates the use of actual monitored household energy as an indicator of the thermal efficiency of a dwelling and subsequently rating of the building thermal performance. The paper reviews evaluation methods used internationally for both building thermal efficiency and building energy labelling and presents results from two discrete studies in South Australia on monitoring actual household energy consumption.

In order to investigate the occupancy effect on household energy, monitored energy data collected from two different housing developments in South Australia were examined. The energy ratings for these homes are compliant with the national agreed protocols for thermal performance modelling of dwellings, where one set of homes is a group occupied by higher socio-economic groups and the other is low income public housing in a colder climate region with much poorer home energy ratings.

The wide variation of actual household energy for the homes that have relatively similar thermal envelopes indicates a lack of meaningful use for actual household energy in disclosure of house energy performance. Therefore, it is argued that thermal modelling software used to rate homes appears a more useful application of a system of disclosure of energy performance than the use of energy bills.

1. Introduction

In recent decades governments worldwide have implemented mandatory energy performance requirements for new housing through regulation in order to reduce levels of energy consumption and lower household carbon emissions. In the UK, 27% of all carbon dioxide (CO_2) emissions are said to be related to housing [1]. The situation is similar in other countries including Australia where energy consumption attributable to housing occupancy is not only a significant expense for individual households but also a significant factor at a national level in overall greenhouse gas contribution [2].

Studies of energy use in Australian housing have focussed on the use of the software tools to measure the predicted energy loads for a typical house and model changes to both design and orientation [3–5] as well as other features that affect the rating (location, adjacent shading, etc.). These software tools model impacts on end energy use, based on default occupancy settings. Although the software is primarily used for design and rating of new buildings, there has been considerable debate about the potential for using the software for evaluating the thermal performance of existing buildings, under a mandatory disclosure regime whereby purchasers of housing can be informed through labels of the likely energy performance of the house and governments and municipalities can understand the energy profile of the residential buildings in their domain. O'Leary [6] provides an analysis of various Australian mandatory disclosure models proposed under a former Australian government initiative that has not been implemented. Some researchers have suggested using actual household energy to rate the thermal performance of homes [7], however there is no conclusive evidence of its validity and still most of the research on use of energy consumption data is within in the commercial sector rather than residential homes.

This paper investigates the use of actual and monitored household energy data for a set of South Australian (SA) homes as a means to evaluate housing energy performance in relation to thermal comfort. Two groups of homes are investigated, representing very high and low star rated buildings. From bill data, the primary energy consumption of each house was determined for analysis of variations and comparison with state averages. The study presented here provides a contribution to the understanding of validity of actual household energy by using sets of homes that have

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http://dx.doi.org/10.1016/j.enbuild.2015.09.018
0378-7788/

similar characteristics related to energy performance, something that is under-represented in the literature to date.

2. International models of energy labelling for housing energy performance

The European Union (EU) responses to the 2010 Energy Performance of Buildings Directive (EPBD) has seen Energy Performance Certification introduced in various forms across individual member states. In Germany a two tiered system of Energy Performance Certification (EPC) for housing exists with an operational rating ("*Verbrauchsausweis*" in German) measuring the energy performance based on the past energy consumption of occupants using actual household energy data. Denmark began requiring energy disclosure on new and resale residential and commercial buildings in 1997. As described by Laustsen and Lorenzen [8] the current Danish rating scheme includes a rating, plan for savings, and direct consumption information. Denmark has shown sustained success with its consistent message with a decrease in energy costs per home of almost 20% since 1997 [9]. In the UK, Simcock et al. [10] argue that actual household energy data can only be one of a range of factors that influence householder perceptions of domestic energy information.

Overall these schemes use actual household energy data as just one component of evaluating the overall energy performance of the house, and therefore do not solely rely on consumption data. Heating and cooling metered energy for a household is a function of four factors: the building shell, the efficiency of the heating and cooling equipment, behaviour and climate. It can be argued that to use metered energy use data in determining the energy efficiency of the building shell in maintaining thermal comfort, requires that metered data is strongly correlated to heating and cooling energy use, which is related to climate. Furthermore, it requires that the building shell is the dominant factor affecting heating and cooling energy use rather than behaviour. Finally, metered data needs to properly account for the efficiency of heating and cooling equipment to evaluate the efficiency of the building shell.

3. Effects of occupancy and behaviour on household heating and cooling energy demand

According to Brouen et al. [11] much of the current debate regarding energy efficiency in the housing market focuses on the physical and technical determinants of energy consumption, neglecting the role of the economic behaviour of resident households. Their study of 3000 Dutch homes includes a more detailed analysis of the sensitivity of energy consumption to variations in household composition where they found in the Netherlands that elderly households use substantially more energy than other family types, and usage is highly responsive to the thermal quality of homes as reflected in the period when they were constructed.

In a separate study by Mavrogianni et al. [12] on excess indoor temperature exposure risk during heatwaves, rankings obtained for dwellings occupied by a family with children at school and dwellings occupied by pensioners were broadly similar for combinations of behaviour and the majority of overheating metrics used in the study. The behavioural impact on energy use in Swedish homes was investigated by Hiller [13] where it was shown the higher consumption of what are termed 'spenders' is characterised by performing activities with long operating times, in combination with high, and fairly high, typical power ratings. In a wide ranging paper that looked at developing more understanding of housing occupancy feedback and reviewing a number of key studies in the field by Stevenson and Leaman [14], various key lessons emerge across the themes of:

- feedback, post occupancy evaluation and user control of buildings [15]
- lifestyle choices and cultural context [16,17]
- regulations and standards impact on dwellings and occupants [7]
- housing management issues.

The research strongly suggests that human behaviour challenges building performance evaluations and that recognition of the diversity of inhabitants and comfort scenarios are required when considering regulation and standards. Housing occupants can use three or more times as much energy for heating as their neighbour, while living in exactly the same type of home [11]. This suggests that even if the building fabric is robust and well insulated with suitable thermal mass, and the home has an efficient energy source, it will still be the inhabitant who ultimately determines how energy efficient a home will be. Even if the amount of energy consumed by the building for heating and cooling space is low, occupants will still be free to use as much energy as they like for other appliances and hot water systems.

These studies are able to use consumption data to identify and categorise different behaviour groups, however what is evident is that by measuring energy use using consumption data the behavioural factors can readily outweigh the housing design characteristics. Therefore, using consumption data to compare the energy efficiency of the building shell of a home can prove unreliable.

4. Effects of climate on household energy demand

Fundamentally the climate and behaviour trigger the demand for heating and cooling which is related to the efficiency of the heating and cooling equipment which relates to the heat flow through the building shell. Energy bill data encompasses the effect of all these main drivers though also accounting for a significant added energy demand by households other equipment.

Heating and cooling accounts for some 48% of energy consumption in homes in the USA [18] down from 58% in 1993 whereas in Europe with a more dominant colder winter climate space heating accounts for over 70% of household energy consumption [19]. Heating and cooling typically represents 38% of household energy use in South Australia [20]. Consequently, in milder climates such as many parts of Australia, heating and cooling will always represent the minority of total household energy.

The dynamics of energy use in a house are strongly affected by climate and much of the study of using metered data for house energy evaluation is from Europe and North America which have more extreme and pronounced winters. Therefore if energy use for heating and cooling is a minority of demand, the use consumption data makes energy performance prediction problematic in relatively milder climates. Here it is therefore hypothesised that a building shell or whole of house rating using software is potentially a better option for disclosure of heating and cooling energy performance of a dwelling than using consumption data.

5. House energy ratings – international predictive models of thermal performance

In the UK the Standard Assessment Procedure (SAP) is the methodology used by the Department of Energy & Climate Change (DECC) to assess and compare the energy and environmental performance of dwellings. The SAP methodology is based on the Building Research Establishment Domestic Energy Model (BREDEM) developed in the 1990s as a validated thermal performance