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HOW DO HOUSEHOLDERS INTERACT WITH THEIR HEATING CONTROLS?

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Abstract

This paper presents measurements of householders' manual interaction with their heating controls. The results demonstrate the importance of measuring heating use behaviour directly rather than relying on thermostat and timer settings or inferring heating use from internal temperature measurements. This is the first time, to the author's knowledge, that manual heating interactions have been recorded. Heating controls will only save energy if used effectively, yet currently, little is known about how they are used. This paper describes an in-depth study of twelve UK residential properties that had new heating controls installed. Heating system interactions with these controls, energy consumption and room temperatures were monitored for ten months from July 2014 to April 2015 inclusive, covering autumn and spring shoulder months and the winter heating season. These measured data were supported by a series of qualitative interviews with the households. The paper reports details of the householders' heating system use, separating the occupants' manual interactions with the controls from their pre-programmed heating schedules. The findings show that the participants had many manual interactions with their heating systems, even during scheduled heating periods; changing heating durations and demand temperatures. The results also identify that manual interactions with heating controls occur more frequently during the winter season than in the shoulder months. The results have important implications relating to assumptions of set-point temperatures and schedule characteristics previously based only on self-reported use or measured internal temperature profiles.

1. INTRODUCTION

Heating controls come in a wide range of styles, have a multitude of different functions and have differing levels of usability, yet they form an essential part of a home heating system. They provide a way for occupants to change the temperature within their home, allow them to programme the heating to come on and off when they want, give occupants the opportunity to set different schedules to reflect their daily needs and often give occupants a sense of reassurance in knowing that their controls will prevent their heating system from freezing while they are away from home. Yet there is little research on the interaction between the heating controls and occupants.

Within the UK, the domestic sector accounts for around 27% of the total energy used and within that space heating accounts for well over 60% of the total domestic energy used [1]. Space heating accounts for 57% of domestic energy used within EU countries, with Poland using 70% of domestic energy on space heating [2]. Within the US it is estimated that 48% of domestic energy goes on heating and cooling [3]. New heating control technology may offer a means to reduce heating energy demand, but only if occupants are able to use them effectively. Previous research has shown that simply adding controls does not lead to a reduction in average maximum recorded temperatures within living rooms, however the potential to save energy is there if new heating control technologies are both appealing to and usable by occupants [4].

Heating controls play a vital part in any home as, not only do they provide occupants with a means to control their comfort, but they also control what is clearly the most energy consuming system within a home [5]. Various studies, across different countries, and both in a domestic and an industry environment, have looked into the usability of heating controls. By understanding more regarding the usability of heating controls it allows for better design to save energy. Usability studies can also uncover any issues with occupants using heating controls that may limit the potential of the controls saving energy. Suggestions regarding the inclusion of feedback to occupants, increased functionalities and targeted functions to specific demographics, the design on user interfaces and even intelligent automated systems, removing much of the occupant interaction need, [6, 7, 8, 9, 10] have all been presented. Yet each of these suggestions still have issues surrounding possible user misconceptions and occupants not adapting to these new heating control technologies once installed.

Currently, the way that occupants actually interact with their heating controls is relatively unknown. In particular, there is little evidence for how often occupants interact manually with the heating controls, besides that self-reported by the occupants. Previous research on reported use of thermostats indicated that the majority of occupants operate their thermostats manually [11] however there are no measured data. This paper presents the findings of an in-depth study that measures how people actually interact with their heating controls over a period of ten months after a new heating controller was installed.

The study described here was a pilot for the larger DEFACTO project (see [12]).

2. METHOD

The study used a mixed method approach which utilised both qualitative and quantitative data to ensure a detailed picture of heating use within homes was gained with a socio-technical focus. Twelve UK households were given a digital programmable thermostat, with a smart phone application, for controlling their heating. Following the installation of the new heating controls, heating system interactions, energy consumption and room air temperatures were monitored in the homes for ten months from July 2014 to April 2015 This was further supported by a series of face-to-face qualitative interviews with the householders.

2.1. Sample households

The sample consisted of a total of twelve households which covered a range of demographics and occupancy characteristics. The households were recruited by a snowballing strategy of staff, friends and family members from one of the project's commercial partners. Households were recruited based on three main criteria: they must own the property, have gas central heating and have a broadband internet connection within the property (to enable the heating system to work as designed, and allow the data transfer). The resulting sample consisted of one flat, five semi-detached houses and six detached houses, with construction dates ranging between 1936 and 2002. The property size varied between the sample with a range of between one and five bedrooms being recorded. Five of the properties had a combi boiler heating system, where domestic hot water is heated on demand, while the remaining had a standard boiler and hot water storage tank. A total of five households had children under the age of 3, and three households had children under the age of 16 (one of these also included a child under 3). All of the houses were located in within the East Midlands region of the UK. Due to the small number of households representing different demographic and occupancy characteristics it was not possible to identify any trends within these which could be representative for a larger sample and was geographically limited.

2.2. Controls and monitoring equipment

The control equipment that was installed gave households the ability to control the thermostat set-point temperature and programme the heating schedule for their property via a digital interface. They also had remote access to programme and control their heating system via a smart phone application. As part of the research project, each house had a sensor installed in every room that recorded air temperature every 30 minutes. Each temperature sensor was placed in a location of the occupants choosing, but with guidance to avoid placing them in direct sunlight or close to heat sources or draughts, to keep them out of reach of small children and pets and to ideally place them on shelves or bookcases and between head and hip height. A current clamp was attached to the tails of the electricity meter to record 10 minutely electricity demand. A pulse counter was attached to the gas meter to record 5 minutely gas demand. An internet gateway, connected to the household's broadband router, allowed both remote control of the heating system via the phone application and for the recorded monitoring data to be collected. This system also recorded any changes to the thermostat set-point and it was possible to identify if the change was due to a programme or a manual intervention. The system was thoroughly tested in one of Loughborough University's test house facilities.

2.3. Data analysis

The heating control device recorded all periods when it was switched to manual from either OFF or AUTO settings and these data, along with the recorded demanded set-point temperature data, were used to analyse the heating use within each of the sample households. To separate the manual use of heating from heating schedules, the daily traces of heating use (recorded set-point temperature) were matched up with the daily data file which recorded manual interaction; this allowed the manual heating to be marked on each daily trace of heating use. The individual daily total durations of heating use, recorded manual use, number of heating periods and set-point temperatures were recorded for each household. The manual use of heating was then calculated as a percentage of the daily heating usage duration. This meant that the difference in heating durations across the sample households was taken into consideration and presented the manual use of the controls as a percentage of the individual households heating usage.

Only five of the twelve households had monitoring data for the whole winter season, which was taken to be October through till the end of February. Missing data in the other homes included gaps within the monitoring data which was likely due to occupants switching the monitoring device off but also any day where the manual use data was not recorded and therefore the percentage of manual use versus scheduled heating use could not be reported confidently. By analysing the five households it eliminated any potential impact that missing data within the remaining sample could have on the hypothesis made regarding manual use of controls. This study also provided the opportunity to compare measured heating schedules and demanded set-points with previous methods used which relied on internal temperature measurements to deduce these heating characteristics [13, 14].

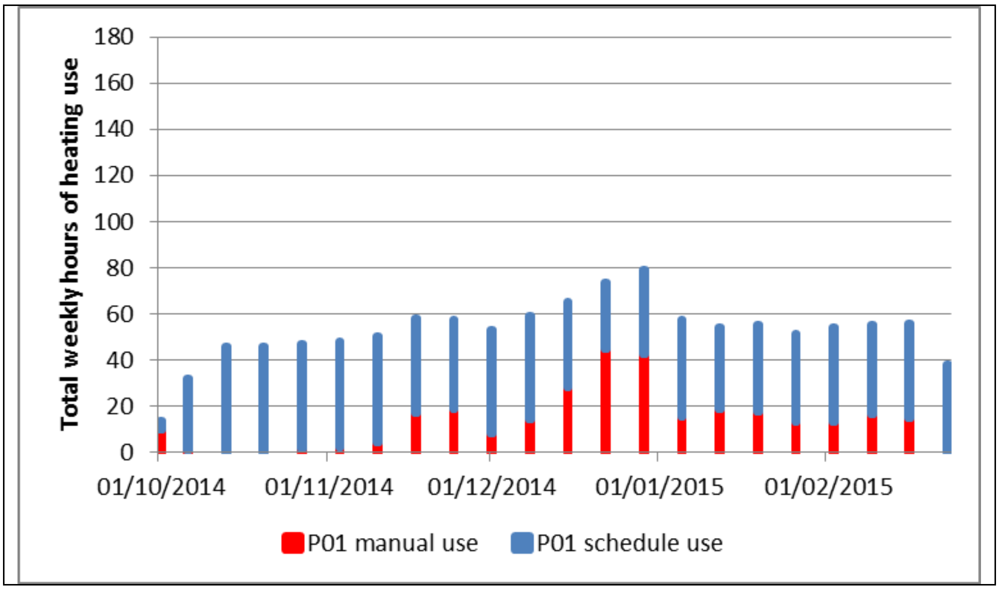
Finally, the households were characterised by their use of the heating schedule functions and whether the scheduled settings were changed over the monitoring period and whether separate settings were used for weekday and weekends within the sample households. This involved analysing the daily heating schedule data for each house and recording any changes made to the original heating schedule first recorded. Changes in set-point temperatures, time periods and durations were recorded. The households were then characterised depending on if they were recorded to change just the set-point temperatures, just the heating timings, durations or a combination of these. By characterising households by their use of the heating controls it was possible to identify whether this had an impact on the manual use of the controls.

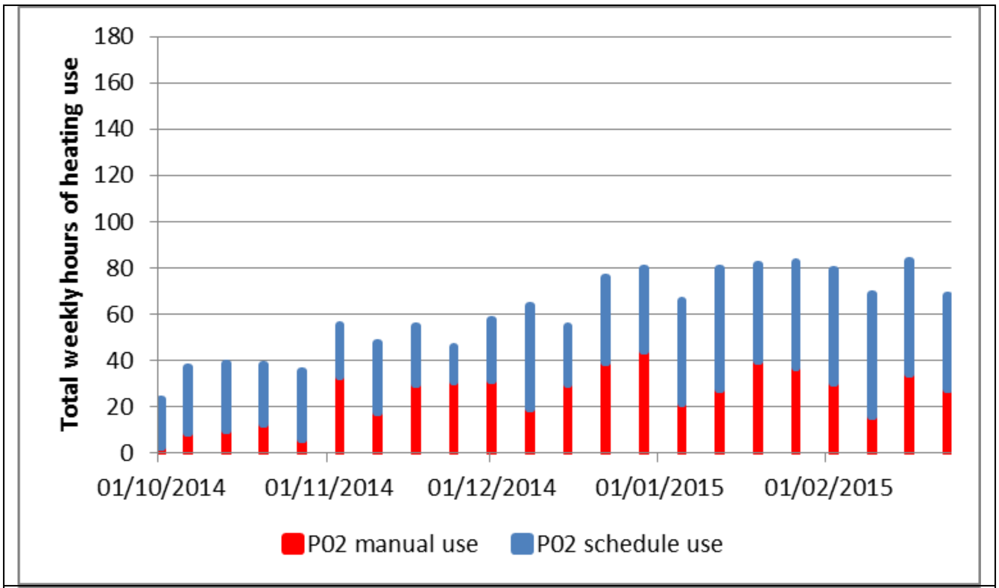
3. FINDINGS

An overview of the headline findings from this study’s measurements of householders’ manual interaction with their heating controls is presented.

3.1. Manual use of controls and variation in sample

The monitoring data for the households showed four of the twelve houses were using their heating during the start of July. The recorded data showed very little use of heating within the autumn shoulder months with six of the twelve households using their heating very occasionally during August and four using their heating within the first three weeks of September. One of these households, P10, used their heating constantly over the summer and autumn period. There was an obvious “switch-on” period, with all households starting to use their heating system regularly from the very end of September and beginning of October, this is likely to have been impacted by the unusually warm September in the UK in 2014.
Figure 1 presents the plot of weekly total hours of heating use split by manual and scheduled heating use for the five sample households across the winter monitoring period. It can be seen that within the five households there is an increase in the total hours of heating used via a manual interaction across the winter season. A gradual increase in the manual use can be observed across the beginning of October which relates to the fact that most households only started using their heating again at the end of September; it can be observed that P04 did not start using their heating at all until the second week of October. The peak in manual use occurred within December or January for the sample. A decrease in the manual use of heating can be observed within February relating to the move into the spring shoulder months. However, within the sample the manual use of heating was still quite prominent during March and April which will have been influenced by the very mild start to the spring season during 2015. The level of manual use did vary across the sample.




Total weekly hours of heating use
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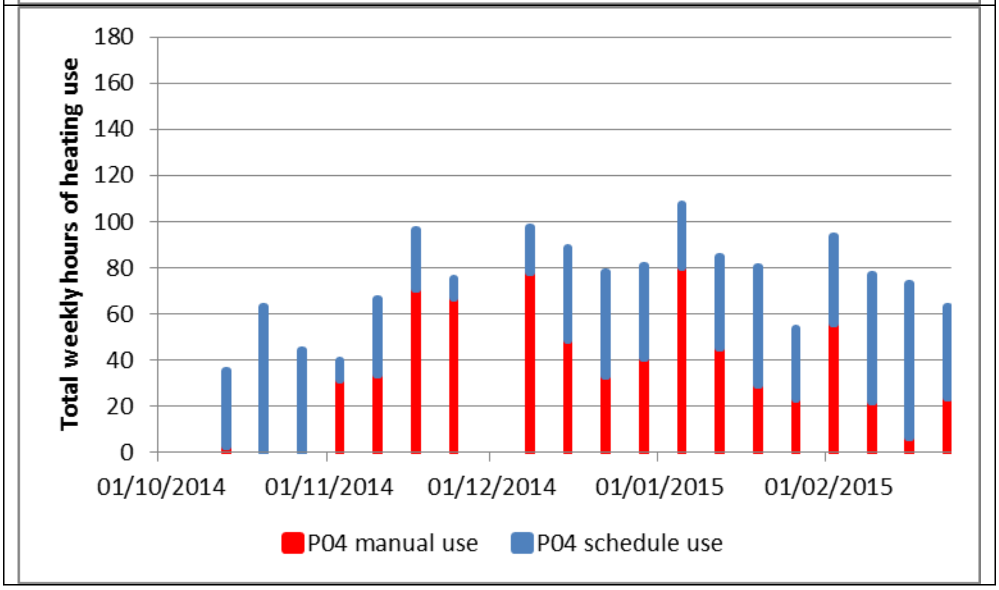
P02 schedule use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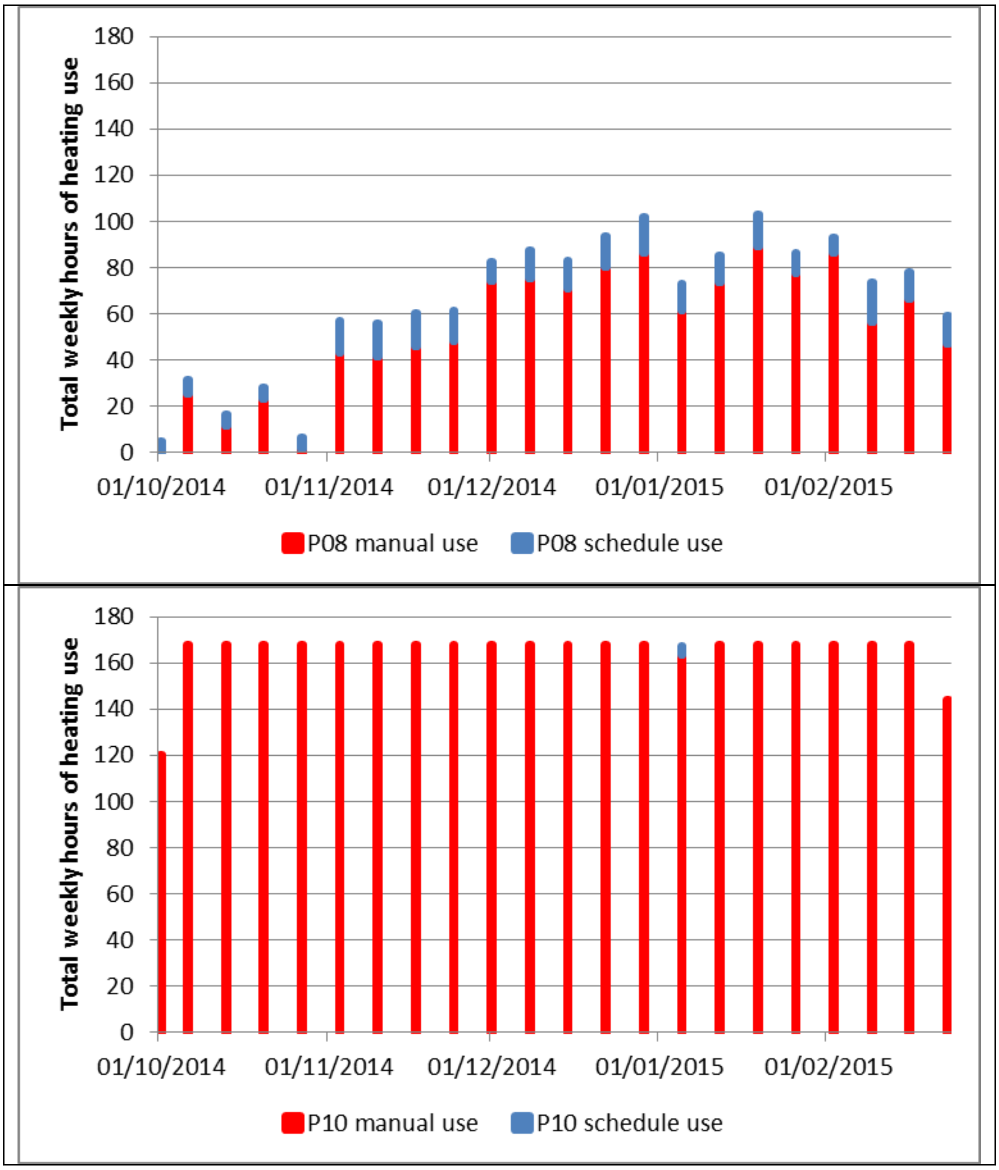

Figure 1: Plots of weekly total hours of heating use through manual and scheduled settings

Table 1 presents descriptive statistics describing the proportions of daily heating use that results from manual interactions, for each month for the five sample households. As the recorded average maximum manual use each month related to the household which left the heating controls on manual constantly throughout the monitoring period, the recorded manual use for this house was almost always 100%. If this house was to be removed from the sample the variation within the sample in October was between 8.2-47.2%, November 11.9-75.5%, December 30.6-85.8%, January 22.8-85.6% and finally in February 15.7-83%. This shows that during the winter season not only did the manual use increase but overall a substantial amount of heating use in homes came from manual use of the controls. The results show that within the five households at least a quarter of heating use within December and January came from manual interaction, whether that was from manual overrides, boosts or simply the preferred use of heating controls. The average external air temperature was actually lower in February than December or January, yet the average percentage of manual heating use started to reduce within February indicating that manual use may be influenced by more than just the external environment.

Month	**Proportion of daily heating resulting from manual use of controls**					
	Mean air temp (^oC)	Min	Max	Mean	Median	Standard deviation
October	12.3	8.2%	100%	37.1%	21.6%	38.5%
November	7.8	11.9%	100%	59.7%	62.6%	32.8%
December	5.4	30.6%	100%	62.5%	48.7%	29.1%
January	4.7	22.8%	99.4%	57.7%	43.4%	33.0%
February	4.1	15.7%	100%	52.0%	32.0%	37.1%

Table 1: Summary of daily manual use of heating controls, for each month, within the five sample households

3.3. Comparison with previous methods

Figure 2 presents a daily trace of internal air temperature measured by the thermostat and a record of whether the heating was active or not (i.e. switched on via programmed heating settings or manual use) for one household in the study. Previous research has taken the steady increase and decrease in internal temperature to deduce the start and end of heating periods. However this fails to show that the second heating period in this example is entirely due to manually switching the heating on and not from a programmed heating schedule. This means the normal assumption of two programmed heating periods would not represent this household's actual heating schedule. Whilst a programmed schedule is more likely to be consistent from one day to the next, a manual interaction could be much more variable and so difficult to predict and model.

Previous methods have also taken the maximum temperature recorded as an indication of the demanded set-point temperature. When this method is applied to this example, a set-point of around 18^oC might be assumed. However the measured set-point temperatures showed that during this example a set-point of 21^oC was demanded during the morning heating period. During the afternoon/evening heating period, which lasted just over 9 hours, a set-point of 21^oC was demanded for the majority however a set-point of 25^oC was also set for 4 hours of this heating period. As it can be seen from the internal temperature trace during both heating periods, the demanded set-point temperature was not reached. This suggests that previous research may have been underestimating the actual demanded set-point temperature within homes.

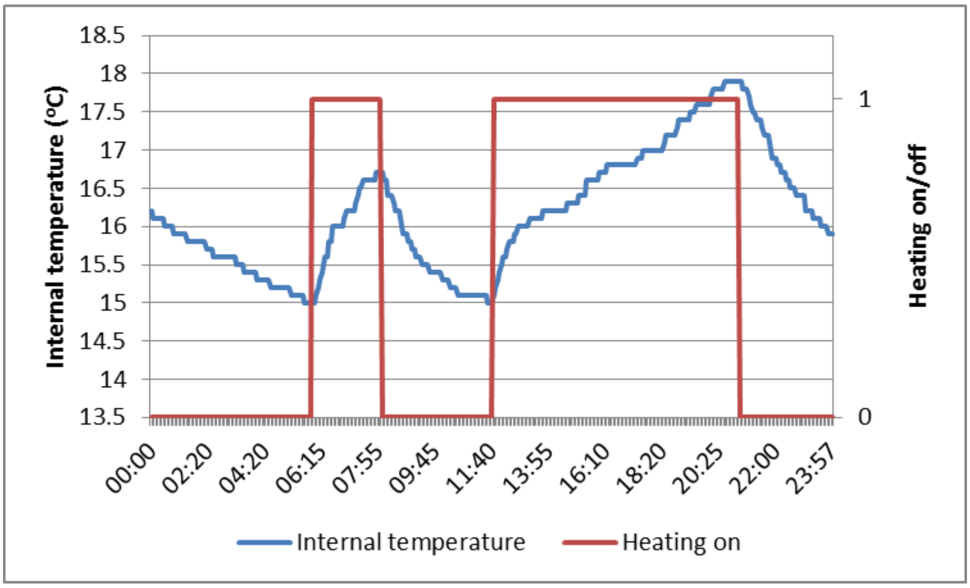

Figure 2: Matching internal temperature against whether heating is on or off

3.4. Characterising heating use

Within the sample it was found that interactions with the heating controls ranged from those who constantly left the controls on auto settings, therefore leaving the heating to be controlled via scheduled heating periods, with the thermostat determining whether the heating should be on or not, to those who set an initial heating schedule and only really interacted with the controls to adjust those schedule settings. There were households which frequently manually adjusted set-point temperatures throughout winter instead of making any adjustments to the heating schedule. Over the course of the winter season, four of the twelve households interacted with the controls to change the time of the heating periods, one house only interacted to change the set-point temperature of the heating periods and four changed both the time and set-point temperature of the heating schedule. Within the sample one household only scheduled the morning period of heating daily and then relied on manual use of the heating every afternoon/evening to suit their daily activity. A further two households chose not to use the controls programming function and relied solely on manual use of the controls. These differences are summarised in Table 2. All households recorded frequent manual interaction with set-point temperatures during the monitoring period, however this ranged from those that only occasionally demanded a higher set-point temperature to those that would regularly change the set-point temperatures, warmer and cooler, as needed.

Type of heating control use	No of households
Constantly left on auto	1
Manually switched heating on and changing set-point temperature as needed	1
Controls used to change time of heating period	4
Controls used to change set-point temp	1
Controls used to change time and set-point temp	4
Morning schedule only set, manual interaction in pm	1
Total number of households	12

Table 2: Summary of how households interacted with the controls

4. DISCUSSION

This study identified trends in the use of heating systems by separating manual interactions with heating controls from scheduled heating settings. The findings showed that manual use of heating increased during the winter season (October-February). This suggests that people do not ‘fiddle’ with their heating during the shoulder months to get the ideal settings and then leave it over winter. Instead participants tended to set a heating schedule and occasionally change this during winter, however relied on manually using the heating on a needs basis during winter. This manual use often meant that the participants were overriding heating schedules on a daily basis but still not changing the actual heating schedule to suit this. Even with this study investigating a small number of households, the level of daily manual interaction varied within the sample substantially, with some households preferring to only manually use their heating controls, ignoring the programming functionality of the new heating controls installed; others completely relied on the programmer and thermostat.

The findings from this study indicate that some new heating control technology might not be as effective at saving energy as calculated. Due to the nature of some households manually adjusting their heating system on a daily basis, it may mean that new technology, which is designed to learn from occupants’ use of heating, may struggle to program ideal settings. This may not result in energy savings due to the sheer level of constant change made to the heating system with manual overrides and set-point temperature adjustments. The findings do however support that some technology may be better suited to certain households than others; for instance, those learning systems would be suited to the occupants who typically leave their settings and maybe only interact with their heating on the odd occasion.

Comparing the measured data from this study with previous methods used within the research field has indicated that manual use of heating could be confused for scheduled heating settings. This could mean that assumptions based on the number of heating periods and duration of scheduled heating might not actually reflect what the occupant is doing with their heating. The difference in the assumed set-point temperature based on internal temperature measurements compared to the actual demanded set-point temperature shows that previous research may have been underestimating the demanded set-point by occupants. This may impact on energy model assumptions and their predictions of energy savings. It is, however, recognised that this difference between assumed and actual will vary from house to house, due to differences in the building fabric and airtightness.

This study is novel in its approach of measuring actual demanded set-point temperatures, heating durations and the level of manual interaction with heating controls. The main limitation was the small sample size due to the study being a pilot for the DEFACTO main study. Additionally, the monitoring data required that the internet gateway in each home was left switched on but some households still switched it off on occasions, resulting in loss of data. The study was also geographically limited and therefore may not be representative of other parts of the UK or elsewhere. However it does provide insights that suggest further work is needed to understand the reasons why occupants chose to manually interact with their controls to such a level.

Further work with a larger sample size of households is needed to investigate the variation of heating use similar to that identified within this study. Future research in the area should also focus on longitudinal investigations of heating use in homes as this will help understand whether heating behaviours change due to the severity of winter weather conditions or not, especially if occupants' experiences during previous winters then impact the next winter heating season.

5. CONCLUSIONS

The results show that most households in the sample made frequent manual adjustments to their heating system using their heating controls rather than reprogramming the central digital programmable thermostat. Many manual interactions occur during scheduled heating periods. These include increasing the thermostat set-point and/or the heating duration. The variation identified regarding the level of manual interactions within the sample suggests that purely relying on assumptions based from set-point temperatures or heating schedule profiles may not show a true picture of occupants' heating behaviour in homes. It is therefore valuable to research the area of manual interactions with controls further, as unknowns about the level of overriding within a sample will mean we cannot accurately determine energy savings through use of new heating control technologies.

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