

DO INTELLIGENT HEATING CONTROLS OUT-SMART ORDINARY USERS?

Becky Mallaband^{1*}, Victoria Haines² and Ashley Morton³

1: School of Engineering & Applied Science
Aston University
Aston Triangle, Birmingham, B4 7ET
e-mail: B.Mallaband@aston.ac.uk*

2: Loughborough Design School
Loughborough University
Loughborough, LE11 3TU
e-mail: V.J.Haines@lboro.ac.uk

3: Department of Civil and Building Engineering
Loughborough University
Loughborough, LE11 3TU
e-mail: A.Morton@lboro.ac.uk

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Abstract

Nearly a third of UK gas and electricity is used in homes, of which 80% is for space heating and hot water provision. Rising consumer bills, concerns about climate change and the surge in personal digital technology use has provoked the development of intelligent domestic heating controls. Whilst the need for having suitable control of the home heating system is essential for reducing domestic energy use, these heating controls rely on appropriate user interaction to achieve a saving and it is unclear whether these 'smart' heating controls enhance the use of domestic heating or reduce energy demand. This paper describes qualitative research undertaken with a small sample of UK householders to understand how people use new heating controls installed in their homes and what the requirements are for improved smart heating control design. The paper identifies, against Nielsen's usability heuristics, the divergence between the householder's use, understanding and expectations of the heating system and the actual design of the system. Digital and smart heating control systems should be designed to maximise usability so that they can be effectively used for efficient heating control by all users. The research highlights the need for development of new systems to readdress the needs of users and redefine the system requirements.

1. INTRODUCTION

Nearly a third (27%) of UK gas and electricity is used in homes, of which 80% is for space heating and hot water provision [1]. Rising consumer bills, concerns about climate change and the surge in personal digital technology use has provoked the development of intelligent domestic heating controls. These can provide householders with increased control over their heating and hot water systems and the option of remote access through a website or mobile phone application. Whilst the need for having suitable control of the home heating system is essential for reducing domestic energy use [2], these heating controls rely on appropriate user interaction to achieve a saving and it is unclear whether these ‘smart’ heating controls enhance the use of domestic heating, improve thermal comfort or reduce energy demand. Technologies are becoming increasingly complex and the potential energy savings associated with the use of these technologies is limited due to poor ergonomics [3]. This paper describes a usability investigation of one particular ‘smart’ heating control which had been installed in a small sample of UK homes.

2. USABILITY OF DOMESTIC HEATING CONTROLS

In recent years, many popular consumer devices have made the switch from analogue to digital, accompanied by the change from analogue to digital displays and from mechanical to electronic operation [3]. Domestic heating controls are following the same trend, allowing for two-way communication between the home and the householders and, with advances in mobile technology, for the ‘home’ to be portable and accessible from any location. Whilst many home appliances labelled as ‘energy efficient’ save the user energy by their purchase alone, heating controls rely on the interaction with users to achieve a saving. However, the potential energy savings associated with the use of these technologies is limited due to poor ergonomics [3]. Although usability has been a topic of investigation for a wide range of human computer interaction devices, the usability of heating controls is less well studied, but especially important when the context of use – the home - is key.

Studies of domestic heating controls have highlighted a number of usability problems [3,4,5,6,7]. Many identify that people do not know how to set up and interact effectively with their heating controls and often cannot complete more complex tasks, reducing the likelihood of efficient use [3,6,8,9,10]. Controls can be unintuitive, poorly labelled, inaccessible and require complex interaction in use. This poor usability can result in a failure to engage with the heating controls, resulting in a lack of ability to undertake tasks or use of the heating system to its fullest capacity; this can be particularly so for older users [6,11]. This has the consequence of not allowing users to reap the benefits of potential energy savings [6]. Exploration of mental models of heating systems have identified misconceptions about the heating system and its components [12,13], suggesting that people do not understand their heating systems and therefore may be unable to control them effectively.

Usability heuristics [14] have been developed for the evaluation of interactive systems such as heating controls and provide good general design guidance. They have been used to highlight gaps in the design of heating controls [3], for example, the need for navigation cues so the user knows where they are in the system, and presenting information in a clear hierarchy. This

means that access to all important and often used actions is available at the home screen level. Other recommendations include the use of plain English, clear affordances so that use of the physical product and its interface is intuitive, the use of large buttons, user friendly instructions and offering a range of products of different complexity to suit different needs. Formal usability expert appraisals and experiments involving domestic heating controls have also been undertaken [3,10], although these studies usually involve controlled conditions and with thermostats which the users are not very familiar.

Occupants have reported that they have a 'good understanding' of how to use their heating controls, but when questioned in depth, are found to not use them as designed [8]. Occupants often do not read instruction manuals and so the operation of the heating systems can be inefficient. When face to face advice, informing residents about how to use their heating controls, was given to social housing tenants [15], the advice appeared to be effective, but instead of reducing energy, the authors report that it resulted in increased energy use through improved thermal comfort for some households. This provides evidence of wider, unanticipated wellbeing gains, sometimes referred to as take-back [16].

Heating controls are going through something of a transition, from the rather mundane appendage to the heating system [10] to a more attractive proposition that includes learning algorithms, remote access, programmable zonal control etc., but it is not clear whether any of these systems meet the user requirements. The consumer demand for effective heating controls is low [17], so there is very limited market pull [3,18]. There is also the potential for increasingly complex heating control systems to add a 'layer of complication, unless they can be designed in a simple and inclusive way' [17]. The inclusion of a smart phone application or 'app' is commonplace with current systems and [19] found just over half of their participants preferring to control their heating via the app. However, the obvious inference here is that just less than half preferred to control their heating in the more traditional way and so these preferences must be considered also. The effectiveness of this increased functionality is not yet proven, especially given the range of ways in which people use their heating systems. In order for new heating controls to have a maximum impact on the energy use of households, the controls must cater for the needs of the full range of users.

It can be concluded that many householders struggle to understand their heating systems and to programme and use their heating controls effectively; these difficulties are exacerbated for older users. However, the very small sample sizes and controlled experiments in most studies mean the results cannot be extrapolated to the wider population. Combe *et al.* [11] conclude with the comment that 'one key aspect of future research remains measuring the scale of the energy savings achievable through improved user interface design'.

3. METHOD

A total of 12 households in the East Midlands area of the UK were recruited as part of the DEFACTO project (see [20,21] for more details). These households were all owner-occupiers, with gas central heating. Following an initial visit and interview, the main heating controls within each home were replaced by a professional installation company. The new heating controls comprised a central in-home display unit which incorporated the main temperature sensor. The heating could also be controlled via a mobile phone app. No other aspects of the heating system were changed. A total of nine households took part in a follow up interview. One adult participant (three males, six females) from each household was interviewed about the use of their new heating controls after a period of at least three months of use. They were also asked to complete three specific tasks representing typical activities of varying complexity to determine the usability of the controls. Participants were filmed talking through each task and rated the ease of completing the task on a 5 point rating scale. Time to complete each task was calculated from the video during the analysis. The interviews were recorded and transcribed in full, then thematically analysed using NVivo 9 and deductively coded using Nielsen's ten usability heuristics [14] as the coding frame:

- **Visibility of system status:** The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
- **Match between system and the real world:** The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
- **User control and freedom:** Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
- **Consistency and standards:** Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
- **Error prevention:** Even better than good error messages is a careful design which prevents a problem from occurring in the first place.
- **Recognition rather than recall:** Make objects, actions and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable when appropriate.
- **Flexibility and efficiency of use:** Accelerators, unseen by the novice user, may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
- **Aesthetic and minimalist design:** Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
- **Help users recognize, diagnose, and recover from errors:** Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

- **Help and documentation:** Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

A separate usability evaluation was conducted on the heating controller by two human factors experts, again using Nielsen's usability heuristics. Each part of the interface was explored in turn and specific issues relating to the physical design of the device as well as interaction with the software were identified.

4. FINDINGS

Findings from interviews with householders are presented in relation to each of Nielsen's heuristics, ordered by frequency in which the topics were discussed by the householders. Summaries from the expert evaluation are included with examples of good and poor usability. Only features that were of particular note are included. The participants' performance when carrying out the specific tasks is also presented at the end of the section.

4.1. Match between system and the real world

All of the households interviewed discussed issues relating to a match or, more often, a mismatch between the system and the real world. This ranged from the use of specific words and language, to the use of on-screen clocks, or how users' habits and lifestyles might fit with the system and most importantly, the app. Participants were asked to explain what they understood by a number of very typical words and phrases found in heating systems, including: 'set-point', 'boost', 'advance' and 'auto'. Users' understanding across these phrases was varied; for example, when asked to explain what they understand by 'set-point', one participant responded with "*I'd think of tennis*" [P02], whilst in relation to 'advance' another responded with "*That...probably means moving forward, I suppose*" [P06]. Some participants relished the addition and flexibility of access via the mobile app that could be used remotely: "*I don't know how I managed without it...Especially when I'm out and about*" [P08]. However, others failed to see any need for the app at all: "*Why would you want to use an app when you're driving home from work? I think, it's...all a little bit of a gimmick...it's almost, the technology's too complicated for itself*" [P02]. The expert evaluation also identified several problems related to the use of technical terminology, particularly as part of the device set up. There were examples of good match with the real world through the use of clear and understandable icons.

4.2. Consistency and standards

All of the participants interviewed raised issues relating to consistency. When trying to carry out more complex tasks, participants struggled to locate the required functions as the screens were not consistently laid out. Users also presumed the device would have similar touch screen capabilities and sensitivity levels to other devices they used regularly, e.g. tablets, smart phones. However, the screen on the heating controller required much more pressure to use effectively. The expert evaluation identified an inconsistency in the use of coloured

borders on various screens; in some cases the colours indicated active screens, in others, the use of colour just outlined display areas.

4.3. Help and Documentation

All but one of the participants interviewed had used the instruction manual since getting their new controls, either at first set up to familiarise themselves with the system (n=3) or through necessity (n=5). Whilst the participants spoke positively about the manual and found the information they needed, the system would be improved if it could be used without documentation. The expert evaluation identified that the product information and on-screen support given are clear and relatively easy to understand. However, the information screen did not display for long enough for a user to make a note of the numbers or information given.

4.4. Aesthetic and minimalist design

Participants were asked to give their opinion on the heating controls as a physical product. All of the participants were positive about the aesthetic nature of the product. Some had suggestions for further improvement, but there were no wholly negative responses, e.g. *“I think it's a really smart looking thing...and I think it looks good in your home”* [P06]. The design of some screens were less clear, especially where two clocks were provided to set the heating schedule, one for am, the other for pm; this design could be simplified. The expert evaluation identified that redundant information relating to hot water use is visible for all users, even those with combi boilers; this does not present a minimalist design.

4.5. Recognition rather than recall

The majority of the participants discussed instances where the system required them to recall information. Many of the participants felt that if they used the system more regularly, they would have remembered the information: *“It's just when you're not using it for two or three months...I can't remember what I've got to do”* [P09]. However, it is common for heating systems to be set up initially by the installer and so householders may not return to the detailed settings until several months later. The systems should allow easy use through presentation of the required information without having to remember sequences of actions. Participants in this study also could not remember details of their passcode which had been set up at installation.

4.6. User control and freedom

Participants talked about being in control of the system and the freedom and flexibility that the mobile app in particular enabled: *“I liked the fact that it's on a timer, so whenever I walk through the door after work, my house is, obviously, warm.... I suppose, if you're out at the weekend and it's colder than you expect it to be and you've got the app, it's at the touch of a button, isn't it...so you don't have to come home and sit in the freezing cold for an hour before it starts to warm up”* [P01]. The app provided improved functionality.

4.7. Visibility of system status

Several of the participants discussed points around the visibility of the system status. Two participants made comments which suggested that their new heating controller was better than their previous equipment in this respect: *“I suppose it tells you all on the screen what it’s doing, doesn’t it? Whereas on the other one you had to press the buttons to see the different information”* [P10]. Other participants discussed negative issues surrounding the visibility of the system status. For one, there was confusion when the system was displaying an error, but they could hear the boiler operating, so they did not know what the system status was. For another, they expressed concern once they had entered information into the device: *“Well, that’s easy, but then I wonder if I’d have saved it correctly”* [P05]. The expert evaluation identified positive usability features such as audible and visual feedback given when buttons are pressed, and information such as the current time, date and temperature clearly visible throughout. However, confirmation of the user’s actions is not always given and so the user has to presume that their settings have been saved.

4.8. Help users recognize, diagnose and recover from errors

Several of the participants who made errors when using the heating controller were only aware of the error when their heating system failed to perform as anticipated, e.g. *“Every morning I would wake up and go, phew, bit brisk [cold] in here today, look at the timer and go, yes, I didn’t do that right again, did I?”* [P01]. Clearly the system was not allowing users to recognise their errors before they affected the system’s use. For other households, there were sometimes external errors which caused problems with their interaction with the heating controller, e.g. one householder inputted their data in the system three times and the information was lost every time. This reduced their trust in the system and so they went on to blame the system for other errors. The heating controller did have a ‘back’ and ‘home’ button on each screen to allow the user to backtrack when required; whilst a helpful feature to recover from errors, this would not avoid all the problems described here.

4.9. Error prevention

Errors were discussed predominantly relating to setting the heating time clocks. The expert evaluation also identified that setting the programmer heating times is not very intuitive. The participants’ experiences of the system suggest that it is not preventing errors and so failing to meet this usability requirement. Errors also occurred through the poor sensitivity of the touchscreen, particularly around the edges of the screen. This meant that participants had to press the screen repeatedly to get the system to respond in the way they expected, often making errors in the process.

4.10. Flexibility and efficiency of use

One participant had been shown a method of use at installation and had then found a quicker way of performing the same task: *“[the installer had] shown me the main control panel...and that was fine but...I discovered a week or so later, there was actually a much more comprehensive way of doing it”* [P02]. This demonstrates the flexibility of the heating controller, allowing operations to be carried out in more than one way. Participants positively

discussed the flexibility of the system through use of the mobile app, for example, how the app enabled flexibility around heating schedules. The system had a passcode protected section, however only one of the participants was familiar with the passcode so this prevented most from making full use of the system. The expert evaluation identified a number of ways the controller was designed to be used flexibly, which allows for user preference and choice. However, multiple key presses were needed to change some of the settings.

4.11. Other usability issues

Several participants talked about the physical nature of the device and how it could better match their home lifestyles. Whilst the device itself was portable, it usually resided within a charging base which was plugged into a power socket. Several householders commented on this charging unit, for example, one household was concerned about the wires hanging down from the unit and whether their young child would be able to grab them, whilst another householder did not like the fact that the unit took up space on the work surface and would prefer it to be attached to the wall. Another participant described their annoyance at the warning beeping sound which was emitted from device when it was removed from its base. In addition, it was noted by householders that once removed from the base, the device did not have a flat surface on which it could be balanced, which they felt limited its usefulness.

4.12. Performance against specific tasks

A number of metrics were used to determine the performance against the specific tasks undertaken by the participants, including successful completion of the task or not, time to complete, time to abandon if they attempted the task but did not complete it, and subjective rating of the ease of each task, on a 5 point scale. The results are presented in Table 1.

Table 1. Performance against specific tasks

Total of 9 participants * 1 person only	Task 1: Heating at 22 degrees	Task 2: Heating on at specific times	Task 3: Heating not below 15 degrees
Percentage completing the task	89%	67%	11%
Average time where successful	16 seconds	47 seconds	28 seconds*
Range of times where successful	4 - 30 seconds	26 - 70 seconds	n/a
Abandonment times (range)	76 seconds*	210 seconds*	18 - 60 seconds
Immediate abandonment of task	None	2 people	4 people
Average rating (-2 very difficult to +2 very easy)	1.3	0.6	-1.3

In general, the participants were able to set the temperature of their heating system successfully, with eight of the nine participants completing this task. The one participant who was not able to achieve this task tried to change the programmed temperature (rather than the current temperature). After 76 seconds, this participant thought they had completed the task, commenting “*Yes, it’s just logical, really*” [P07], however, they had not set the system

correctly. The average time to complete this task successfully was 16 seconds (range 4-30 secs) with an average rating that suggests most people found this easy to complete. Setting the programmer so that the heating would come on at particular times was a more complex task to complete, requiring adjustment of the two time clocks, and participants took longer to complete this task (mean 47 secs, range 26-70 secs). There was also a lower overall success rate (67%, six of the nine participants completing this successfully). Two people did not even attempt this task, with one commenting that their husband would do this, the other saying they would refer to the manual for help; a third person persisted for three and a half minutes before giving up. Those that were able to complete the task rated it as relatively easy or very easy, however the average across the group was lower as the two participants who did not attempt it rated it as very difficult. The third task required participants to set up a frost protection temperature by accessing the maintenance area of the system which required a passcode. In many cases, participants were not able to even find this area and searched in the programme area of the interface. There was no particular pattern to their searching, participants simply pressed random buttons hoping that something relevant would appear. Four of the nine participants abandoned this task immediately. Only one participant was able to successfully complete this task, which they rated as relatively easy. The average rating for this task was the lowest of the three, suggesting that most people considered it difficult. Interestingly, one participant who failed to complete both tasks 2 and 3 still rated the activity as relatively easy. Many of the participants were reluctant to undertake the various tasks as requested as they were concerned about messing up their own heating systems. This indicates that they were not confident in using the heating controls as they did not feel able to return the system to its previous settings.

5. DISCUSSION

Evaluation of the new heating controller in this study by both users and human factors experts has identified several aspects of the system that are well designed and meet the users' needs. In particular, there were benefits of the new controls in comparison to the participants' previous analogue systems. The aspects of the system which allowed flexibility around individual lifestyles and preferences were positively received. However, some participants could not see the benefit of the app feature, as they had no present need for it. The majority of participants had needed to refer to documentation to help them use and set the system using the controller, indicating a lack of intuitive design in the system. Some participants felt their use of the system would have been better if they had used it more recently, but heating controls are often only used intermittently and so need to be simple to use even after long periods without interaction. Mismatches between the system and the real world were identified; these cause frustration to the user, are likely to increase the number of errors in use of the system and limit potential energy savings. Whilst the complexity and poor design of systems can make tasks more difficult or time consuming than necessary, the resourcefulness and perseverance of householders means that they are able to operate their heating systems in an acceptable way. However, this may not be the most efficient, in financial or energy terms.

There were other areas where further improvement will provide a better level of usability, to reduce user frustration and help prevent errors. In particular, there is a need for heating control systems to match the environment in which they are placed - the home. This need is all encompassing and should include the language used, the imagery and icons, the logic employed, the physical design of the product and the operations and settings available. These systems need to match the requirements of all users, and further research should be undertaken to understand how those with more regular heating patterns might benefit from the smart features. Importantly, the technology needs to facilitate use for users who enjoy using the more advanced features, and those who would like to retain simple control. This includes providing touchscreens which respond to gesture control with minimal effort, so that their use is intuitive and learning transferable from other devices. Clearly this will assist with error prevention, which will reduce frustration and the time taken to complete specific tasks. The controls should allow basic but quick interaction even for the novice user. Some householders will want to access the more sophisticated aspects of their heating controls, but, as this study demonstrated, many people are not able to complete these more complex tasks and so it is likely that a system will not be used to its maximum efficiency or effectiveness if superficial control only is possible.

Nielsen's usability heuristics [14] provided useful guidelines for evaluating the controls and this study has indicated that mismatches between the system and the real world are where the majority of the usability problems occurred. However, Nielsen's description of this heuristic could be expanded to consider the wider scope of the home environment in which heating controls are used. The inclusion of a mobile app allows users to have the ability to control their heating from anywhere and so interaction with the system and therefore the home is no longer limited to one location. This allows the freedom to control the heating in a way that best suits the individual, but puts increased demands on the design of the interface. Users need freedom of choice and should not be limited by the heating system's own logic and prescribed settings.

5.1. Limitations and further work required

Whilst the user evaluation highlighted some important issues with the system and some positive elements of usability, this type of evaluation is limited without detailed knowledge of the consequences of the control use. Combining the evaluation with an expert evaluation allowed some issues which would only be identified with very regular use of the system within a domestic environment. However, the detailed nature of this study meant that the sample size was limited and, although the sample included a spread of participants, it is not known how representative of the wider population it is. Clearly, further in-context research with larger samples is needed and is ongoing, but this comes at a cost and requires participation of households in longitudinal studies at scale.

6. CONCLUSIONS

Whilst the 'smart' heating controller assessed in this study was generally considered to be an improvement on the participants' old style analogue heating controls, the new controls

presented a level of functionality and complexity that was not desired by all. Although using only a small sample, this study investigated heating controls fitted within real homes, where householders had been using the controls for at least three months prior to the investigation. Nevertheless, householders reported a range of issues relating to poor usability and were unable to complete some specific tasks set; some had needed to consult the instruction manual, indicating a lack of intuitive use. For these users, the smart heating controls did not meet all their needs. Nielsen's usability heuristics provided a good framework for evaluating the heating controls, but did not cover the full range of interactions likely with a home heating system. Further study is needed to identify the consequences of poor usability in heating controls and to ascertain whether poor controls design is purely a time consuming frustration for the user, or whether it has additional thermal comfort and energy impacts.

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