Milton Keynes Energy Park Revisited: changes in internal temperatures

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The Carbon Reduction in Buildings project has undertaken a pilot longitudinal survey based on a study of 160 'low-energy' homes in 1989 in Milton Keynes Energy Park. In that study, a sub-sample of 29 dwellings was monitored on an hourly basis for internal temperature for the living room and main bedroom over 2 years. The follow up study has been in progress since 2005 and consists of 15 dwellings from the original detailed survey. Findings include that under an average daily external temperature of 5 ºC, internal temperatures were predicted from regression analysis to be 20.1ºC (95%CI:19.7, 20.5) for the living room in 2005 and 19.5 ºC (95%CI:19.1, 19.9) for the bedroom. This was not significantly different from the 1990 baseline study, except for main bedroom evening temperatures (6pm-11pm) which were found to have decreased by -1.3°C (95%CI -2.4, -0.08; p-value 0.04). This may be indicative of higher ventilation rates since almost all participants in 2005 reported opening bedroom windows through winter.

Keywords: temperature, longitudinal, survey, domestic.

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Introduction

In 2003 the domestic sector accounted for 27% (41.2 million tonnes of carbon) of all UK CO_2 emissions. After declining from the 1970s, emissions have been rising since 1997 (36.9 million tonnes) at a rate of approximately 2% per year [1, 2]. In light of such trends and in the face of challenges posed by climate change, accurate and detailed information regarding internal temperatures are needed for dwellings to formulate reliable models of energy consumption by the UK domestic building stock; especially if these models are to unravel the interactive effects of socio-technical factors, i.e. the changing relationships between building operation and occupant lifestyle, as building standards are increased.

One common example of such interaction is usually termed *'take back'* factor, whereby improvements in energy efficiency to existing dwellings often result in higher thermal comfort levels rather than simply lower energy consumption. [3] These phenomena may have considerable implications when applied at the national scale. By combining a top-down model of domestic consumption based on national energy statistics with heat balance equations and measured data from various studies, Shorrock and Utley have estimated that in centrally heated homes mean internal temperatures for the 6 months of winter have increased from 17.44˚C in 1990 to 19.14˚C in 2001;[1] with the further expectation that this rise would eventually stabilise at approximately 21˚C with a spread across from hallway to living room of approximately 2 degrees Celsius for well insulated homes. Supporting empirical temperature data from large scale studies is however scarce, with the English House Condition Survey (EHCS) last collecting spot temperature measurements for living rooms and halls (under a variety of external conditions) in 1996.[4] Even now the most comprehensive study in terms of the number of properties visited and range of rooms monitored is the 1981 UK Nation Field survey of House Temperatures. [5] However this study was limited to spot measurements typically during the daytime whereas mean temperatures are required to determine energy use. More recently 1,604 dwellings were intensely monitored in a range of dwellings across the UK however the occupants were predominately low income and either young families or over 60.[6]

Carbon Reduction in Buildings (CaRB) is one component of the Carbon Vision Buildings programme of research that has been established to identify ways of achieving 50% reduction in the carbon 'footprint' of new and existing buildings in the UK by 2030. The main objective of the CaRB project is to develop a socio-technical model of energy use for the UK building stock and it includes longitudinal studies to investigate such factors and their influence on trends in energy usage. However rather than rely on initiating studies from scratch, where inevitable delays would be incurred before significant trends could emerge, the project has sought suitable prior studies with accessible temperature, energy, and social data to serve as a baseline survey.

One such study was undertaken in Milton Keynes Energy Park (MKEP), part of a low density town located North-West of London, which was established in 1986 for residential development of low energy homes. The majority of these dwellings essentially follow conventional housing design for the

UK but were built to higher standards than required by the building regulations at that time. They incorporated energy efficiency features, such as increased floor and wall insulation, frequent use of double glazing, and condensing boilers, so that they corresponded to SAP ratings of 75-90.[7] Some dwellings contained novel or experimental systems, such as gas-air central heating or heat recovery ventilation systems.

In 1989, 160 low energy homes in MKEP (covering a range of 35 different designs) had hourly energy data monitored by the National Energy Foundation. A sub-sample of 29 dwellings also had temperatures monitored hourly in the living room (including relative humidity), main bedroom, and one other location (usually hallway). A social and behavioural survey of the occupants was also conducted in four stages. Overall it was found that there was a 28% reduction in energy consumption compared with the housing stock at that time,[7] but temperature data have remained unpublished. The results of this monitoring study were predominately used to develop and refine the BRE domestic energy model (BREDEM), which in various forms still lies at the base of much domestic energy modelling in the UK such as the SAP.

With recovery of a large portion of the original monitoring data, as well as some of the social demographic data, this study has provided an invaluable opportunity for CaRB to conduct a follow up study by recruiting participants from the sub-sample and to investigate changes in internal temperatures over a period of 16 years. In contrast with many previous studies aimed at determining the impact of energy efficiency interventions (using 'before and after' measurements), the MKEP homes in the baseline study were specifically built as low-energy homes with owners enrolled from the outset and equipment installed during construction. It is assumed that after an initial settling in phase, any *take back* factors due to the energy efficiency of their new homes are with respect to conditions prior to the baseline study (say, in comparison with the occupant's previous accommodation) and should not be apparent here. However, given that the sample dwellings were relatively well-insulated and have central heating, the following hypotheses were put forward:

1. Average internal temperatures should be higher at both time points compared with findings from previous studies of dwellings with central heating and of lower energy efficiency.
2. With the exception of conservatories, there will be a relatively low range of temperatures spanning the various rooms in each dwelling.
3. It would be expected that temperature levels should be maintained, even under mid-winter conditions in the UK, rather than decline rapidly with external temperature.
4. Changes in internal temperature may still have occurred over 15 years due to changes in lifestyle and in some cases due to changes to the building itself. Given possible increases in expectations of comfort (for instance, in line with experiences at the workplace) internal temperatures are expected to have increased since the 1990 baseline.

Methodology

Original data retrieved from the baseline study and used in this paper included hourly internal temperature and relative humidity data, as well as external weather data. After considerable processing, a period of 18 months lasting from 6 January 1989 to 30 September 1990 was selected on the basis of having reliable data collected from the majority of study dwellings. A limited dataset of information from the social survey was also recovered. For convenience the baseline survey is also referred to as the *1990 study*.

For the follow up survey by CaRB in early 2005, an information pack describing the proposed study was delivered to the original sub-sample of 29 dwellings in the detailed study of the MKEP 1990 baseline. From subsequent visits and telephone calls contact was made with 23 households, with 15 recruited for the follow-up study. The reasons given for the non-participation were 'lack of availability due to work commitments during the set up and survey phase', 'being away from home during most of the study period', 'moving to another home during the study period, and illness'.

Building and social surveys were conducted at the beginning of the 2005 study, with up to a maximum of ten temperature and relative humidity data-loggers (placed at locations throughout each dwelling but always including the living room and main bedroom). These were initially set to take measurements at 10 minute intervals, although for compatibility average hourly data were used for comparison with the baseline data. In subsequent stages of the survey half-hourly data were collected on a sub-set of rooms.

Statistical Analysis

The final sample size for the analysis across both 2005 and 1990 studies was reduced to 13 dwellings, after 2 were eliminated due to unreliable or highly variable data in either 1990 or 2005 (possibly due to unusual occupancy patterns). The first phase of the 2005 study lasted over 4 weeks in February and March and comprised of two distinct spells of weather, the first an unusually cold spell lasting 2 weeks (with average temperature 1.4°C, standard deviation 2.5°C), followed by a warmer spell (8.5°C, SD 4.3°C). Two spells of similar external temperatures were selected from the 1990 study, the first from October 1989 (2.1°C, SD 3°C) and the second March 1990 (8.1°C, SD 4.1°C). This formed the basis of an initial comparison for average daily temperature under similar external conditions.

The follow up study continued through to July 2005 with data-loggers replaced in living rooms and the main bedroom. This permitted regression analysis of both baseline and follow up data for internal temperatures as a function of external temperature (when average external temperatures were below 13 degrees). This resulted in a predicted internal temperature with 90% confidence intervals under external conditions of 5°C for each dwelling. Student T-tests (paired comparison) were then used to detect any change in predicted mean temperature readings in living room and main bedroom at the two time points. For all statistical analysis were carried out in SAS version 9.1.

Results

Basic sociodemographic changes observed from 1990 to 2005 are given in Table 1. While this small sample from Milton Keynes is not expected to be representative of the national population, it does reflect a marked decline in the number of children (≤16 years) and an increase in the number of adults broadly consistent with an aging population in the UK. Similarly it shows a decline in the number of occupants per dwelling and an increase in dwelling size (extensions/conservatories added to 4 dwellings).

Table 1: Socio-demographic changes of the sample from 1990 to 2005.

Dwellings (N=13)	1990	2005	%change
Number of people	39	34	-13%
Number of children	14	4	-71%
Number of adults	25	30	20%
Number of employed	22	26.5	20%
Average Floor area (m^2)	108	112	4%
Flr area/ person	36.0	42.9	19%

Table 2 draws a comparison between average daily temperatures measured in 1990 and 2005 under similar conditions due to spells of cold and warmer external weather. Even on a dwelling by dwelling basis (Student T-test, paired comparison), no overall statistically significant difference was detected between these daily average temperatures measured in 2005 and 1990. However for both studies living rooms recorded both the highest average temperature of 20.1°C and for most dwellings were higher than the main bedroom. From the 2005 study (and with exception of conservatories) temperatures were within a range of less than 2°C, and were consistently higher than spot readings from the survey from Hunt and Gidman.[5]

Table 2: Comparison of daily temperatures for cold and warm weather spells from 1990 and 2005.

Location (n)	Cold Spell °C (SD)		Warm Spell °C (SD)	
	1990	2005	1990	2005
Ext. Temperature	2.1 (3.0)	1.4 (2.5)	8.1 (4.1)	8.5 (4.3)
Living (13)	20.1 (2.4)	20.1 (2.6)	21.3 (2.1)	20.8 (2.4)
Dining (7)		20.1 (2.7)		21.1 (2.3)
Kitchen (12)		20.1 (2.6)		21.1 (2.5)
Bedroom1 (13)	19.8 (2.1)	18.8 (2.3)	21.1 (2.1)	20.4 (2.4)
Bedroom2 (12)		19.1 (2.1)		20.6 (2.3)
Bedroom3 (4)		19.6 (2.1)		20.7 (2.2)
Bedroom4+ (2)		19.4 (1.6)		20.6 (1.8)
Bathroom (6)		19.0 (3.8)		20.3 (3.4)
Office (8)		19.2 (1.9)		20.8 (2.3)
Hall (6)		18.2 (3.3)		19.4 (2.8)
Conservatory (3)		8.5 (4.3)		14.8 (5.8)
Other (4)		18.4 (3.5)		19.8 (3.0)

Figure 1 shows hourly temperature profiles for both studies under mean external conditions of 5°C for an example dwelling and then the overall average in 1990 and 2005. Profile curves have been plotted using the spline function. In spite of the large variation in temperatures, the cyclical variation with household activity through the day is clearly visible; rising from ~6am until ~10pm with the period from 12am to 5am being notable for a decline in temperatures while the heating system was turned off. Living room temperatures in 2005 appear to decrease at a faster rate in 2005 than in 1990 suggesting an increased heat loss in the living room in 2005 compared to 1990.

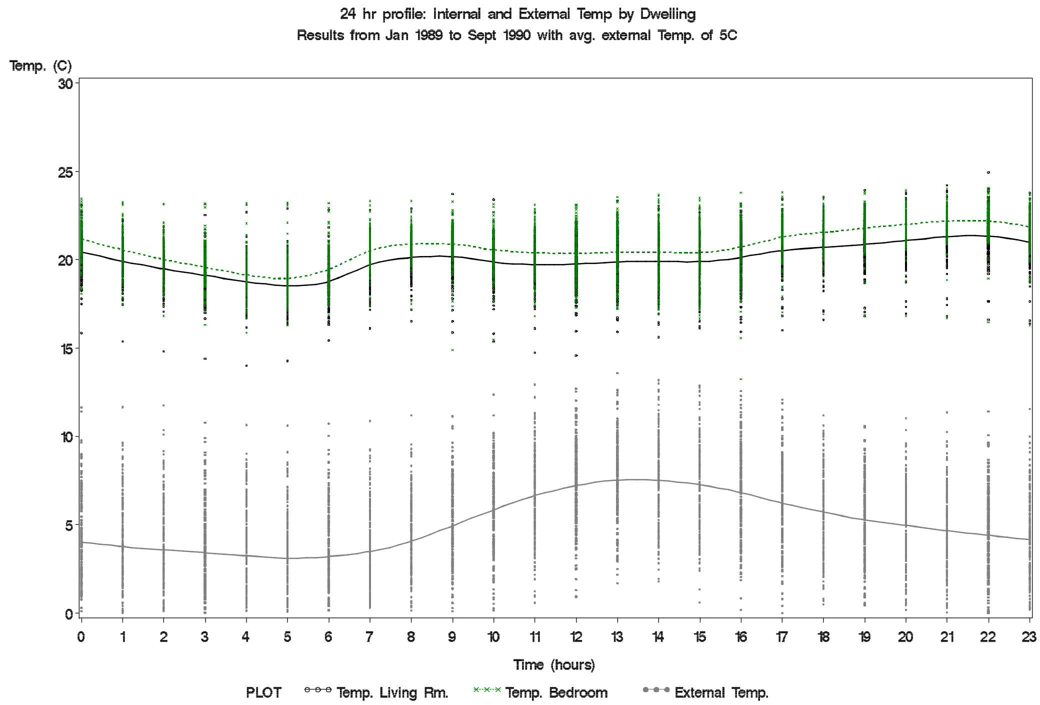
Figure 2 compares the internal against external temperatures for the living room and bedroom in 1990 and 2005 for an example dwelling, whereas Figure 3 shows the average for all 13 dwellings. In every case a clear turning point (to a different gradient) was evident around external conditions of 12-16°C when the heating systems were turned on. Above this temperature incidental gains were sufficient to heat the property and internal temperature increases at a faster rate with external temperature. Below this range temperatures are maintained in a relatively tight band, but with a slow decline as external temperature decreases (~1°C for every drop of 5°C in external temperature). Alongside the spline curves indicated on the graphs, linear regression analysis was undertaken using data obtained when external conditions were less than 13°C to obtain predicted internal temperatures and confidence intervals at a standardised external temperature of 5°C. For dwelling A in 2005 this was found to be: living room 19.7 (95%CI: 19.3, 20.1); bedroom 20.1°C (95%CI: 19.8, 20.5). This analysis was repeated for all dwellings and for different time periods during the day to account for occupancy patterns.

Table 3: Average predicted internal temperature for various time periods based on regression models for each dwelling and external conditions of 5°C:

Room	**1990** **Mean Temp. at 5C**	**2005** **Mean Temp. at 5C**
Living Rm		
24 hr avg	20.1 (19.9, 20.4)	20.1 (19.7, 20.5)
6pm-11pm	21.7 (21.5, 22.0)	21.2 (20.7, 21.6)
12am-5am	19.1 (18.9, 19.4)	19.4 (18.9, 20.0)
Bedroom1		
24 hr avg	20.0 (19.8, 20.2)	19.5 (19.1, 19.9)
6pm-11pm	**21.2 (20.9, 21.4)**	**20.0 (19.6, 20.3)**
12am-5am	19.4 (19.1, 19.7)	19.2 (18.6, 19.7)

The average results for both rooms and for each period examined are given in Table 3. While average differences indicate that bedroom overnight temperatures may have decreased from 1990 to 2005, low sample size and considerable variation across houses have meant that that a dwelling by dwelling comparison (Student T test, paired comparison) only a detected significant decline by -1.3°C (95%CI -2.4, -0.08; p-value 0.04) for evening temperatures.

Figure 1: Plot of 24 hr temperature profile for living room and main bedroom for example dwelling A in 1990 (top) and 2005 (bottom).



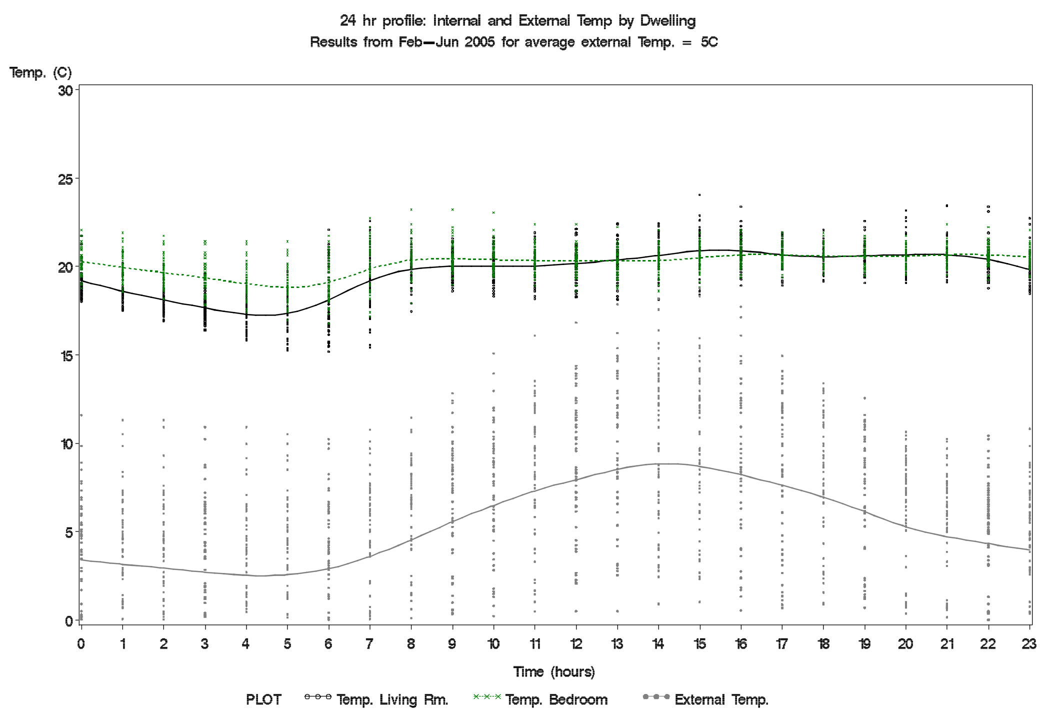
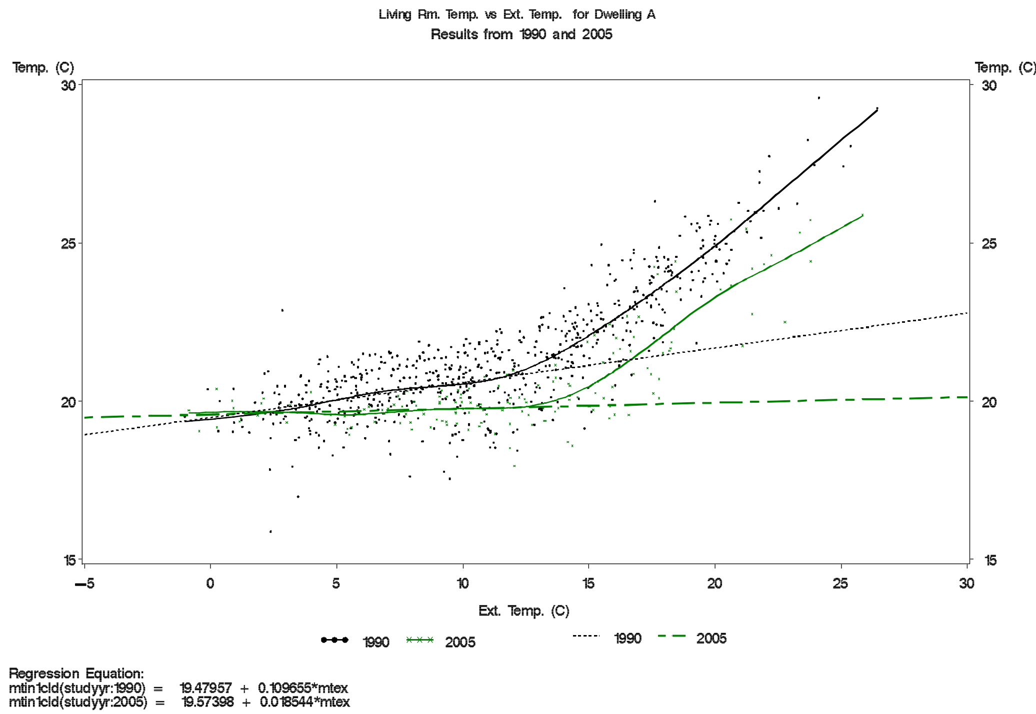


Figure 2: Plot of daily internal vs external temperature in 1990 and 2005 for living room (top) and main bedroom (bottom) for example dwelling A. Regression line is fitted when ext. T < 13°C



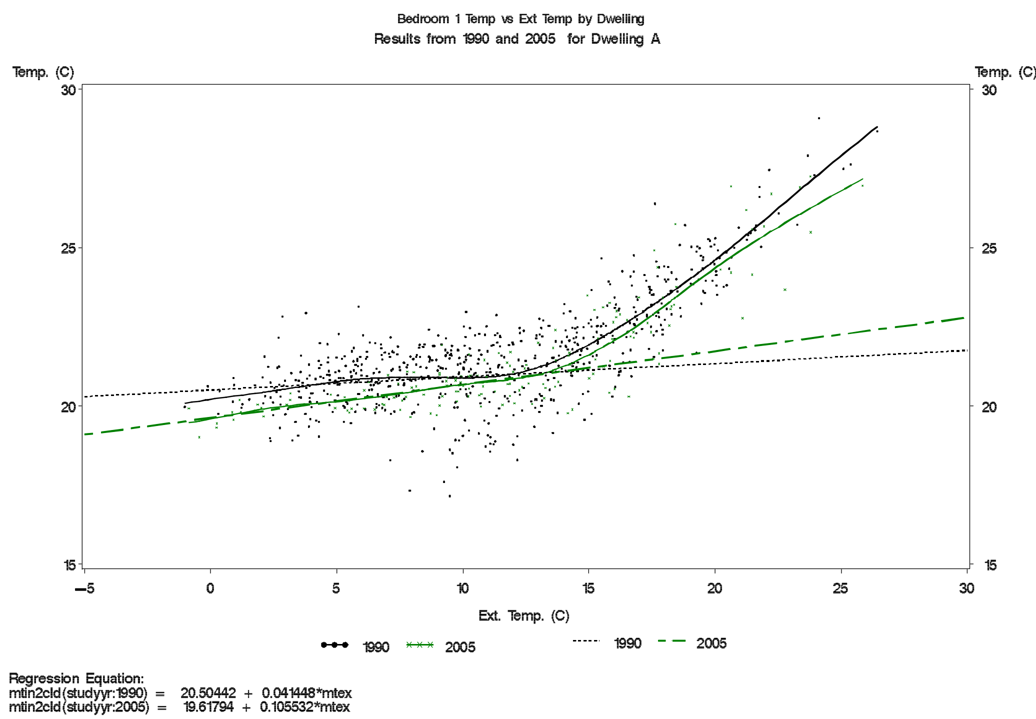
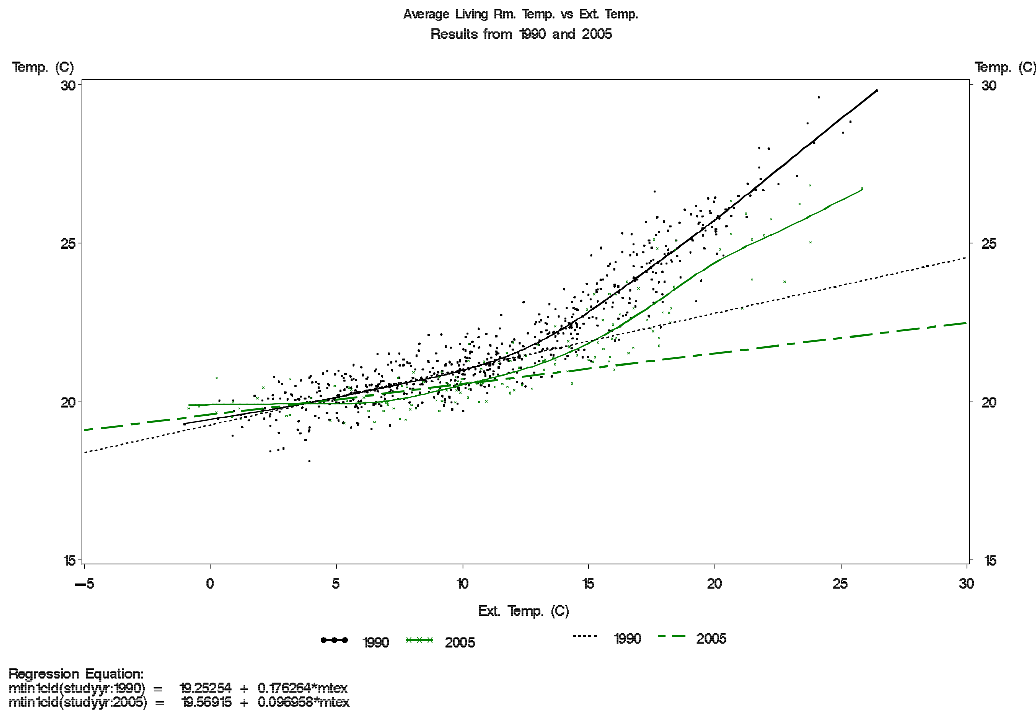
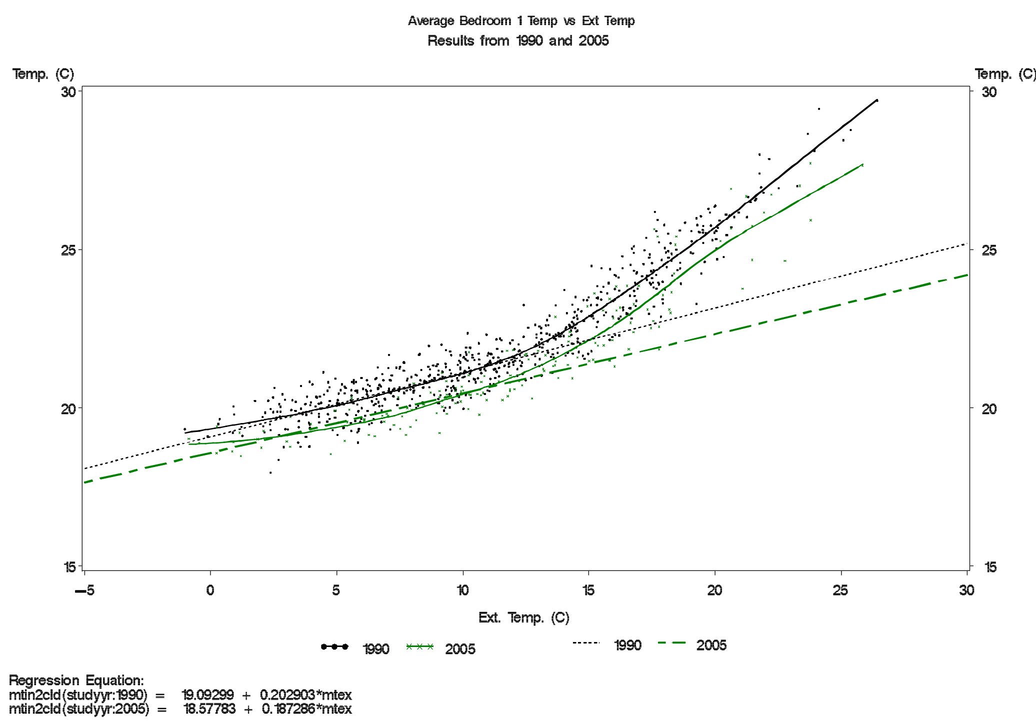


Figure 3: Plot of daily average internal (over all dwellings) vs external temperature in 1990 and 2005 for living room (top) and main bedroom (bottom). Regression line is fitted when ext. T < 13°C





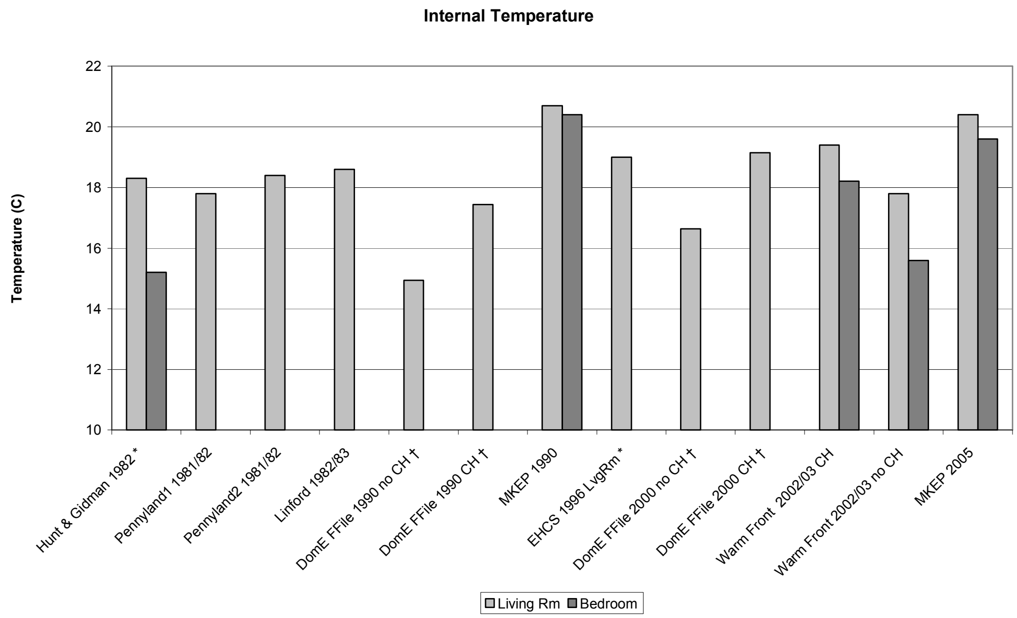


Figure 4: Comparison of predicted daily internal temperatures from MKEP with results from previous studies (including spot measurements).[1, 5-6, 8-9] Temperatures are averages (Warm Front and MKEP under standardised temperatures of 5°C), except where * indicates spot measurements, † indicates modelled.

Figure 4 compares the data collected as part of this study with other previous monitoring and modelling studies. [1, 5-6, 8-9] At both time points the MKEP dwellings have higher internal temperatures consistent with well insulated centrally heated dwellings, compared with standard dwellings or those that low income occupants.

Discussion

This survey has provided a unique opportunity to revisit data from intensively monitored low energy homes in MKEP and measure changes in internal temperatures over a 16 year period. The baseline study in 1990 and follow up survey and monitoring in 2005 of 13 dwellings produced results generally consistent with expectations for centrally heated and well insulated homes. They showed both higher average internal temperatures and a narrower spread of values across rooms than have been found in the Gidman and Hunt survey, and for living rooms and bedrooms in other studies.[5-6, 8-9] In both Milton Keynes studies internal temperatures were well-maintained as external temperatures reached mid-winter levels, with a rate of ~1°C drop for every external decline of 5°C.

It was expected that internal temperatures may have increased since 1990 in line with greater comfort levels, whereas no significant changes were detected except that temperatures decreased by -1.3°C (95%CI -2.4, -0.08; p-value 0.04) in the main bedroom during the evening (6pm-11pm). Such differences may have existed at other times but small sample size and large variation between dwellings did not result in other statistically significant results. Although not in the direction expected, the finding of a decline in temperature during evenings may still reflect changes in behaviour (and of expectations of comfort levels): 11 of the 13 dwellings reporting that they opened their bedroom windows.

Thus one result of this research has been to highlight the possibility that once comfort levels have been reached with respect to temperature, changes in ventilation rates may be identified as another key cause of take back factor to account for changes in energy consumption. Further research is necessary but at a national scale such phenomena may have important implications in predicting trends in energy consumption as the standards of the building stock are improved. Temperatures may stabilise but energy consumption could continue to rise if ventilation rates increased. Second, the relatively small monitored temperature difference between the living room, bedroom and other rooms suggests that the often assumed 2°C temperature difference between different zones in the dwelling [1] may not be applicable to well insulated centrally heated dwellings.

Unfortunately the small sample size of the current pilot study and limited social data retrieved from 1990, restricts the potential to identify further underlying factors, such as by adjusting for the level of home maintenance or socioeconomic status, to explain the observed changes in more detail; however the CaRB project will expand the scale and scope of its longitudinal research in the near future.

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