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VARIATION OF INDOOR TEMPERATURES AND HEATING PRACTICES IN UK DWELLINGS

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Abstract: The UK government is committed to making significant reductions in CO_2 emissions by 2050. To meet this target a considerable 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. A number of policies have been launched which aim to reduce energy use from UK dwellings. The rebound effect has meant that energy savings that result from energy efficiency improvements to dwellings have sometimes been lower than expected. Housing stock energy models can be used to predict the energy savings that result from changes to the thermal efficiency of the housing stock due to policy measures. Most stock models, however, assume blanket heating practice behaviour. If improvements in the thermal efficiency of dwellings results in changes to the heating practices used by occupants this will reduce the accuracy of the predictions of energy models and could reduce the probability of meeting emissions reduction targets. A number of temperature monitoring studies in the UK have been undertaken which can start to inform modellers of the variation in indoor temperatures throughout the housing stock. It is important to assess how indoor temperatures relate to technical and social indicators such as efficiency of the building fabric and heating systems or the age and income of household occupants. This information will allow modellers to better predict the indoor temperatures demanded by household occupants and consequently improve the accuracy of energy predictions. 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 in over 300 homes. Household data, including socio-demographic information, was collected for each household. This dataset is used to

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investigate the relationship between indoor temperatures and house type. The results confirm that house type is related to differences in indoor temperatures but this relationship is not significant during heated periods. Further analysis is ongoing to identify how other social and technical factors relate to indoor temperatures. Analysis of covariance 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). A better understanding of indoor temperatures will aid policymakers in the successful targeting of energy efficiency initiatives.

Keywords: *Heating practices, Indoor temperature, Occupant behaviour, Domestic energy use*

1 Introduction

The UK government has committed to an 80% reduction of 1990 CO_2 emissions by 2050 as part of the 2008 Climate Change Act (DEFRA, 2008). In 2009 energy used in domestic buildings accounted for 28.5% of total UK energy use (ONS, 2010). Space heating is the most significant end use of energy in domestic buildings being responsible for more than 50% of energy use (BRE, 2008). If emission reduction targets are to be met a significant decline in energy used for space heating is required. A number of policies aiming to reduce energy used for domestic space heating have consequently been launched.

One such initiative is the third phase of the Carbon Emission Reduction Target (CERT) (DECC, 2011). CERT requires all energy suppliers with more than 50,000 customers to make savings in the CO_2 emitted by households and necessitates suppliers to make 68% of these savings by supplying professionally installed insulation measures.

The rebound effect has questioned the effectiveness of making energy efficiency improvements to domestic dwellings (Herring, 2009). 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 (Hong et al., 2006). This can be explained by the increased indoor temperatures that sometimes occur after fitting insulation or a more efficient heating system. These elevated temperatures reduce the energy savings expected from the efficiency measures. If the potential ‘rebound’ from energy efficiency improvements is not accounted for when calculating savings from policy initiatives such as CERT the government will fail to meet the expected emissions targets.

Building stock energy models can be used to assess the potential savings related to policy initiatives. Many stock models are broadly based on the British Research Establishment Domestic Energy Model (BREDEM) (Shorrock and Anderson, 1995). The literature on BREDEM suggests blanket behaviour using a thermostat setting of 21°C and a heating period of 9 hours per day. A parametric sensitivity analysis undertaken by Firth et al. (2010) has shown that these behavioural elements of the model are the most significant factors. It is therefore valuable to ascertain how indoor temperature varies across different households in the housing stock. This information will allow modellers to better predict the indoor temperatures demanded by household occupants and consequently improve the accuracy of energy predictions.

A number of temperature monitoring studies have been undertaken in the UK that have started to gain insight into indoor temperatures in dwellings. Shipworth et al. (2010) measured temperature in a large sample across the UK. 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. Oreszczyn et al. (2006) monitored temperature in over 1600 low income dwellings. Average living room temperature was reported to be 19.1°C. 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 20.1°C. Both of these studies have standardised reported temperatures for an external temperature of 5°C. There are, however, a number of differences in the makeup of the sample that may influence indoor temperatures; Oreszczyn focused on low income dwellings while Summerfield monitored low energy buildings. A deeper understanding of how technical (building type and efficiency) or social (age of occupants, households income) variables relate to differences in indoor temperature is required to aid comparison of the indoor temperatures reported in these studies. If indoor temperatures are higher in more efficient homes then this should be taken into account when calculating the savings from improved thermal efficiency of the building stock that relates to policy initiatives such as CERT.

This paper presents initial analysis of temperature data collected in over 300 houses across Leicester, UK between July 2009 and February 2010. An earlier more limited, analysis has been reported elsewhere (Kane, et al., 2011). This paper extends that analysis as well as using a modified data set. This work aims to inform energy modellers in their understanding of how heating practices are related to differences in thermal efficiency of buildings.

2 Data collection and analysis of indoor temperatures

2.1 Face to face interviews

The indoor temperatures measurements were taken as part of the 4M Project. The 4M Project - Measurement, Modelling, Mapping and Management (4M): An Evidence-Based Methodology for Understanding and Shrinking the Urban Carbon Footprint – is a research project between four Universities funded through EPSRC, a UK Research Council (Lomas, 2010). The research aims to be representative of the urban environment and Leicester city was chosen as a case study. An integral part of this work was a large-scale city-wide housing survey carried out in Leicester, UK in 2009-2010. Households were selected randomly after stratifying by percentage of detached dwellings and percentage of households with no dependent children. Due to the large scale of the survey the interviews were conducted by the National Centre for Social Research (NatCen) (NatCen, 2011). NetCen has experience of delivering large scale surveys and used trained surveyors familiar with computer aided personal interviewing (CAPI) for face to face interviews. The surveyors did not have any specific prior knowledge of building energy. 575 households (approximately 1 in 50 homes in Leicester) took part in the survey. During the survey participants were asked to take part in a number of follow up activities one of which included indoor temperature monitoring.

2.2 Indoor temperature monitoring

481 households agreed to have temperature sensors placed in their home at the time of the interview. Sensors were placed in both the living room and the main bedroom in 469 households. Hobo temperature sensors were used to monitor indoor air temperature every hour between July 2009 and February 2010 (Figure 1). The sensors were calibrated by Tempcon Ltd and were found to be accurate to ±0.4°C (Tempcon, 2010). Guidance on the placement of sensors was provided by the interviewers and stated that the Hobos should be placed away from heat sources and not in direct sunlight. This was to ensure that temperature data related to ambient temperature. As temperature data were collected within a single urban area it was assumed that outdoor temperature was the same across the whole sample. Outdoor temperature data was measured by Leicester City Council at their central weather mast at one hour intervals and was provided for use within 4M. Temperatures reported here were measured at a height of 2 metres. At the end of the monitoring period prepaid envelopes were sent to each household with a request for Hobos to be returned. 620 Hobos were returned from 321 households.

Figure 1: Hobo data logger used to measure indoor air temperature in 292 dwellings in Leicester.

2.3 Data cleaning and manipulation

Hobo data loggers were downloaded individually and data saved into excel files. Each file was checked to ensure that the temperatures were measured in heated spaces and sensors had not been placed in direct sunlight. Households with an average evening (17:00-23:00) temperature lower than 10°C and higher than 25°C and were checked. Minimum and maximum temperatures were calculated; households with maximum temperatures higher than 30°C or minimum temperatures lower than 5°C were also checked. The checks involved plotting daily heating profiles to see if heating could be observed. Where low temperatures were observed temperatures from previous months were checked to see if the sensors had been moved. Indoor and outdoor temperatures were also compared to identify whether the indoor temperatures were overly influenced by changes in outdoor temperature. Where the indoor temperature followed outdoor temperatures too closely it was assumed that the sensor was in an unheated space. To ensure the validity of data and analysis techniques average temperatures for February 2010 in both bedroom spaces were calculated by two researchers using different methods.

Survey data was also checked to ensure validity. A number of errors missed by NatCen surveyors who did not have specific building energy expertise were identified. These variables required cleaning, for example, responses to the question regarding the type of wall construction that was used when the property was built were poor. Solid wall construction has been less common since 1930; therefore, any household that stated that their home had solid walls after 1930 or cavity walls before 1930 were checked using Google street view. It is possible to many cases to identify wall construction by viewing the brickwork. Where the wall type was deemed to be clearly incorrect it was changed, instances where it was not clear were unchanged.

3 Results

3.1 Mean temperatures according to house type

Mean temperatures for all 292 households were calculated. Mean living room temperature according to house type and relating to different parts of the day are reported in table 1. Mean temperature for the whole sample was 18.4°C. This is lower than reported by previous studies, however, these temperatures were measured during a cold month when the mean outside temperature was only 2.5°C which is lower than the 5°C standardised temperature reported by other studies. Flats have the highest average temperatures of 19.6°C. Detached dwellings have the lowest average indoor temperatures of 17.6°C. In all house types temperatures are warmer in the evening period compared to other times of the day. This suggests that the evening is the most occupied time of day.

Table 1: Mean indoor temperature for February 2010 measured in 292 dwellings.

		Mean living room temperature (°C)				
		Whole day	Morning (7:00-9:00)	Day (9:00-7:00)	Evening (17:00-23:00)	Night (23:00-7:00)
All dwellings	(n=292)	18.4	17.5	18.2	19.4	18.1
Detached	(n=29)	17.6	16.3	17.2	18.6	17.1
Semi detached	(n=130)	18.5	17.5	18.2	19.6	18.2
End terrace	(n=29)	18.2	17.6	18.2	19.5	18.2
Mid terrace	(n=70)	17.9	17.1	17.8	18.9	17.7
Flats	(n=34)	19.6	19.1	19.6	20.2	19.3

Average temperature profiles were plotted for all 292 dwellings. These show average temperature at each hour of the day. An average profile for each house type was calculated to show how temperature varies throughout the day (Figure 2). Flats have higher temperatures throughout the day and cool slower during unheated periods compared to other house types. Detached dwellings have the lowest average temperatures with a low temperature of 16.1°C at 6 o'clock in the morning. End terrace and semi detached properties have similar indoor temperatures throughout the day. Peak temperature in all house types is reached during the evening. This again suggests that the evening period is the most occupied time of the day.

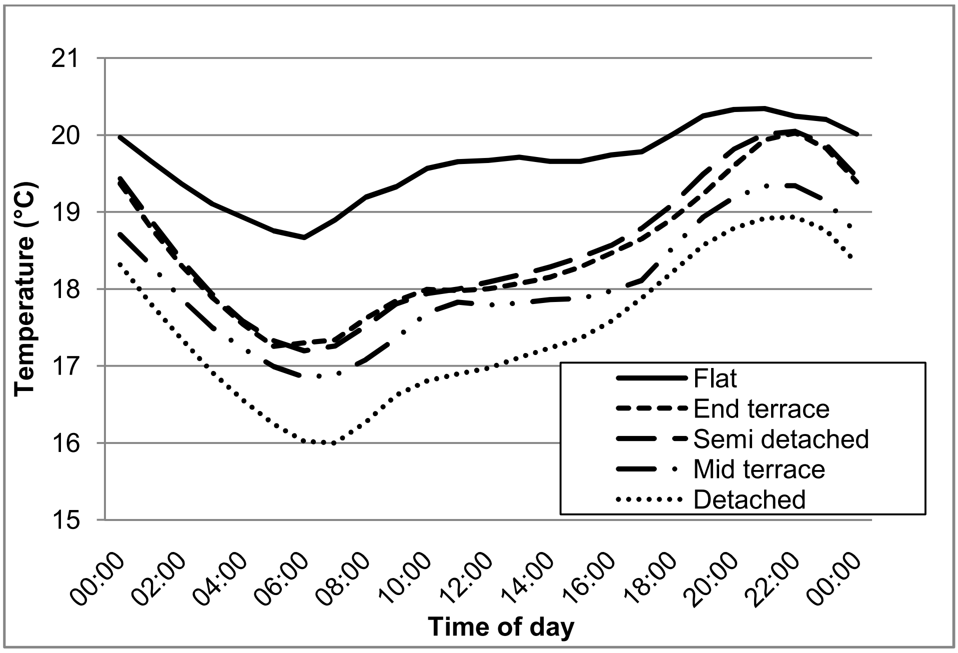

Figure. 2: Average temperature profile for February 2010 of all 292 dwellings according to house type.

3.2 Average temperatures during occupied periods

To gain a further insight into the variation in indoor temperatures during occupied periods average evening temperatures of all 292 dwellings were plotted (Figure 3). There is a variation in average evening temperature of over 10°C in all house types. This plot suggests that household occupants demand very different indoor temperatures during occupied periods. Both occupants that demand high and low temperatures can be seen in each house type. Continued analysis of this data set is required to see if both households with high and low temperature can be identified and therefore targeted for specific energy efficiency policies.

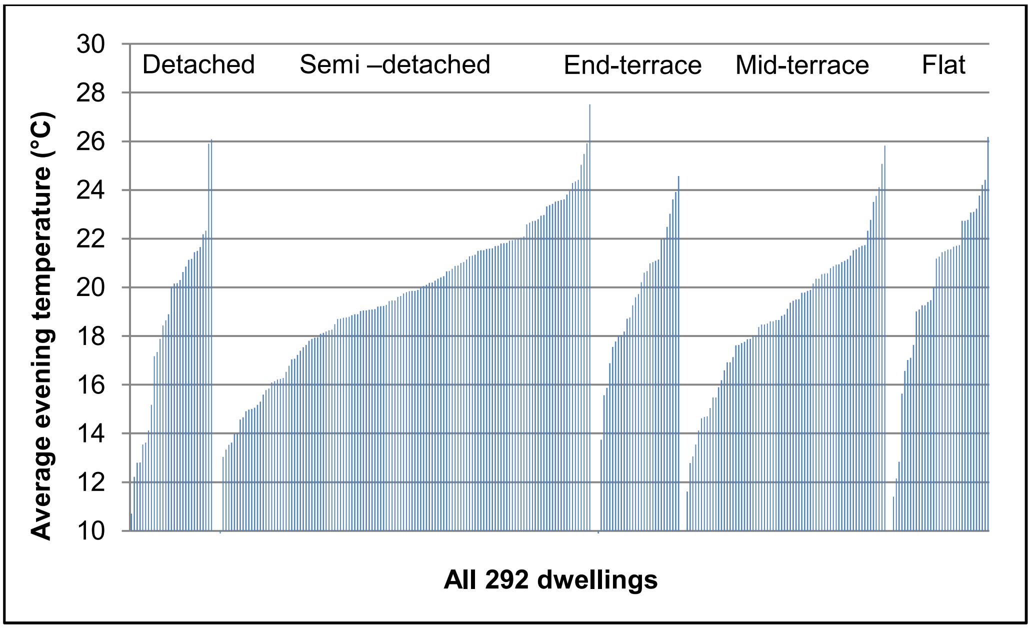

Figure 3: Mean evening (17:00-23:00) temperature in all 292 dwellings measured in February 2010.

The relationship with indoor temperature and house type was tested for statistical significance using Analysis of Variance (ANOVA) (Table 2). The relationship between house type and indoor temperature is statistically significant for all the periods except the evening period. This suggests that when the heating system is not in use the heat lost through the building fabric is related to differences in house type. During heated periods, however, the influence of house type is reduced due to the use of heating. Further analysis is required to see if other technical or social factors influence indoor temperatures at different times of the day or whether only occupant choice can account for the large variation in indoor temperatures.

Table 2: Statistical significance of house type to living room temperature at different times of the day using Analysis of Variation.

	Significance (α=0.05)
Whole day	0.049
Morning (7:00-9:00)	0.007
Day (9:00-7:00)	0.027
Evening (17:00-23:00)	0.229
Night (23:00-7:00)	0.043

4 Discussion

It is important to understand the drivers of indoor temperatures and the effect of changes to the thermal efficiency of building fabric to ensure the effectiveness of policy initiatives. It has been shown that during unoccupied periods house type influences indoor temperature. This suggests that during unoccupied periods the indoor temperature of dwellings is related to the proportion of exposed wall area and the overall heat loss parameter of the dwellings. During occupied periods, however, occupants heat their homes to the temperatures that they demand and in most cases they are able to do this due to improvements in the efficiency of heating systems. Households demanding high indoor temperatures can be found in all house types. The preferred demand temperature of occupants is therefore a significant area for further analysis. If households with high demand temperatures can be targeted there is potential for significant energy savings. Further analysis of this dataset is required to establish whether different social or economic groups of household occupants heat their homes differently and could therefore be targeted for energy efficiency improvements

Indoor temperature is related a number of variables including the efficiency of buildings and heating systems, outdoor climate and occupant behaviour. This first stage of analysis has not established the interactions between these drivers. Therefore further analysis will include analysis of covariance to identify the interaction between variables which influence indoor temperatures in households. This analysis aims to identify any variables that could be used to target households with high demand temperatures where the most significant energy saving could be made.

5 Conclusions

Preliminary analysis of indoor temperature data measured during February 2010 in 292 households in Leicester has been presented. Average temperatures were calculated to identify variations in indoor temperature in dwellings. The data were used to explore the relationship between house type and indoor temperature. Mean temperatures and average temperature profiles showed that flats had higher indoor temperatures than other house types. This may be a result of the limited exposed wall area of flats which makes them more thermally efficient compared to other house types. However, during heated periods there was a variation of 10°C in all house types, this suggests that during heated periods heating practices have a greater impact on indoor temperatures than the thermal efficiency of the building.

Further analysis is required to explain whether the variation in indoor temperature can be explained by social or technical factors or whether the differences are a result of occupant choice. There are many interrelated drivers of indoor temperatures in domestic dwellings which require understanding if energy reduction policy is to be fully effective.

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