Understanding occupant heating practices in UK dwellings

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Abstract: The 2008 Climate Change Act has committed the UK government to reduce CO_2 emissions by 80% of 1990 levels by 2050. To meet this target a significant reduction in energy consumption will be required from domestic dwellings and in particular space heating which accounts for more than 50% of the energy used in the UK housing stock. The UK government has initiated a number of policies to reduce energy use from UK dwellings. Energy savings that result from energy efficiency improvements to dwellings have sometime been lower than expected as a result for the rebound effect. Discussion of the rebound effect has questioned whether these polices will result in the CO_2 reductions required to meet the national targets. Large-scale survey research has shown that energy use is related to climate, built form of properties, efficiency of heating systems, socio-economic indicators and occupant behaviour. Temperature monitoring studies have been undertaken to gain insight into how occupants heat their homes. If the variation in indoor temperatures can be explained by; (1) social determinants such as age, income and the number of household occupants and; (2) technical determinants such as house type, house age and level of insulation then this would enable energy efficiency initiatives (e.g. cavity wall installation or education programmes) to be targeted where they will be most effective. This paper presents preliminary results from a large-scale city-wide survey of over 500 homes in the city of Leicester, UK. temperature measurements were recorded at hourly intervals over a nine month period for the living room and main bedroom spaces in over 300 homes. Household data, including socio-demographic information, was collected for each household. This dataset is used to investigate indoor temperatures across house types. The results confirm that house type is related to differences in indoor temperatures. Flats have the highest average temperatures while detached homes have the lowest. To gain insight into heated periods households with average evening temperatures were identified. It was found 45% of mid terrace properties had evening temperatures below 18°C and more than a third of detached and semi detached home also had cold evening temperatures. There are a number of reasons for low indoor temperatures in dwellings during occupied periods including inefficiency of buildings and heating systems, the inability of occupants to afford heating and personal choice. It is concluded that to meet Government CO_2 reduction targets the rebound effect should be taken into account when calculating the energy savings expected from energy efficiency programmes. Further analysis is ongoing to identify how other social and technical factors relate to indoor temperatures. Multiple regression analysis will be used to identify how internal temperatures are correlated against a number of determinants including building characteristics (built form type, age, heating system type, heating controls) and household characteristics (age of occupants, income).

Keywords: *Indoor temperature, Heating practices, Household behaviour, Space heating, Energy efficiency.*

1. Introduction

The 2008 Climate Change Act committed the UK government to reduce CO_2 emissions by 80% of 1990 levels by 2050 [1]. To meet this target a significant reduction in emissions will be required from all energy sectors. In 2008 energy use from domestic buildings accounted for 27.5% of total UK energy consumption [2]. CO_2 emissions associated with domestic buildings are predominantly related to electricity generation and energy used for space and water heating. Space heating accounts for 57% of all energy used in UK domestic buildings [3]. Reducing the energy used for space heating is a challenge as it is related to the technical performance of the building and its heating systems, as well as the behaviour of occupants [4, 5]. The UK government has introduced a number of policies that are designed to reduce the energy use related to space heating. One of these is the 'Green Deal' which was announced by the UK government in 2010. Householders will be given a loan to make energy efficiency improvements to their properties and are expected to make repayments using money saved due to lower energy bills [6]. Technical improvements to dwellings such as cavity wall or loft

insulation or the installation of energy efficient boilers do not always result in the expected energy savings [7]. This was evidenced by the Warm Front study, energy use was measured before and after energy efficiency improvements and theoretical energy use compared to actual energy use. It was found that actual energy improvements were approximately 30% less than expected [7]. This phenomenon is called the 'rebound effect' and brings into question the ability of households to make payments based on energy savings [8]. Literature on the 'Green Deal' does not discuss how payments will be made if energy efficiency improvements do not result in financial savings. The rebound effect has been used to argue against making efficiency improvements in the existing housing stock [9]. As a consequence, Government emissions targets based on expected energy savings are unlikely to be met. This criticism, however, does not account for the improvements in health and wellbeing of occupants that are related to the increase in indoor temperatures that can be the result of energy efficiency measures [10]. The challenge for policy makers is to address energy and CO_2 reduction while accounting for the 'rebound' effect. One example of this is the households in fuel poverty. A household is said to be in fuel poverty if they require more than 10% of their income to heat their home to a comfortable temperature [11]. In 2007 3.5 million households in the UK were in fuel poverty [11], if energy efficiency improvements were made in these dwellings it is assumed that energy savings would be minimal, as indoor temperatures would increase in many of the households.

The health and wellbeing of the occupants has been addressed for new builds since the publication of the Code for Sustainable Homes in April 2007 [12]. Health and wellbeing have, however, not been addressed in discussions about energy efficiency improvements in older properties which make up the majority of the housing stock or in the energy saving advice that is provided by local and national government. Generic energy saving advice such as 'turn your thermostat down 1°C will save you 10% of your heating bills' may be appropriate for some households but not occupants that are already living in cold homes [13]. These issues raise two concerns; (1) how can energy efficiency policies ensure both energy savings and improved health and comfort of occupants and; (2) what energy savings should be expected as a result of energy policies after the indoor temperatures in some households have increased. The mitigation of the effects of climate change is a strong driver for energy reduction but should not be addressed outside of the context of other health and comfort issues. For energy policy to effectively reduce CO_2 emissions and improve the health and comfort of building occupants more information about the housing stock and the drivers of indoor temperatures is required. The accidental benefits of energy improvements such as improved health of occupants should not be ignored. Joined up solutions designed to reduce energy consumption in the housing stock while improving the thermal comfort of vulnerable household occupants are required to address a fully sustainable approach to emissions reduction programmes. The benefits of the rebound effect should, therefore, be recognised despite the reduction in CO_2 emissions savings that may result in a portion of the housing stock. For policy makers to accurately predict the result of energy efficiency improvements at the national scale the proportion of dwellings where reduced savings are expected should be considered.

To promote the health and wellbeing of building occupants the World Health Organisation (WHO) has suggested dwellings are heated to indoor temperatures of 21°C in the living room and 18°C in bedroom spaces [14]. Previous temperature monitoring studies provide insight into the temperatures to which UK dwellings are heated. To understand whether dwellings are heated to the recommended temperatures it is important to ascertain what the indoor temperatures are in living spaces during occupied periods. Shipworth et al. (2010) measured temperature in a large sample across the UK [15]. Daily peak temperature was estimated to be

21.1°C. This finding, however, can be easily influenced by periods of high internal or solar heat gain. Other studies have reported temperatures averaged over the whole day. Oreszczyn et al. (2006) monitored temperature in over 1600 low income dwellings. Average living room temperature, adjusted for outdoor temperature, was reported to be 19.1°C [10]. Summerfield et al. (2006) monitored indoor temperatures in 14 UK dwellings built to high thermal standards and found that the average living room temperature was 19.1°C [16]. Yohanis and Mondol (2010) reported an average living room temperature of 19.4°C measured in 25 dwellings in Northern Ireland [17]. All of the average temperatures reported in the UK studies are lower than the recommended temperature of 21°C.

The temperatures reported in these papers have not been analysed to ascertain which dwellings have low indoor temperatures. In order to inform how policy can be targeted a sample which includes all house types and people groups is required. These studies have gained valuable insights into indoor temperatures in UK dwellings but have not reported indoor temperatures during occupied periods. Isaacs et al. (2010) monitored temperature in New Zealand homes and calculated average temperatures for different parts of the day [18]. Average temperatures suggested that many dwellings were not heated to the 21°C recommended by the WHO [18]. Dwellings heated by solid fuel were found to have warmer living room temperatures on average than those heated in other ways. This finding led to a policy change by the New Zealand government to subsidise the installation of wood burners as well as gas and electric fires. Empirical evidence is required to see if any changes to UK CO_2 reduction policy are necessary.

This paper presents initial analysis of temperature data collected in over 300 houses across Leicester, UK between July 2009 and March 2010. This data set is novel as it is the first large scale study to focus on a single UK city. This work seeks to identify where energy efficiency initiatives should be targeted. This information is key for the accurate prediction of CO_2 savings so that Government can ensure that targets are met. Dwellings with low indoor temperatures during heated periods will be identified as it is assumed that these dwellings would benefit from efficiency improvements without the expectation of energy savings. Findings will be valuable for policy makers to ensure that energy efficiency policy will deliver estimated CO_2 emissions reductions and additional benefits for the health and comfort of vulnerable portions of society.

2. Methodology

Data were collected during a large-scale city-wide housing survey carried out in Leicester, UK in 2009-2010 [19]. The Living in Leicester (LIL) Survey was designed by the 4M project - Measurement, Modelling, Mapping and Management (4M): An Evidence-Based Methodology for Understanding and Shrinking the Urban Carbon Footprint - a collaboration between four Universities funded through the Engineering and Physical Sciences Research Council (ESPRC). 4M is studying CO_2 emission sources and sinks in urban areas and has collected data from households within Leicester including indoor air temperatures in domestic buildings. Households were randomly selected after stratifying by percentage of detached homes and percentage of households with no dependent children in each of the 36 middle layer super output areas. 575 households were involved in face to face interviews which were conducted by the National Centre for Social Research (NatCen).

Hobo data loggers (Figure 1) were used to monitor air temperature every hour between July 2009 and March 2010 in a subset of these households. The sensors were calibrated by Tempcon Ltd and were found to be accurate to ±0.4°C [20]. NatCen interviewers asked the occupants to place the Hobos in the living room and main bedroom. Guidance on the placement of sensors was provided and stated that the Hobos should be placed away from heat sources and not in direct sunlight. A distinct advantage of this data set compared to previous national studies is that outdoor temperature and climate can be assumed to be the same across the whole sample. At the end of the monitoring period the Hobos were returned in pre-paid envelopes. 620 Hobos were returned from 321 households. Only households with temperature data for living room spaces were suitable for this analysis. 31 households were excluded from the analysis for a number of reasons including; loggers failing to download; data not being available for the whole monitoring period; and average temperatures being below 10°C (when it was assumed that sensors were in unheated spaces, misplaced or faulty).

Figure. 1 Hobo data logger used to measure indoor air temperature in 290 dwellings in Leicester City.

Temperature data for the month of February 2010 were analysed to provide understanding of heating patterns during a typical winter heating period. The average daily temperature profile was calculated for each house. Although average temperatures were calculated for both living room and bedroom spaces only living room temperature considers the ability for households to heat their living spaces to adequate temperatures. Consequently, this analysis concentrates on living room temperatures. Average temperatures for morning (7:00-9:00), day (9:00-17:00), evening (17:00-23:00) and night (23:00-7:00) were calculated to aid understanding heated and unheated periods. Temperature data were combined with data on the built form of the properties for analysis.

3. Results

3.1. Analysis of indoor temperature data

Average temperatures were compared to those measured in New Zealand homes, which is a comparable study reporting average evening temperatures [18] (Table 1).

Table 1. Average temperatures reported. Temperatures in Leicester for the 4M project are reported for February 2010. New Zealand (HEEP) temperatures are for the whole winter.

Room		Average evening temperature (°C)			
		Morning (7:00-9:00)	Day (9:00-7:00)	Evening (17:00-23:00)	Night (23:00-7:00)
Living room	4M (n=290)	17.4	17.8	18.7	18.9
	HEEP (n=348)	13.5	15.8	17.8	14.8
Outdoor	Leicester	1.5	3.6	2.6	1.6
	New Zealand	7.8	12.0	9.4	7.6

Indoor temperatures measured in Leicester were found to be higher than those measured in New Zealand; average evening temperatures were 18.7°C and 17.8°C respectively. Temperatures in UK dwellings are also more uniform throughout the day; New Zealand morning temperatures were 13.5°C compared to 17.4°C in Leicester. There are numerous

reasons why this might be that case, these include that homes in Leicester may have longer heating periods, better thermal insulation, more efficient heating systems or occupants that prefer warmer indoor temperatures. Average temperature profiles were used to identify the variation of indoor temperatures relating to different house types (Figure 2). None of the property types had average temperatures that reached the temperatures recommended by the WHO. It was observed that flats were warmer for the majority of the day, on average, compared with other house types. It is hypothesised that this is due to flats being more thermally efficient than other property types as they have less exposed surface area. Detached dwellings reach the lowest temperatures. Although mid terrace properties have less exposed wall area than end terraces and are assumed be more thermally efficient, lower temperatures on average were observed. Further data analysis is required to comment on the reasons or validity of this observation.

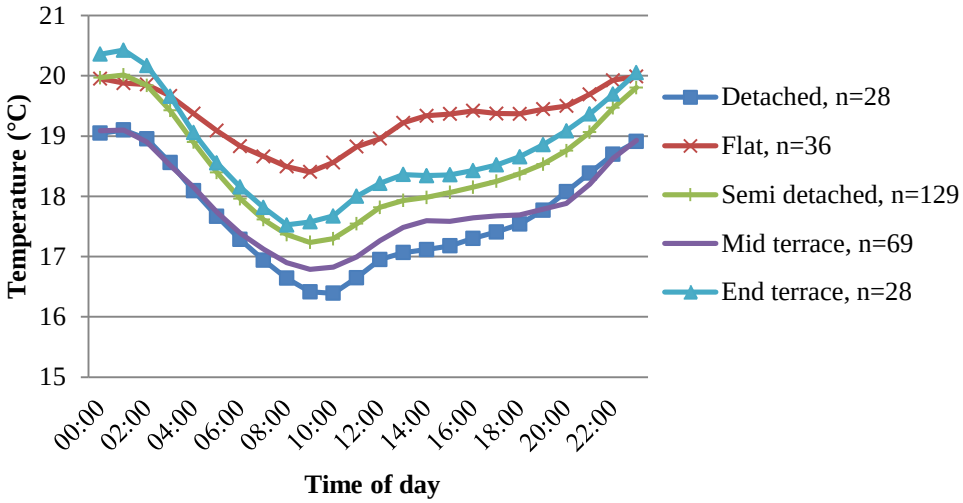

Figure 2. Daily living room temperature profile averaged for each hour in February 2010 for indoor temperatures measured in 290 homes in Leicester.

3.1 Recognising rebound in UK policy making

Analysis was carried out to identify the proportion dwellings where energy efficiency improvement may not result in the expected energy savings. To do this it was assumed that the heating was operational in all dwellings during evening periods. A histogram of average evening (17:00 – 23:00) temperatures illustrates the variation in indoor temperatures during heated periods (Figure 3). Mean evening indoor temperature was 19.9°C with a standard deviation of 2.1°C. 7% of dwellings can be observed to have evening temperatures over 22°C (Table 2). In these homes it is assumed that energy efficiency improvements are expected to result in energy savings as higher indoor temperatures are unlikely to be desired. 36% of dwellings had evening temperatures below 18°C and therefore it is assumed that energy efficiency improvements may not deliver energy savings but contribute to increased indoor

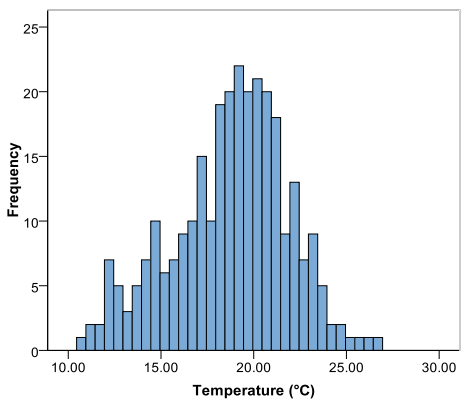

Figure 3. Histogram of average evening living room temperature measured in 290 households in Leicester during February 2010.

temperatures. These data were divided into house types to see whether certain house types could be targeted by policy makers. 45% of mid terrace properties were found to have low evening temperatures and more than a third of detached and semi detached homes also had low evening temperatures. Further analysis of these data is required to identify which other social and technical variables also relate to indoor temperatures and to test the statistical significance of these results.

Table 2. Average evening temperatures under18°C measured in dwellings in Leicester in February 2010

	% with average evening temperature under 18°C	% with average evening temperature above 22°C
All dwellings (n=290)	36	7
Detached (n=28)	39	4
End terrace (n=28)	29	7
Flat (n=36)	25	14
Mid terrace (n=69)	45	6
Semi detached (n=129)	35	6

3.2 Discussion

A challenge in this analysis is the number of influences on indoor temperatures. Thermal comfort is defined as a product of indoor temperature, mean radiant temperature, air speed and occupant activity. Indoor temperature is related to the outdoor climate, the efficiency of the built form and heating systems in dwellings as well as occupant behaviour. Gathering and analysis of data to inform policy makers is therefore complex and it is important not to make assumptions. For example, if improvements were made to a buildings' air tightness this would reduce the energy lost via infiltration and reduce drafts (air speed). This could increase occupant thermal comfort while indoor temperatures could remain the same or even be lowered. This measure would reduce energy use from the dwelling but this could not be observed by using only indoor temperature data. It should also be noted that although it is assumed here that there is a portion of the housing stock where occupants are unable to maintain their preferred temperature due to the inefficiency of building fabric or heating systems or the inability to afford heating, there are some occupants that prefer lower indoor temperatures. Further analysis and data collection are therefore required to continue to develop the understanding of the drivers of indoor temperatures in domestic dwellings and how these can be analysed to inform policy makers. This will include using analysis of covariance to identify the variables which influence households to have high or low temperatures during occupied periods. This analysis will address whether other social and technical factors can explain more of the variation in indoor temperatures. This dataset will be used to explore relationships between indoor temperature and income, house price, built form, controllability of heating systems, age of property and number of occupants. Outdoor air temperature, average temperatures during heated periods and estimations of daily heating period and demand temperature based upon analysis of daily temperature profiles will also be considered.

4. Conclusion

This paper presents initial analysis of indoor temperature data measured during February 2010 in 290 households in Leicester, UK. Average temperatures were calculated to identify variations in indoor temperature in dwellings. The data were used to address how house type relates to indoor temperatures. Temperature profiles showed that on average flats had higher

indoor temperatures than other house types. It is suggested that this was due to flats being more thermally efficiency due to their limited exposed wall. Average temperatures for evening periods were calculated to identify the proportion of Leicester properties which have high and low evening temperatures. It was found that 36% of the households had average evening temperatures below 18°C which is below the 21°C recommended by the WHO. Nearly half of all mid terrace properties and over a third of detached and semi detached properties were found to have evening temperatures below 18°C. Further analysis is required of this data set to fully address the reasons why these properties have low temperatures during occupied periods. There are many drivers of indoor temperatures in domestic dwellings which require understanding if energy reduction policy is to be fully effective. It is concluded that to meet Government CO_2 reduction targets the rebound effect should be taken into account when calculating the savings expected as a result of energy efficiency programmes.

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