Usability of residential thermostats: Preliminary investigations

Alan Meier [a,*], Cecilia Aragon [a], Therese Peffer [b], Daniel Perry [b], Marco Pritoni [c]

[a] Lawrence Berkeley National Laboratory, Berkeley, California, USA
[b] University of California, Berkeley, California, USA
[c] University of California, Davis, California, USA

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ABSTRACT

Residential thermostats control 9% of the total energy use in the United States and similar amounts in most developed countries; however, the details of how people use them have been largely ignored. Five parallel investigations related to the usability of residential thermostats were undertaken. No single investigation was representative of the whole population, but each gave insights into different groups or usage patterns.

Personal interviews revealed widespread misunderstanding of thermostat operation. The on-line surveys found that most thermostats were selected by previous residents, landlords, or other agents. The majority of occupants operated thermostats manually, rather than relying on their programmable features and almost 90% of respondents reported that they rarely or never adjusted the thermostat to set a weekend or weekday program. Photographs of thermostats were collected in one on-line survey, which revealed that about 20% of the thermostats displayed the wrong time and that about 50% of the respondents set their programmable thermostats on "long term hold" (or its equivalent). Low-income families were visited and their thermostats photographed. Even though 85% of the respondents declared that they use programming features to automatically raise or lower the temperature, the photos indicated that 45% were in hold. Laboratory tests were undertaken to measure usability of thermostats. A measurement protocol was developed and a metric was created that could quantitatively distinguish usability among five thermostats. This metric could be used to establish minimum levels of usability in programmable thermostats and other energy-using devices with complex controls.

1. Introduction

Residential thermostats have been a key element in controlling heating and cooling systems for over sixty years. During this period, consumer expectations regarding the quality of the indoor thermal environment have increased. People expect thermostats, by controlling the heating and cooling systems, to carefully regulate temperatures, respond rapidly to changes in preferences or outside conditions, all with only infrequent input by the occupants. Modern, programmable, thermostats are typically marketed as "energy-saving" and consumers typically justify their purchase with this goal in mind.

Residential thermostats have been relatively ignored as a focus of research. This may be surprising given that they control 9% of the total energy use in the United States [1] and similar amounts in most developed countries. With such a large amount of energy in play, it is essential to understand the thermostat's technology and the way the occupants interact with them. Furthermore, thermostats themselves are undergoing a dramatic change in capabilities. Today's thermostats generally control only temperature; however, in the near future they may control ventilation and humidity, and take into consideration occupancy and the price of the energy. Finally, thermostats are being connected to the Internet and expanded networks inside homes, suggesting that controls are likely to become much more complex.

In 1995, the Energy Star Program established technical specifications for "energy-saving" programmable thermostats. Many building codes and government programs require installation of programmable thermostats because of their assumed energy savings. Nevertheless, there have been few careful studies of the energy savings attributable to these thermostats. Several recent field studies have found no significant savings in households equipped with programmable thermostats compared to households with manual thermostats [2–5]. Two other studies found that homes relying on programmable thermostats actually consumed more energy than those where the occupants set the thermostats manually [6], especially in homes equipped with heat pumps [7]. Anecdotal evidence suggested that the thermostats were overly complex and

* Corresponding author. Energy Analysis Department, Lawrence Berkeley National Laboratory, MS90R2000, Berkeley, CA 94720, USA. Tel.: +1 510 486 4740.
E-mail address: akmeier@lbl.gov (A. Meier).

that consumers were unable to operate them in a way that obtained energy savings compared to manually operated thermostats. As a result, Energy Star terminated the thermostat endorsement program in 2009.

We describe below the results from five parallel investigations related to the usability and actual use of residential thermostats. They focus on programmable thermostats because programmable thermostats now represent about 40% of thermostats in existing US homes and nearly 100% of thermostats in new homes. The studies were designed to assess the extent to which the occupants were able to successfully exploit the new features of programmable thermostats. None of the studies attempts to be comprehensive, yet each offers different insights into the way in which people interact with thermostats.

2. Earlier studies of thermostat usability in the literature

The performance of specific components − the furnace, compressor, heat exchanger, fan, etc. − of heating and cooling systems has been studied in great detail over the years. Curiously, the thermostat, that is, the control of the heating and cooling system, has received relatively less attention. A survey of the literature broadly dealing with thermostats was recently undertaken by researchers at Lawrence Berkeley National Laboratory [8].

The *usability* of thermostats has been the subject of even less research even though it is a popular complaint and topic for anecdotes. To be sure, thermostat manufacturers have undertaken research into the effectiveness of their designs, but the results have been mostly confined to proprietary reports. Manufacturers consider any insights gained through their usability studies to be a competitive advantage. Furthermore, manufacturers tend to focus on their own products rather than examining generic effectiveness of the devices.

Researchers have periodically commented about usability problems associated with thermostats both when specifically examining thermostats or in the course of other research. Table 1 summarizes the usability problems identified in the literature. Surprisingly few comments have been made over the past twenty years, especially compared to investigations of other components in heating and cooling systems.

An important concept is the mental model assumed by thermostat users. Kempton [24] used ethnographic methods to interview occupants and building supervisors to derive insights. For example, many occupants treated thermostats more like a valve rather than a switch. Thus, the occupants expected heat to be delivered faster when they set higher temperatures. This led to energy-wasteful operating outcomes because indoor temperatures would overshoot desired temperatures. (Our own research indicates that this remains a popular mental model [25].)

Table 1
Usability problems associated with programmable thermostats identified in the literature (Note: "PT" = Programmable Thermostat.)

Programmable Thermostats Complaints/Issues	References
PTs are too complicated to use	[9–18], [4], [19]
Buttons/fonts are too small	[10], [20], [12], [13], [21], [18]
Abbreviations and terminology are hard to understand; lights and symbols are confusing	[20], [12], [13], [16], [22], [18]
The positioning of interface elements is illogical	[20], [12], [18]
PTs are positioned in an inaccessible location	[16], [21]
Setting the thermostat is troublesome	[14], [17], [4], [21]
It is difficult to set time and date	[10]
PTs give poor feedback on programming	[16], [18]
PTs are not attractive to use	[23]

Problems with thermostats are not limited to North America and the unique heating systems found there. In Finland, Karjalainen [26] conducted qualitative and quantitative surveys on thermostat use in homes and offices. He concluded that many people had misconceptions about how thermostats and their heating systems actually operate (such as treating the thermostat as a valve rather than a switch) and that they found thermostats too complicated to use with confidence.

In the UK, Rathouse and Young [19], conducted six focus groups to investigate issues in use of heating controls. Based on the users' experiences and complaints, Rathouse and Young formulated recommendations for manufacturers and installers including that manufacturers offer a variety of products of different complexity to suit different needs.

Consumer magazines occasionally evaluate thermostats. Usability is typically one of the factors considered in the overall ratings. These evaluations generally took place in conditions where usability problems would be minimized. For example, when *Consumer Reports* [10] evaluated fifteen thermostats, the tests were conducted in a well-illuminated room, by highly-trained panelists comfortably seated at a table (a situation rarely encountered in homes). Even then, the panelists found some of the thermostats difficult to use. Consumer magazines in other countries, notably Germany [27] and Sweden [28] have also reviewed thermostats. Both investigations included usability as a consideration but only in a qualitative sense. Heating controls are somewhat different in Europe because the heating technologies are different; in addition, few residential systems include cooling.

In spite of the relatively sparse literature describing usability problems associated with thermostats, many attempts to design more usable thermostats have been undertaken by manufacturers, researchers, and students. In Human Factors courses at universities, designing a more user-friendly thermostat is a popular assignment. This is another indication of the observed poor usability of these devices. Nevertheless, few groups have tried to document the extent of poor usability before embarking on new designs.

There appears to have been an upsurge in activity related to designing new thermostats. Many small firms—often with roots in Silicon Valley—have entered the market. We attribute this to declining costs of key components (logic circuits, displays, and communications), expertise in design processes developed for smart phones, easier connections to the Internet, and the prospect of time-of-use pricing for electricity. Thermostats are also gradually becoming less like an appendage to the home's heating and cooling system and more like a new category of consumer electronics.

3. Field evaluations of programmable thermostats

3.1. Approach to evaluations

We undertook a wide range of studies to determine the extent to which occupants were able to successfully use the features of programmable thermostats. We chose them in order to learn what kinds of data could be collected, how useful a larger survey would be, and to give us insights to specific groups (such as low-income users). These studies included:

1. Personal interviews with people regarding their thermostat habits
2. An on-line survey
3. An on-line survey supplemented with respondent-supplied photographs of their thermostat
4. A survey of homes participating in a weatherization program
5. Laboratory tests of people's ability to perform tasks on thermostats