How People Actually Use Thermostats

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ABSTRACT

Residential thermostats have been a key element in controlling heating and cooling systems for over sixty years. However, today's modern programmable thermostats (PTs) are complicated and difficult for users to understand, leading to errors in operation and wasted energy. Four separate tests of usability were conducted in preparation for a larger study. These tests included personal interviews, an on-line survey, photographing actual thermostat settings, and measurements of ability to accomplish four tasks related to effective use of a PT. The interviews revealed that many occupants used the PT as an on-off switch and most demonstrated little knowledge of how to operate it. The on-line survey found that 89% of the respondents rarely or never used the PT to set a weekday or weekend program. The photographic survey (in low income homes) found that only 30% of the PTs were actually programmed. In the usability test, we found that we could quantify the difference in usability of two PTs as measured in time to accomplish tasks. Users accomplished the tasks in consistently shorter times with the touchscreen unit than with buttons. None of these studies are representative of the entire population of users but, together, they illustrate the importance of improving user interfaces in PTs.

Introduction

For over sixty years, residential thermostats have played a key role in providing thermal comfort while controlling the energy use of heating and cooling systems. More recently PTs have appeared which, in theory, allow even greater energy savings without sacrificing comfort or convenience (Nelson & MacArthur, 1978). In practice, the transition to PTs has offered both benefits and drawbacks. This paper surveys the history of thermostats and the introduction of PTs, addressing several questions:

- What thermostats are present in today's homes and how are they used?
- How successful are modern thermostats at achieving the occupants' thermal goals?
- Are the owners of PTs achieving expected energy savings?
- What difficulties do people experience when using thermostats?
- Have usability issues been adequately investigated and measured?

Background

This section provides a brief synopsis of research relevant to each of the questions posted above.

What thermostats are present in today's homes and how are they used?

Two types of thermostats have dominated the U.S. market: manual or mechanical thermostats, such as the Honeywell Round introduced in 1953, and PTs, such as the Honeywell RTH7600 shown in Figure 1. The modern PTs are digital successors to the clock or setback thermostat that grew in popularity after the 1973 energy crisis. Cheaper displays and increased processing power have permitted other features to emerge, such as touchscreens, color displays, internet connections, Home Area Networks (HAN) connections, remote controls (i.e., through cell phone or internet), voice controls, external communication (i.e., through radio-link to utility), ventilation, humidity controls, and zonal controls.

Figure 1: A round thermostat, a clock setback thermostat and touchscreen programmable thermostat.

US residential thermostats control HVAC systems that are responsible for roughly 11% of the nation's energy use (Energy Information Administration (EIA), 2008). Government policies, as well as higher energy costs certainly encouraged consumers to install PTs. PTs are now purchased more than any other thermostat design although manual thermostats are still common in existing homes. In 2005 the Residential Energy Consumption Survey (RECS) (Energy Information Administration (EIA), 2005) found the following:

- 14% of U.S. households report having no thermostat
- 56% had a manual thermostat
- 30% (34.6% of thermostat owners) had a PT.

In California, the 2005 RECS reported:

- 19% of households had no thermostat
- 37% had a manual thermostat
- 44% (54% of thermostat owners) had a PT.

The increased number of PTs in California versus nationwide reflects the last 30 years of energy codes that required a setback or PT.

According to the American Home Comfort Survey (Decision Analyst, 2008):

- 36% of US households had PTs in 2004, and the percentage increased to 42% in 2008.

PTs can be programmed to change temperature setpoints on a schedule but perhaps half of households actually use PTs in this way. According to the 2005 RECS (Energy Information Administration (EIA), 2005), during the heating season:

- 60% of households with PTs used them to reduce temperature at night
- but only 45% reduced the temperature during the day.

During the cooling season:

- 55% of households with PTs set them to increase temperature at night as well as during the day.

Most PTs have two additional operating modes that abort the programmed schedule: hold and temporary override (override/temp) mode. Override/temp allows the occupant to temporarily raise or lower the desired temperature until the next scheduled time program. The hold mode is a permanent change, and functionally turns the PT into a manual thermostat. Only a few studies examined the fraction of homes where these thermostat settings are frequently enabled. Carrier examined the operating mode of PTs installed in households in new York and California homes (Archacki, 2003). Carrier PTs enabled real-time communication access and provided actual thermostat data, thereby avoiding errors related to self reported thermostat settings (Lutz & Wilcox, 1990; E. Vine & Barnes, 1989) Of the 35,471 thermostats monitored overall:

- 47% were in program mode, in which the thermostat uses the schedule previously input by the occupant to control temperature setpoints
- 53% were in hold mode.

California households had higher rates of enabling some kind of program:

- 65% were in program mode
- 35% were in hold mode.

If these studies are representative of the country as a whole, then approximately half of US PTs were not used as designed. Put another way, the PTs were simply used as manual thermostats.

How successful are modern thermostats at achieving the occupants' thermal goals?

Several studies have argued that thermal comfort is perceived as the main concern in the interaction with thermostats (Hackett & McBride, 2001; Kempton & Krabacher, 1987; Lutz & Wilcox, 1990; Lutzenhiser, 1992; Weihl & Gladhart, 1990; Woods, 2006). It is difficult to understand if the modern PTs are effective in achieving occupants' thermal goals. Most of the thermal comfort testing and surveys in residences have been of small sample size and not representative of all socioeconomic and demographic classes. Even recent surveys such as the Residential Energy Consumption Survey (RECS) struggle with definition of terms such as PT, setpoint, zones. One national survey reported that thermal comfort throughout the home tends to be problematic (Decision Analyst, 2008):

- 68% of homeowners found at least one room too hot in the summer
- 60% found at least one room too cold in the winter.

When asked about their home comfort system, residents many requested the following improvements:

- better air purification (76%)
- improved air flow (69%)
- better temperature control (68%)
- more even temperature (65%)
- faster heating and cooling (64%)
- better humidity control (64%).

These improvements more likely depend on the whole heating/cooling system rather than the thermostat. Furthermore, many factors influence thermal comfort, such as air temperature, radiant temperature, air speed, humidity, level of clothing/activity (American Society for Heating Refrigerating and Air-Conditioning Engineers (ASHRAE), 2004; Fanger, 1970; Nicol & Humphreys, 2009) as well as psychological, behavioral, and physiological factors (Beshir & Ramsey, 1981; Brager & de Dear, 1998; Humphreys & Nicol, 1998; Karjalainen, 2007; van Hoof, Kort, Hensen, Duijnstee, & Rutten, 2010). However, most commercially available thermostats (the main device to affect house thermal environment) control only air temperature, while other parameters are left unmonitored and uncontrolled.

Are the owners of PTs achieving expected energy savings?

PTs are typically marketed as "energy-saving." In addition, many building codes and government programs require PTs because of their assumed energy savings. There have been surprisingly few careful studies of the energy savings attributable to PTs. Several recent field studies have shown no significant savings in households using PTs compared to households using non-PTs (Cross & Judd, 1997; Haiad, Peterson, Reeves, & Hirsch, 2004; Nevius & Pigg, 2000; Shipworth, et al., 2010). Two other studies argued that homes relying on PTs consumed more energy than those where the occupants set the thermostats manually (Sachs, 2004), especially with heat pumps (Bouchelle, Parker, & Anello, 2000). According to these analyses, a PT itself did not guarantee reduction in energy consumption, but instead depended on how the device was programmed and controlled by the household. The availability of a PT did not change setback behaviors: the study showed that people who setback temperature with a manual thermostat kept doing so, and did not increase their energy savings; those who were not used to changing temperature setpoints did not setback with PTs. The EnergyStar™ endorsement program for PTs, which had been in place since 1995, was recently discontinued in December 2009 based on these and other results.

What difficulties do people experience when using thermostats?

One of the barriers of using PTs to save energy is that users often fail to use these devices as they were designed. People find PTs difficult to program and to understand (Boait & Rylatt, 2010; Consumer Reports, 2007; Critchleya, Gilbertsona, Grimsleya, Greena, & Group, 2007; Karjalainen & Koistinen, 2007; Nevius & Pigg, 2000; Rathouse & Young, 2004a). Therefore a look into human factors and usability may provide insights into the design of future PTs to improve energy performance. Indeed, over 20 years ago, Vine encouraged the integrative analysis of engineering, social and behavioral variables to "save energy the easy way" (E. L. Vine, 1986).

We compiled complaints and unexpected beliefs held by thermostat users from studies conducted by U.S. and European researchers. Many of these observations were by-products of other investigations. Table 1 summarizes the misconceptions about energy and thermostats, complaints of the customers dealing with PTs and PT manuals, and the significant barriers to the adoption of PTs.

Table 1: User complaints regarding programmable thermostats

Energy Misconceptions	**References**
Heating all the time is more efficient than turning heat off	(Norman, 2002; Rathouse & Young, 2004b)
People have no knowledge of the annual/daily running cost	(Rathouse & Young, 2004b)
People ignore the temperature set in their own thermostats	(Rathouse & Young, 2004b)
People have little knowledge of how the HVAC system works	(Diamond, Remus, & Vincent, 1996; Karjalainen, 2008; Rathouse & Young, 2004b)
People ignore the environmental impact of overheating	(Rathouse & Young, 2004b)
Thermostat Misconceptions	**References**
Thermostat is simply an on/off switch	(Rathouse & Young, 2004b)
Thermostat is a dimmer switch for heat (valve theory)	(Karjalainen, 2008; Kempton, 1986; Rathouse & Young, 2004b)
Turning down the thermostat does not reduce energy consumption (or not substantially)	(Nevius & Pigg, 2000; Rathouse & Young, 2004b)
Boiler thermostat is used to change the temperature in the room (as if it is a room thermostat)	(Rathouse & Young, 2004b)
People are afraid of using PTs (unknown terrible	(Diamond, 1984a, 1984b; Karjalainen, 2008;

consequences)	Nevius & Pigg, 2000; Rathouse & Young, 2004b)
Programmable Thermostats Complaints/Issues	**References**
PTs are too complicated to use	(Boait & Rylatt, 2010; Consumer Reports, 2007; Critchleya, et al., 2007; Diamond, 1984a, 1984b; Diamond, et al., 1996; Freudenthal & Mook, 2003; Fujii & Lutzenhiser, 1992; Karjalainen, 2008; Linden, Carlsson-Kanyama, & Eriksson, 2006; Moore & Dartnall, 1982; Nevius & Pigg, 2000; Rathouse & Young, 2004b; Vastamaki, Sinkkonen, & Leinonen, 2005)
Buttons/fonts are too small	(Consumer Reports, 2007; Dale & Crawshaw, 1983; Diamond, 1984a, 1984b; Rathouse & Young, 2004b) (Moore & Dartnall, 1982)
Abbreviations and terminology are hard-to-understand; lights and symbols are confusing	(Dale & Crawshaw, 1983; Diamond, 1984a, 1984b; Karjalainen, 2008; Lutzenhiser, 1992; Moore & Dartnall, 1982)
The positioning of interface elements is illogical	(Dale & Crawshaw, 1983; Diamond, 1984a, 1984b; Moore & Dartnall, 1982)
PTs are positioned in an inaccessible location	(Karjalainen, 2008; Rathouse & Young, 2004b)
Setting the thermostat is troublesome	(Freudenthal & Mook, 2003; Linden, et al., 2006; Nevius & Pigg, 2000; Rathouse & Young, 2004b)
It is difficult to set time and date	(ConsumerReports 2007)
PTs give poor feedback on programming	(Karjalainen, 2008; Moore & Dartnall, 1982)
PTs are not attractive to use	(D. S. Parker, Hoak, & Cummings, 2008)
Thermostat Instruction Manual Complaints/Issues	**References**
Too technical – only for plumbers	(Freudenthal & Mook, 2003; Rathouse & Young, 2004b)
Not enough pictures and diagrams	(Rathouse & Young, 2004b)
Too wordy, time consuming, too detailed, better to focus on basics, not procedural (need step by step instructions)	(Rathouse & Young, 2004b)
Better if attached to the control (easy to lose)	(Rathouse & Young, 2004b)
Barriers to Using PTs	**References**
Payback and increased convenience are not worth the cost	(Nevius & Pigg, 2000)
Presence of alternative heating/cooling devices not controlled by PTs, (for example wood stoves)	(Nevius & Pigg, 2000; Rathouse & Young, 2004b)
Age dependent problems with programming	(Freudenthal & Mook, 2003; Sauer, et al., 2009)
Unpredictable time at home makes programs useless	(Nevius & Pigg, 2000; Rathouse & Young, 2004b)
Incorrect mental models about good indoor temperature	(Karjalainen, 2008; Vastamaki, et al., 2005)
Thermal feedback is delayed (thermal inertia) and desired thermal comfort is delayed	(Rathouse & Young, 2004b; Vastamaki, et al., 2005)
Conflicts among people in the household with different thermal needs and operating practice	(McCalley & Midden, 2004; D. Parker, Barkaszi, Sherwin, & Richardson, 1996; Rathouse & Young, 2004b)
Aesthetics of the device	(Gupta, Intille, & Larson, 2009)
People want to retain control	(Kempton, Reynolds, Fels, & Hull, 1992)
Special HVAC systems (Evaporative Cooling, Heat Pumps) work differently than normal systems and require a different operating mode, user practice and thermostat setting	(Bouchelle, et al., 2000; Diamond, et al., 1996)
High priority for heating in people's expenditures	(Rathouse & Young, 2004b)

Have usability issues been adequately investigated and measured?

Many of the complaints and barriers to using PTs are associated with their poor usability. Yet only a few researchers performed usability tests (Bordass, et al., 2007; Consumer Reports, 2007; Freudenthal & Mook, 2003; Karjalainen, 2008; Peffer, 2009; Rathouse & Young, 2004b; Sauer, et al., 2009) even though the PT's poor usability is broadly acknowledged and despite the abundant literature on usability guidelines. We suspect that considerable proprietary research has been conducted by thermostat manufacturers but this has not been reported in the literature. Only one study analyzed actual PTs available in the United States (Consumer Reports, 2007). We conclude that the way users actually operate their thermostats has not been carefully investigated and may have a significant impact on energy used for heating, cooling and ventilation.

Assessing Usability of Programmable Thermostats

We have begun a wide range of studies to determine the critical usability characteristics of PTs, the most urgent improvements needed, and other barriers preventing people from using the devices as designed. Four separate studies are described below.

Personal interviews regarding thermostat habits

In the first study, we administered six semi-structured qualitative interviews in Berkeley and San Francisco to assess whether people have a general understanding of how thermostats work. The age of interviewees (students or professionals) spanned from mid-twenties to late-thirties. Interviews were recorded in the interviewees' houses; in the Results section we summarized the most intriguing findings.

Online survey

In the second study, we posted a 15-question survey through Facebook, Craigslist, and other online distribution channels. No compensation was provided for completing the survey. Questions ranged from brand and placement of thermostats within the home to their perceived effectiveness and specified temperature settings. Additional topics included human interactions with the device, such as frequency of adjustments and use of hold modes. Relevant demographic information, including geographic location and primary household language, was also collected.

Survey among low-income families

In the third study, we surveyed 20 low-income families in Wisconsin during the late winter 2010. A weatherization organization administered the survey and photographed the thermostats. The photos contained objective data, such as type and brand of thermostat, use of hold mode, accuracy of time settings, temperature set and any other characteristic noticeable from the display. We then compared these objective data with self-reported questionnaire responses, and noted the inconsistencies.

Usability test

In the fourth study, we tested several users' interactions with two thermostat models. The experiment was intended both to gather qualitative information and to test possible metrics for a future larger scale study. We asked the subjects to perform four relevant tasks on two available thermostats. The tasks were:

- Task 1: *Set the thermostat to today's date and current time*
- Task 2: *Set your thermostat to reflect your weekday schedule and home temperature preferences*
- Task 3: *What is the current temperature? Please raise the temperature two degrees*
- Task 4: *You're going away on vacation for two weeks. Please lower the temperature for the time that you are away.*

The thermostats were placed in the users' homes next to their existing thermostats to accurately replicate the use conditions of their actual thermostats, including lighting and accessibility. Users stood up while performing the tasks. Six people (ranging in age from their mid-twenties to early forties) performed the test on both thermostats. The thermostat order was alternated for each user to account for any learning that might occur. All tests were recorded with a video camera for the purposes of analysis. To compare usability of the two devices we chose the following: i) time needed to perform a task, ii) rate of success.

Results and Discussion

Personal interviews regarding thermostat habits

Many of the complaints and problems listed in Table 1 also emerged in our interviews. For example, improper placement of thermostats such as on another floor or in the warmest/coolest room affects the accuracy of sensors and has consequences on settings. We found that in the majority of the households thermostats were improperly positioned. Moreover, location can affect the readability of the device. For example, in one household the thermostat was installed in a dark hallway and rotated 90 degrees. Many people admitted to using their PT as an on/off switch instead of programming it, as reported in previous studies. The users in the remaining households rarely changed the scheduled settings, often only once per year, and instead frequently used override modes. Most of the interviewees showed little knowledge of the thermostat and a few were also worried about touching it: "I don't touch it because I don't understand it" or "I don't want to mess it up." A further complicating factor in assessing the effects of controls on energy consumption is that supplementary heating/cooling systems, such as fans, additional air conditioning units and fireplaces, were often used and not controlled by the thermostats.

Online survey

The online survey yielded 81 respondents from ten US states and 57 cities. Most thermostats were not selected by the residents and were in locations decided by others. Only 19% of thermostats were chosen by respondents or someone in their household. With regards to settings, 89% of respondents reported that they rarely or never adjusted the thermostat to set a weekend or weekday program, and 54% of respondents used the on/off switch at least weekly. While it is noted that the sample is not necessarily representative, these results suggested that thermostats were often used as manual instead of programmable devices. When asked about the feedback given by the thermostat on confirming changes, 43% of respondents reported poor feedback, 29% fair, 19% good feedback, and 8% were unsure).

Survey among low-income families

The low-income survey captured a variety of behaviors with thermostats. About a third of the interviewees reported that they change settings every day, a third never change the thermostat, and a third weekly at most. Although most (85%) of the respondents declared that they use programming features to automatically raise or lower the temperature, the photos indicated a very different breakdown:

- 45% were in hold
- 30% were programmed
- 10% were manual thermostats (not programmable)

- 5% were off
- 10% operational status was not visible in the picture.

This small survey (again unrepresentative) reveals that people either do not understand what "programmable" means, or they know very little about how to operate the thermostat. In light of these findings, self reported behavior or settings should be considered carefully.

Usability test

We tested the ability of users to perform common tasks on a popular touchscreen thermostat and a button model. Figure 3 shows the average time to completion of the task for each of the six participants with both thermostats.

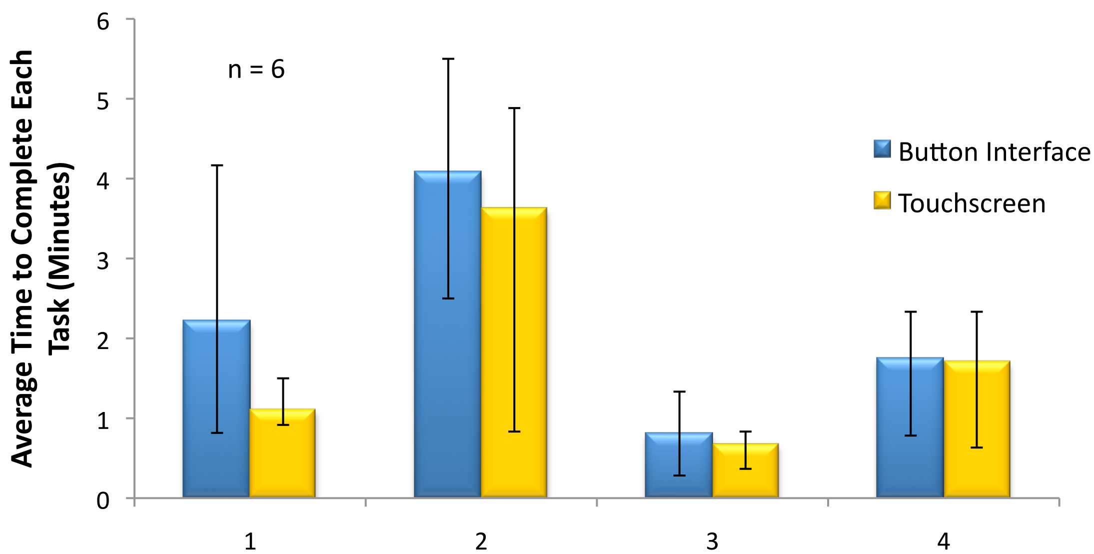

Fig 3: Average time to completion of each task

The thermostat with the button interface had a cover protecting and concealing the programming buttons which notably influenced the time to complete the first task. Four out of six people could not open the cover of the button interface without additional help. One user noted her frustration searching for the buttons behind the cover by saying "This is a really good design for a treasure chest...are you allowed to help me get the cover off?" The easiest task was Task 3 in which the users were asked to temporarily change the temperature by two degrees. Task 4 proved the most difficult for users, as only one out of the six users used the proper hold mode to set the temperature for a two-week vacation. The rest of the users turned the device "off", went through the long process of changing all of the schedule settings for each day or were unable to successfully complete the task.

Several users had difficulty confirming their settings or would falsely confirm their settings. For example, when asked to set the time one user confirmed with confidence that she had completed the task but in reality she had set Monday's wake up time. Neither thermostat adequately allowed users to confirm settings. Additionally, we found that users were often confused when they needed to switch between different modes (display, time settings, temperature settings) and they did not consistently understand the meaning of labeling. One of the interviewees asked "Is this in a different language? …What does 'Motuwethfr' mean?" She misunderstood the abbreviations for Monday, Tuesday, Wednesday, Thursday and Friday in the settings mode. With both thermostats, users were confused about which numbers represented the current indoor temperatures and which represented the temperature for their scheduled settings. Although the two thermostats were produced by the same manufacturer they used different text, icons and labels to represent similar operations.

Further discussions with users after the test revealed other problems not necessarily connected to the described tasks. One user explained that when he adjusts the thermostat he chooses "round numbers" and that setting a thermostat is really "a process of trial and error" for comfort. User comments while selecting a temperature suggest that people set thermostats to feel comfortable and temperature choice is not necessarily based on maximum energy efficiency. Another user who worked from home found confusing the terms used to describe the schedule (wake, leave, return and sleep). In addition, there was confusion about switching between heat and cool modes. Users either did not account for the heat or cool modes, or noted that they would prefer setting the temperature without having to factor in the season and HVAC setting.

While more usability testing is needed to confirm the quantitative results, several possible considerations help explain why the touchscreen interface took less time than the button interface for users to perform all given tasks. One noted difference between the interfaces was the greater space for text and buttons allowed on the touchscreen device. Several different controls could be fit onto the same space and in full text on the touchscreen interface. Therefore if a user pressed "Schedule" this control then displayed the "Edit" control in the same space occupied previously by the text for "Schedule." This contrasted with the button interface which had abbreviated controls (including "pgm, clr, clk") that were crowded together and often confusing for users. Another notable difference between the two devices was the touchscreen interface's ability to provide a menu with a narrative for each task. If users were viewing their schedule they had controls displayed that allowed them to "Go Back," "Edit" or be "Done" with their schedule. These narrative menu controls appeared to make more sense to users.

Conclusions

PTs can reduce heating and cooling energy consumption when the devices are used correctly. However, our review of the literature, combined with the results of four usability studies, illustrate the technical and conceptual barriers to correct use. The PT's full technical energy savings potential is unlikely to occur and sometimes will result in increased energy consumption.

At the same time, PTs are acquiring new functions and responsibilities, include time-of-use response, network connections, and humidity and ventilation controls. We are concerned that these features will be incorporated before the existing ones have been fully integrated and consumers can successfully operate them. Without careful attention to usability, the users will be frustrated and confused, frequently selecting settings that result in unnecessarily high energy consumption. Some design principles already exist; these must be employed along with standardization of terms, symbols, and procedures where appropriate.

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