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# Thermostat Interface and Usability: A Survey

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**Environmental Energy Technologies Division**

**September, 2010**

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## Disclaimer

# Thermostat Interface and Usability: A Survey

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# Introduction

Thermostats have controlled heating and cooling systems in homes for over sixty years. The home thermostat translates occupants' temperature preferences into system operation and displays system conditions for occupants. In this position of an intermediary, the millions of residential thermostats control a huge amount of fuel and electricity consumption. In the United States, for example, residential thermostats control approximately 50% of household end energy use, which corresponds to about 11% of the nation's total energy use (Energy Information Administration (EIA), 2008). The technologies underlying modern thermostats are experiencing rapid development in response to emerging technologies, new demands, and declining costs. Energy-efficient homes require more careful balancing of comfort, energy consumption, and health. Coordinating these concerns requires new capabilities from thermostats, including scheduling, control of humidity and ventilation, and ability to respond to dynamic electricity prices. Future thermostats will increasingly join communication networks inside homes. For these reasons, the success of the thermostat as an interface between occupants and the home's environmental systems deserves investigation.

The first step in our research was to collect information about residential thermostats. It soon became apparent that the terms and symbols were an important aspect, partly because manufacturers and researchers had not settled on consistent definitions. For this reason we began by compiling a dictionary of terms, symbols, features, and icons associated with thermostats. We then investigated the history of thermostats so as to better understand their origins and relationship to heating, cooling, and other environmental controls. With this foundation, we focused on the previous research related to the technologies, effectiveness, and usability of thermostats. The review is organized to address questions that we believed were necessary to understand prior to beginning our own research. The goal of the literature review was not to answer the questions; rather, we sought to describe the type and range of research as well as key results. In this way, previous research and conclusions could inform our—and others'—research plans. In the process of collection and compilation, we believe that we have gained new insights which are presented in the context. Finally, we discuss how new and anticipated features will address some of the problems that have been observed as well as respond to new technical and economic imperatives.

The report is mostly organized to reflect these steps. However, the lists of features and symbols were moved to appendixes because of their unusual formatting requirements.

# History

## The First Thermal Controls[1]

Since the first fire was lit in a cave, heating and cooling for thermal comfort in dwellings has required human intervention. The Romans were among the first to move from the concept of a simple open fire to a central heating system, where hot air from a wood fire flowed through under-floor chambers. Because the fire required constant attention to remove ashes, add fuel (wood in small pieces), and control the fire to maintain a suitable balance of air flow and temperature, only the wealthiest could afford the staff (usually slaves) required to maintain the fire in a private residence.

Cornelius van Drebbel (born in 1572 in Alkmaar, Holland) is commonly credited with inventing the thermostat–automated temperature control in the form of a mechanical device. Van Drebbel was able to regulate the temperature of ovens and chicken incubators.

The reliance on inexpensive labor or slaves to heat homes was still in evidence for most of the nineteenth century. There were some early adopters of the residential thermostat, one of whom was H.L. Mencken, who wrote: "…Of all the great inventions of modern times the one that has given me the most comfort and joy is one that is seldom heard of, to wit, the thermostat." A key reason for his joy was that during the First World War, furnacemen took better paid jobs at shipyards. Consequently Mencken's house was never comfortable, and he had to tend his own coal furnace—dirty, back-breaking work. Upon installation of a gas furnace controlled by a thermostat, Mencken said, "I began to feel like a man liberated from the death-house. I was never too hot or too cold. I had no coal to heave, no ashes to shift. My house became so clean I could wear a shirt for five days. I began to feel like work, and rapidly turned out a series of imperishable contributions to the national letters. My temper improved so vastly that my family began to suspect senile changes." Mencken clearly saw the thermostat as a device of liberation in the same way that automatic washing machines, dishwashers, vacuum cleaners, and refrigerators have removed much of the burden of household labor.

## Early Modern History

Modern thermostat history in the U.S. revolves around a couple of companies who are still in the business of building thermal controls today: Johnson and Honeywell. In 1883, Warren S. Johnson (of Johnson Controls) received a patent for the first electric room thermostat. Upon his death in 1911, Johnson Controls focused on temperature controls for nonresidential buildings only. At almost the same time in 1885, Albert Butz developed a furnace regulator that used a "damper flapper" to control air entry (and thus heat output) to a furnace. His company, the Electric Heat Regulator Co., eventually became Honeywell Inc. In 1906, Honeywell produced the first automatic programmable setback thermostat. It used a clock to turn the temperature down at night and up in the morning. The first anticipator thermostat was produced in 1924. The anticipator regulates the furnace heating cycle time by reducing overshoot at the end of furnace cycles.[2] The first modern thermostat is the ubiquitous Honeywell Round which emerged in 1953 (Figure 1), and is still available today. By 1960, typical

[1] These first two sections were adopted from earlier work written by one of the authors (Meier & Walker, 2008).

[2] When a furnace is on, an electric current passes through the bimetallic coil of the thermostat. The resulting heating and expansion of the bimetallic coil makes the furnace turn off before the thermostat reaches the set temperature. Hence electromechanical anticipators account for increases in room temperature due to residual heat in the furnace and ducting and the time lag. Modern thermostats perform this task with a digital signal.

thermostats had heating and/or cooling control (COOL-OFF-HEAT) as well as fan control (AUTO-ON).


Figure 1: From left: a Honeywell Round thermostat, a Honeywell setback thermostat, and a Lux programmable thermostat. (Source: http://www51.honeywell.com/honeywell/about-us/our-history.html, T.Peffer , http://www.luxproducts.com/thermostats/hp2110.htm)

## Programmable Thermostats[3]

In 1978, the first energy code in California required clock or setback thermostats (Figure 1) for new homes. Programmable thermostats (PTs) can be programmed on a timed schedule to lower the temperature at which the heating system turns on (or conversely, raise the temperature setpoint at which the air conditioning system turns on) at night or when the building is not being used. Part of the 2008 California Building Energy Efficiency Standards, commonly referred to as Title 24, requires that PTs have the ability to set temperature preferences for at least four different time periods per day. These changes in temperature setpoints are intended to reduce the time during which the heating and cooling equipment are operating (cycle time), and thus save energy. By the mid-1980s, the “modern” look for thermostats was a plastic rectangular box with digital display and push buttons for programming. The analog display that provides a visible scale of temperatures was replaced with digital numbers. The Americans with Disabilities Act (ADA) guidelines prohibited devices which require the twisting of one’s wrist. In response to this requirement, thermostat manufacturers replaced the more haptic and intuitive Honeywell Round interface with push buttons and simple slider bars. Throughout the 1990s programming grew more complex, with seven-day programming, override, and hold functions. In the 1990s, the ENERGY STAR label was introduced to help consumers purchase energy efficient equipment. To qualify for an ENERGY STAR label, the appliance must comply with ENERGY STAR eligibility requirements. For programmable thermostats, these requirements included certain features: default energy-saving and comfort setpoint temperatures, cycle rate setting, recovery systems, and a hold or override option. Table 1 lists the default temperature setpoints and period labels.

[3] The next three sections borrow extensively from one author’s previous writing (Peffer, 2009).

| Table 1: Programmable Thermostat Setpoint Temperatures | | |
|---|---|---|
| **Setting** | **Setpoint Temperature (Heat)** | **Setpoint Temperature (Cool)** |
| Wake | ≤70°F | ≥78°F |
| Day | setback at least 8°F | setup at least 7°F |
| Evening | ≤70°F | ≥78°F |
| Sleep | setback at least 8°F | setup at least 4°F |

Table 1: ENERGY STAR Thermostat Setpoints (Environmental Protection Agency (EPA), 2007)

In the last few years, manufacturers have pursued a number of strategies to create easy-to-use thermostats, as shown in the following examples:

- Carrier brought in the design expertise of IDEO—the design firm that developed the first Apple computer mouse—to create the Infinity thermostat for their top-of-the-line residential HVAC systems.
- The NightBreeze thermostat, from the Davis Energy Group, was another attempt to improve on aesthetics while adding night ventilation control.
- A few thermostat manufacturers feature voice-controlled thermostats, intended for easier programming.
- In general, the newer models of thermostats boast larger liquid crystal display (LCD) screens, some with touchscreen capability. White-Rodgers offers simple colors on their touchscreen display 90 series™ Blue thermostat.
- Outdoor temperature display with a wireless sensor is available on the White-Rodgers Blue thermostats.
- Internet-linked thermostats allow PC-based controls via web interfaces.

New features include zonal control, where heating, cooling, ventilation, and/or humidity levels can be controlled separately in different rooms or areas in a house. Residents can also control their thermostat remotely via the telephone or Internet. The AMX ViewStat communicating thermostat can receive price or emergency signals from the electrical utility and boasts a full color display as well as a paintable surface.


Figure 2: From left to right: Carrier's Infinity thermostat, NightBreeze thermostat, and White-Rodgers Blue thermostat (Source: http://www.residential.carrier.com/products/controls/infinity.shtml, http://www.davisenergy.com/technologies/nightbreeze.php, http://www.emersonclimate.com/en-US/products/thermostats/Pages/thermostats.aspx)

## Networked Thermostats

A networked thermostat communicates within or outside the home to systems other than the HVAC system. In the last ten years, many U.S. utilities have deployed pilot projects including programmable communicating thermostats (PCTs) in order to explore the opportunities and challenges associated with implementing residential and commercial demand response programs. A PCT can communicate with a default one-way statewide demand response communication system that utilities will use to notify customers of price events and emergencies (Gunther, 2007). In addition, the customer has the ability to set heating and cooling offsets during price events; the defaults are set for +4ºF for cooling, and -4ºF for heating. The original proposed policy for the 2008 California Title 24 stipulated that the customer would be allowed to override the offset for price events, but not allowed to override the utility-specified temperature setpoint or offset during an emergency event to avoid blackouts (ibid). The utility override was subsequently removed in response to public input—reflecting a "Big Brother" interpretation by the public.

In the last several years, the growing prevalence of cell phones, home area networks (HAN), and the Internet in residences has promoted the use of remote control devices as well as Internet-enabled thermostat control. Several applications have been developed to enable control of a thermostat using a cell phone (Figure 3). Global Positioning Systems (GPS) in cell phones have been used to convey occupancy to smart thermostats, which can then predict arrival times of a home's occupants and modify the setpoint accordingly (Gupta, Intille, & Larson, 2009). An "Internet thermostat" describes a programmable thermostat that connects to an IP (Internet Protocol) network; models are currently being made by Proliphix, Aprilaire, and Ecobee (Figure 3). Internet connectivity has spawned companies such as EcoFactor, which sells an energy-saving thermostat service. Further, companies such as Control4 who specialize in home automation, have added a comfort function to their home management interface to remotely control an Internet thermostat (Figure 4) from the TV or other display.


Figure 3: From left: iPhone app for thermostat control, and an Ecobee Internet thermostat
(Source: http://www.smarthome.com/iphone_thermostat_control.html, http://www.ecobee.com/product/smart-overview/)


Figure 4: Control4 home automation interface
(Source: http://www.control4.com/commercial)

## In-Home Energy Displays

With the deployment of smart meters in California and Europe, many manufacturers now produce in-home energy displays (HED). Indeed, new meters allow quicker and more detailed communication with utilities and provide information on users' energy consumption almost in real time. By gathering information from the new meters or from alternative energy detectors, the HEDs provide clearer feedback to the users. Most of them show only the total electricity use, but some show

also the energy consumption of single appliances (i.e., AC systems) and gas consumption (i.e., gas furnaces used for space heating). We will discuss the importance of feedback in a following section. Several HEDs provide web-based energy displays, such as GreenBox Technology, Tendril Network's TREE system, and Lucid Design Group's Building Dashboard. Both a Whirlpool study (Stein & Enbar, 2006) and recent studies in Europe (Van Elburg, 2008) indicate that most people prefer a dedicated display device rather than a web page on their computer. The PowerCost Monitor by Blue Line Innovations is a nice example of a simple aesthetic display with minor graphics. The Energy Detective has slightly more complex functionality, including both monthly and daily energy and cost information, as well as a projected energy bill. A few displays are geared towards demand response price alerts by displaying different colors, such as The Energy Joule by Consumer Powerline and the In-Home Display by AzTech (Figure 6). Only a few have bar graph displays instead of numbers (such as the EMS-2020 and the EcoMeter). A new display called the PowerPlayer provides a simple aesthetic display, with the ability to set a goal, such as a monthly budget, and shows progress towards that projected goal. Some displays do not include numbers at all but rely on colors, movement, or animation to convey energy consumption, reward conservation, or alert a person to price changes. A recent review by Stein and Enbar (Stein & Enbar, 2006) includes a few innovative displays, such as changing wallpaper or an animated bunny (ibid). The TellEmotion Green Lite system uses an animated polar bear on an iceberg that reacts to real-time energy usage to encourage and reward conservation (Loeb, 2009). In general the trend seems to be toward designs which appeal to consumer's aesthetics, following popular consumer electronics. As displays become cheaper, we see larger displays, graphics, and color.


Figure 5: The Energy Joule, AzTech and PowerPlayer energy displays
(Source: http://www.ambientdevices.com/products/energyjoule.html, http://www.generalpacific.com/services/metering/aztech-in-home-display, Home Automation Europe brochure (2008) )

## Concluding Remarks Regarding the History of Thermostats

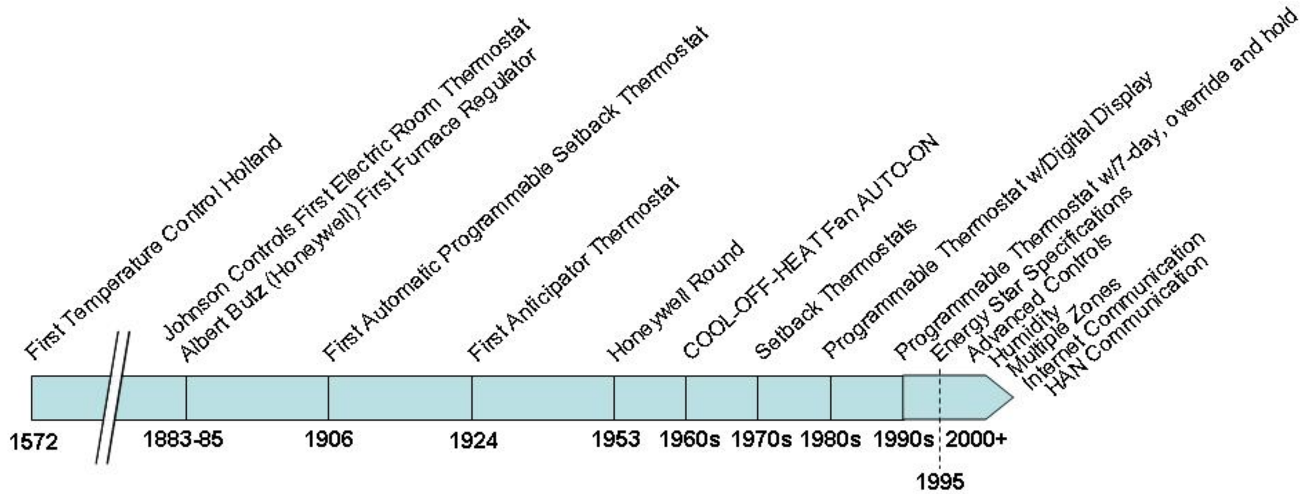


Figure 6: Timeline of thermostat development

The capabilities and sophistication of residential thermostats slowly expanded for the first century of their use. However, the last decade has seen the rapid acceleration of thermostat development (Figure 6). Thermostats not only control temperature; they are evolving towards a new type of consumer electronics and away from an appendage to a heating system. Thermostat functions will increasingly overlap with other devices such as home energy displays, computers, and mobile phones. Moreover, thermostats will be tied increasingly to building networks, which will provide better information about occupancy, activity, preferences, and other relevant conditions (e.g. if windows are open, no forced ventilation is needed), in service of saving energy.

# Thermostat Architecture and Features

A thermostat is a device that regulates and maintains the temperature of a system near a desired setpoint. In most cases the thermostat does this automatically by switching heating or cooling devices on until a target temperature is reached, then switching the system off. A programmable thermostat can adjust the temperature according to a series of programmed settings that take effect at different times of the day. The thermostat also provides feedback by confirming the temperature setpoint, current temperature, and the daily and weekly schedule chosen by the users. The goal is to provide thermal comfort and save energy by minimizing HVAC operation when not needed.

## Basic architecture of a programmable thermostat


Figure 7: Programmable Thermostat
(Source: http://yourhome.honeywell.com/home/Products/Thermostats/7-Day-Programmable/RTH7500D.htm, M.Pritoni)

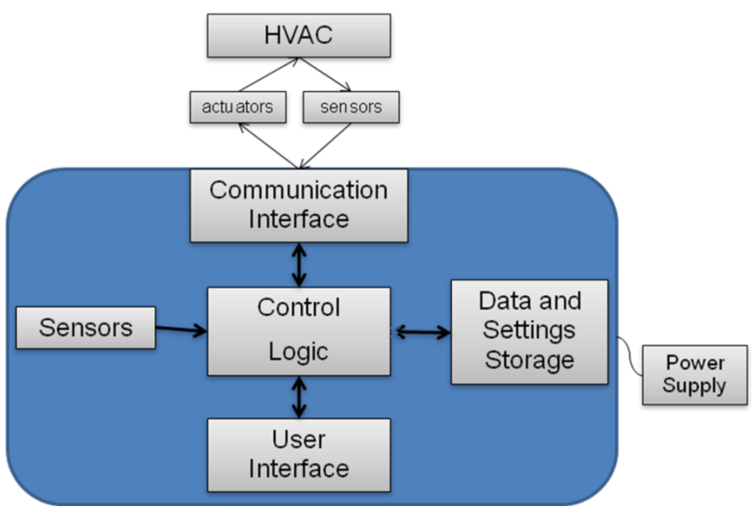


Figure 8: Programmable Thermostat architecture

The basic architecture of a thermostat and its logical components are shown in Figure 8 and described below:

1. *User interface*: The user interface (UI) is the input/output system for controlling the thermostat. In most cases it is the only part visible to the users. The UI allows users to choose settings and input preferences while providing feedback, such as current temperature, set temperature, and time of the day. The thermostat interface can be mechanical, digital with buttons, or digital with touchscreen. New interfaces such as web interfaces, mobile interfaces, TV interfaces, audio, and remote controls will be described later.
2. *Sensors*: For basic functioning of a thermostat, only a room temperature sensor is needed. Additional sensors could monitor humidity, outside temperature, or occupancy.
3. *Data and settings storage*: Data can be stored in permanent or volatile memory. These data, such as time of the day and target temperature for each program, are needed for the thermostat logic to operate correctly.
4. *Communication interface*: At a minimum, a thermostat must be able to communicate with the HVAC, generally through wired connections. Further capabilities may allow communication with additional devices such as appliances, gateways, HEDs, smart meters, etc. using various protocols. These topics will be briefly described later.
5. *Control logic:* Control logic is the set of algorithms that determines when the system switches on and off. Data is read from settings, user interface, and sensors. From this information, the control logic activates the HVAC system to reach the desired temperature.
6. *Power Supply:* Digital thermostats require electric power for operation; this can be provided with batteries or a connection to mains power (typically through some sort of power supply to reduce the voltage). Thermostats often employ both systems, using the batteries to preserve settings in the event of power outages or other failures.

We found over 150 different features that have been developed by manufacturers and are currently available on the market. The next section will describe the main feature categories related to the user interface; a complete list of features is included in the Appendix B.

## User Interface

This section describes different thermostat interfaces and their associated inputs (controls) and outputs (displays). We try to identify the different thermostat modes of interaction that are available. Multiple modes are present when the same user input (for instance the same button press) produces different results depending on some other selected parameters (for example, switching modes from RUN to SET Time). We describe progressively more complex thermostat interfaces and show how the added features make the interfaces less intuitive. The types of thermostats discussed below are: mechanical thermostat (not programmable), mechanical clock setback thermostat, programmable thermostat with buttons, programmable thermostat with touchscreen. Another common thermostat not discussed is a digital thermostat (with respect to controls and display) that is not programmable.

## Mechanical NON-PT

A mechanical thermostat (Figure 9) allows control of heating/cooling and ventilation systems. It has no clock function, and therefore is not a setback or programmable thermostat; thus the temperature must be manually changed whenever a different temperature is desired (e.g., at night or during unoccupied periods). Nevertheless, this thermostat is simple and intuitive, as each control has only a single function and there is only one mode related to the status of the thermostat. Moreover, the controls are positioned in the same location as the label showing the related information (for example, the fan controls also indicate the current fan status).

Modes: 1

Features:

- Info Displayed: 4
  - System operation (cool, heat, off)
  - Fan operation (on, off, automatic)
  - Current temperature
  - Target temperature
- Controls: 3
  - System operation (cool, heat, off) control (lever)
  - Fan control (lever)
  - Target temperature adjustment (knob)

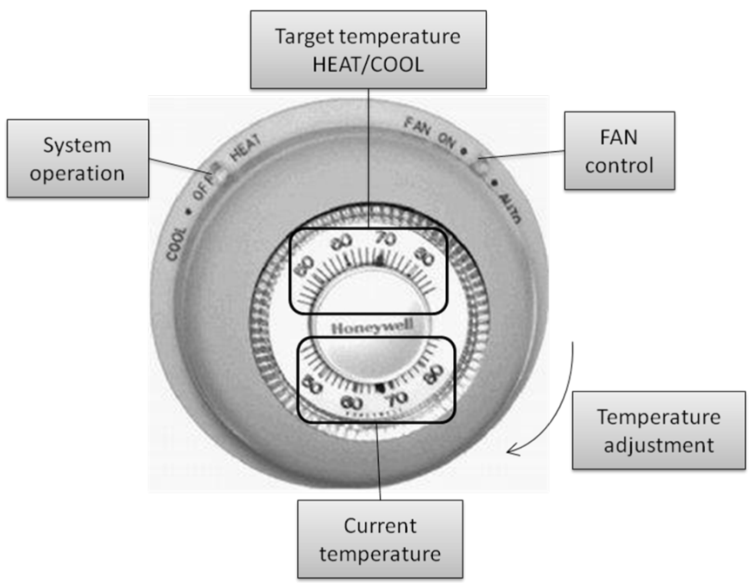


Figure 9: Mechanical NON-Programmable Thermostat Interface
(Source: http://compare.ebay.com/like/290465804506?ltyp=AllFixedPriceItemTypes&var=sbar, M.Pritoni)

## Mechanical PT (Setback)

A mechanical clock setback thermostat adds a primitive time control that typically allows two programs per 24-hour day, one for the occupied period during the day and a setback temperature for the night/sleep period. While some models have the time control on the front of the thermostat, the

model shown in Figure 10 has the clock hidden inside the cover. The same program is repeated each day. More sophisticated mechanical clock thermostats may allow four or more periods to be set per day. Usually, only two distinct temperatures—for comfort and for setback—can be set, even if multiple periods are permitted. The user selects these temperatures simply by sliding two levers along an analog temperature scale, in much the same manner as a non-PT mechanical thermostat. This design, while simple to manufacture and relatively easy to program, sacrifices comfort on weekends since the identical program is repeated each of the seven days of the week without variation. To overcome this deficit, a pushbutton is sometimes provided to allow the user to explicitly switch (once) the current period from one setpoint to the other. The usual use of this button is to override a setback that takes place during the workday when the home is normally unoccupied.(Wikipedia, 2010)

- Modes: 2 (1 hidden)
- Features:
  - Info Displayed: 6 (one inside cover)
    - System operation (cool, heat, off)
    - Fan operation (on, off, automatic)
    - Current temperature
    - Comfort and setback temperature for heating
    - Comfort and setup temperature for cooling
    - (Time period settings)
  - Controls: 5 (one hidden)
    - System operation (cool, heat, off) control (lever)
    - Fan control (lever)
    - Comfort and setback target temperature control (lever)
    - Comfort and setup target temperature control (lever)
    - (Time periods) (wheel control)

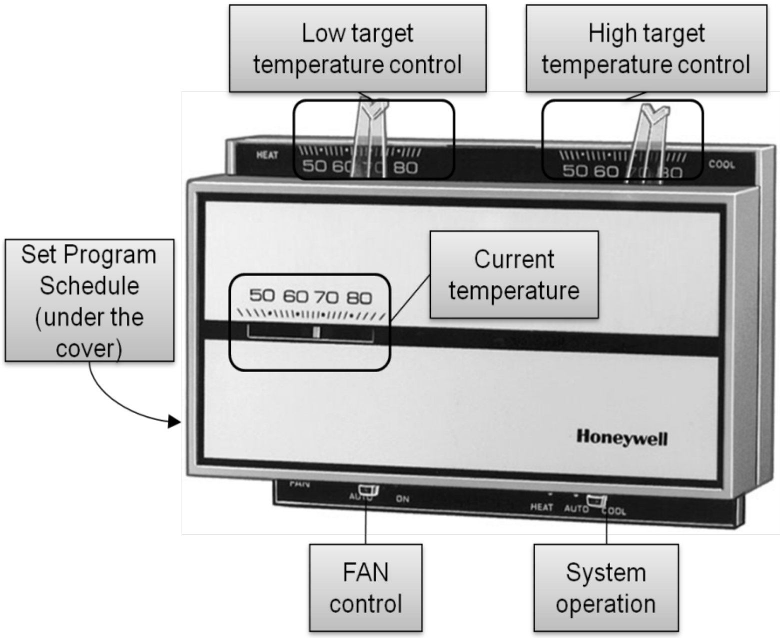


Figure 10: Mechanical Setback Thermostat Interface
(Source: http://www.iaqwholesale.com/index.php?main_page=popup_image&pID=2815)

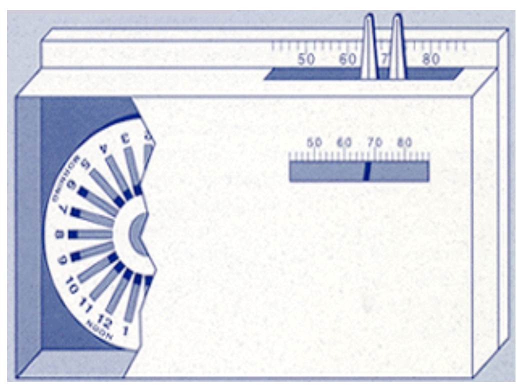

Figure 11: Schematic of clock mechanism hidden behind cover
(Source: (National Renewable Energy Laboratory (NREL), 2010))

## Digital PT with Pushbuttons

Digital PTs with pushbuttons have been available in the marketplace for more than two decades, and basic models are very affordable. Usually these PTs allow users to set different temperatures for two to four periods per day. Most of them also have a function to temporarily override the programmed temperature, and restore the normal settings when the next period begins. Another typical function is the hold function, which allows the user to disable the programmed temperature and specify a temperature which remains until the hold is released by the user. Figure 12 shows a digital PT with buttons. In this particular model, the four daily programs can have different

settings during weekdays, Saturday and Sunday (these PT are commonly known as 5+1+1). Notably, this PT has five modes and eight controls, with different functions depending on the selected mode. The text displayed on the LCD display also varies in different modes. Note that the cover has a plastic device that does not allow the cover to be closed unless the dial is set to run mode. The complexity of this interface is much higher compared to the previous devices.

- Modes: 5
  - RUN
  - SET day/time
  - SET weekday program
  - SET Saturday program
  - SET Sunday program
- Features:
  - Info Displayed: 9 (three inside the cover)
    - (System operation (cool, heat, off, emer))
    - (Fan operation (on, automatic))
    - (Mode)
    - System operation (cool, heat) text in the display
    - Target temperature
    - Time of day
    - Day of the week
    - Change battery indicator
    - Hold indicator
  - Controls 8 (seven hidden)
    - (System operation (cool, heat, off, emer) control (switch))
    - (Fan control (switch))
    - Temperature control (up and down buttons)
    - (Mode change control (dial))
    - (Hold button)
    - (Go to next program button)
    - (Reset button)
    - (Review schedule button)
- Note: This model does not display the current temperature in the RUN mode. (check)

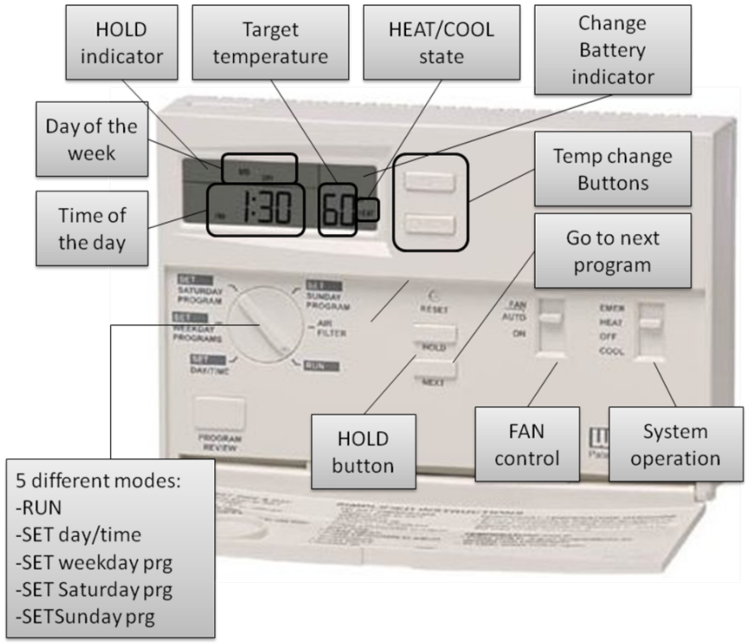


Figure 12: Digital Programmable Thermostat Interface (buttons)
(Source: http://www.luxproducts.com/thermostats/hp2110.htm, M.Pritoni)

## Digital PT with Touchscreen

Touchscreen thermostats use the display as a combined input and output device. Touchscreen PTs typically use menus to list options, while labels and locations of touch buttons change with the mode. A touchscreen provides the user interface with more flexibility than a pushbutton PT. An example of touch screen is provided in Figure 13. Only some options are visible in the interface at a given time, while most of them are hidden (compare Figure 13 and Figure 14). Further, several other configuration options (40 in this model) are activated using numeric codes. These options are likely to be accessed infrequently, however they are impossible to find without the manual. As an example, the Features and Controls described below are available in RUN mode.

Modes: several (use of menus and touchscreen make definition of modes difficult)
- RUN
- SET day/time
- SET program for each day (temperature and time)
- SET target humidity
- (Configuration modes ~40)

Features:
- Info Displayed: 12 in RUN mode
  - System operation (cool, heat, off, auto)
  - Fan operation (on, automatic, program)
  - System status (on in one zone, on in multiple zones, off)
  - Target temperature
  - Current temperature
  - Current humidity
  - Day of the week

Change battery indicator
Hold indicator
Temporary override indicator
Keyboard lockout indicator
System failure indicator

Controls: 5 in RUN mode (others are available in other modes)

System operation (cool, heat, off, auto) control
Fan control
Temperature control x2 (up and down buttons)
Schedule Menu

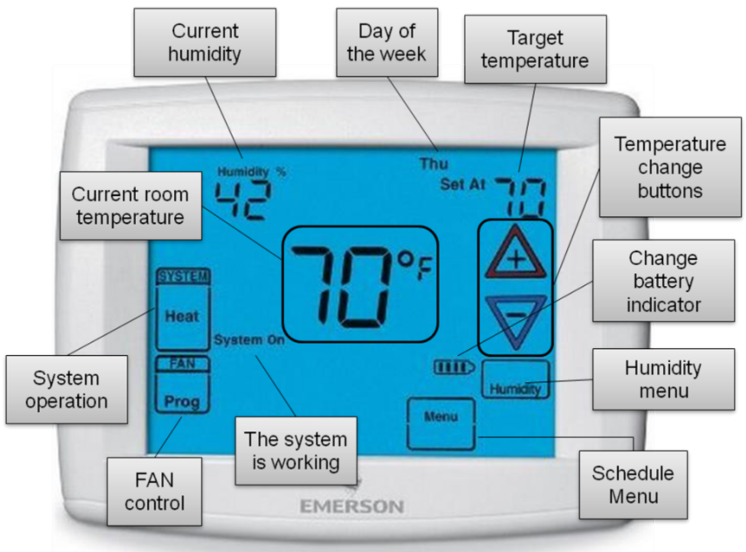


Figure 13: Digital Programmable Thermostat (touchscreen)
(Source: http://www.emersonclimate.com/en-US/products/thermostats/Pages/programmable_universal_thermostats.aspx)

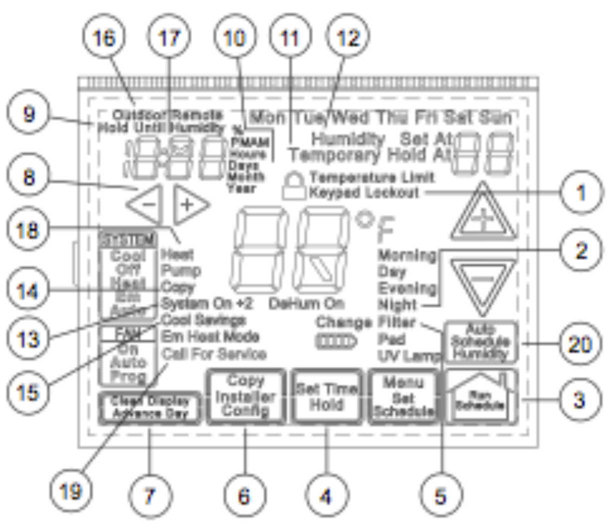


Figure 14: Digital Programmable Thermostat (touchscreen), list of all functions

(Source: White-Rodgers 1F95-1291 Installation and Operating Instructions Manual at http://www.emersonclimate.com/en-US/products/thermostats/Pages/programmable_universal_thermostats.aspx)

The present analysis includes only traditional wall mounted interfaces, but new interfaces such as web or mobile interfaces will be briefly described in a following section. A more detailed overview of current features implemented by thermostat manufacturers is available in Appendix B, while a list of standardized icons is shown in Appendix C.

## Programming Functions

The thermostat regulates the HVAC operations with control logic. The user enters his or her preferences into the thermostat's control logic via programming functions. The minimum set of information necessary is:

- Date
- Time of day
- Program (schedule and desired or target temperatures for heating and/or cooling as in Figure 15)

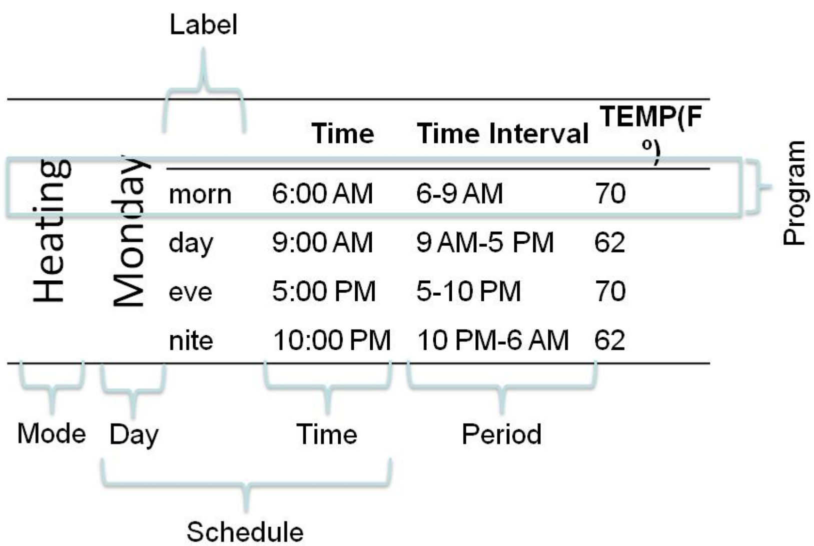


Figure 15: Program Terminology

### Automatic/Default settings:

Most modern PTs have pre-set programs, as shown in Table 2. The ENERGY STAR program mandates–or did until the program was terminated–only the setback and setup differentials, not the time schedule. Consequently each manufacturer was able to implement different schedules and different temperatures, and still conform with the requirements to qualify for ENERGY STAR endorsement.

| | PERIOD | HEAT | COOL |
|---|---|---|---|
| WEEKDAYS preprograms | MORN<br>DAY<br>EVE<br>NITE | 6:00 AM 70°<br>8:30 AM 60°<br>3:00 PM 70°<br>11:00 PM 65° | 6:00 AM 75°<br>8:30 AM 85°<br>3:00 PM 75°<br>11:00 PM 80° |
| SAT & SUN preprograms | MORN<br>DAY<br>EVE<br>NITE | 6:00 AM 70°<br>6:15 AM 70°<br>3:00 PM 70°<br>11:00 PM 65° | 6:00 AM 75°<br>6:15 AM 75°<br>3:00 PM 75°<br>11:00 PM 80° |

Table 2: Example of Thermostat Programs

A few thermostats that we reviewed automatically update time and date using radio synchronization.

## Program Capabilities

Newer PTs generally have four daily periods and can be equipped with different schedule capabilities:

- repeat the same setting every day (1-day programming),
- have different settings for the weekdays and weekend (5+2 programming),
- have different settings for weekdays, Saturday and Sunday (5+1+1), or
- have different settings for all the days of the week (7-day).

We also found a few PTs that allow different programs for each day of the year (366-day programming).

## Entering Program Settings

The PT interfaces typically do not display an overview of the settings as represented in Table 2, instead they display fragments that the user can view sequentially.

Let's imagine starting to configure a heating program for the first time. The information we enter is the schedule (day and time) and the temperature for each period of the day. We want to warm up the house from 6:00 am to 8:30 am (70ºF), then we want to reduce the heating (60ºF) from 8:30 am till 5:30 pm, because nobody is at home. Then we want the home to be warm again starting from 5:30 pm until 10:00 pm (68ºF). During the night, from 10:00 pm to 6:00 am, we reduce the temperature (62ºF) while in bed asleep.

The typical interface of a digital PT with buttons (the most common type) in program mode is displayed in Figure 16. In this example one button is used to move between time and temperature, one to go to the next period and the two arrows to increase or decrease the parameter. The parameter under revision keeps flashing until the system exits from the setting mode. Buttons are generally multi-functional, performing different functions according to the current mode.

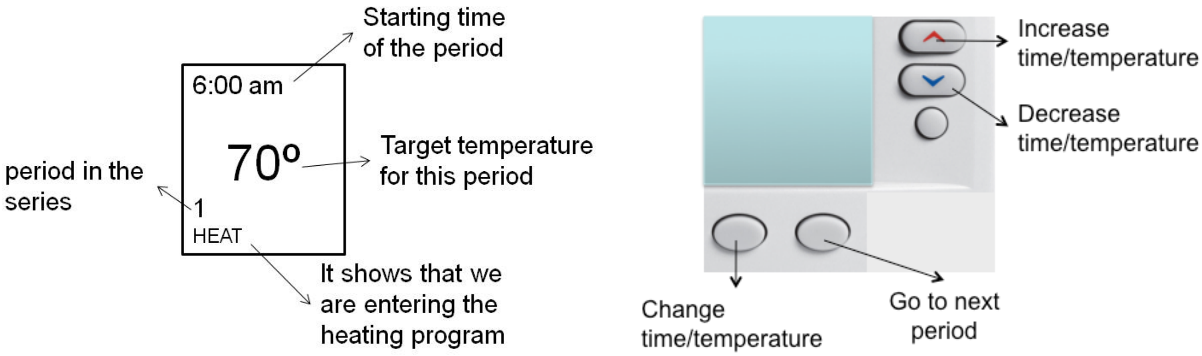


Figure 16: Program mode, setting one period

Notably, in Figure 16

- It is possible to see only the starting time of the period (e.g. 6:00am), not the ending time (e.g. 8:30am); consequently it is difficult to know the duration of the period for which we set a temperature.
- Periods can be indicated in different ways (1, 2, 3, 4 or morn, day, evening, nite, wake, leave, away, home, sleep, dawn, dusk occupied, unoccupied, etc…), depending on manufacturer and model.
- HEAT in different modes has different meanings. For instance, in this example HEAT means we are entering the settings for heat (we might set them any time of the year), while in run mode it means that the heating system is activated (switch is set to Heat mode) and/or is currently on (furnace is running).

All the periods of the day can be set in the same way as shown in Figure 17, navigating through periods with buttons. In most of the PTs we surveyed, navigation is possible only in the program mode; put another way, every time you review your programs you can accidentally change them. A few thermostats had a review mode or a confirmation button to avoid mistakes.

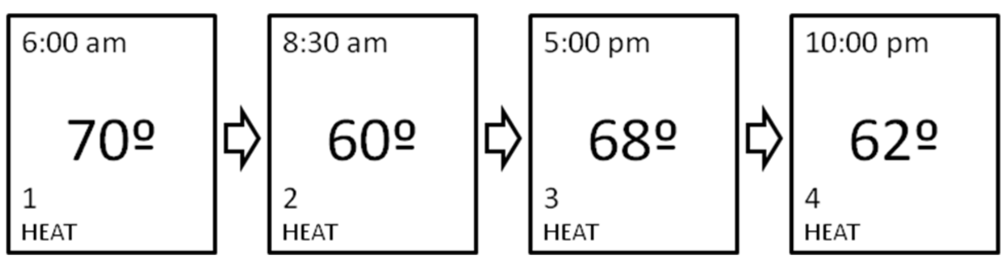


Figure 17: Program mode, setting one day

Few PTs display a global overview of the daily-weekly programs in a single screen as shown in Table 3; however, one example with global overview is shown in Figure 18.

| Time | TEMP(F°) |
|---|---|
| 6:00am | 70 |
| 8:30am | 60 |
| 5:00pm | 68 |
| 10:00pm | 62 |

Table 3: Programs Overview

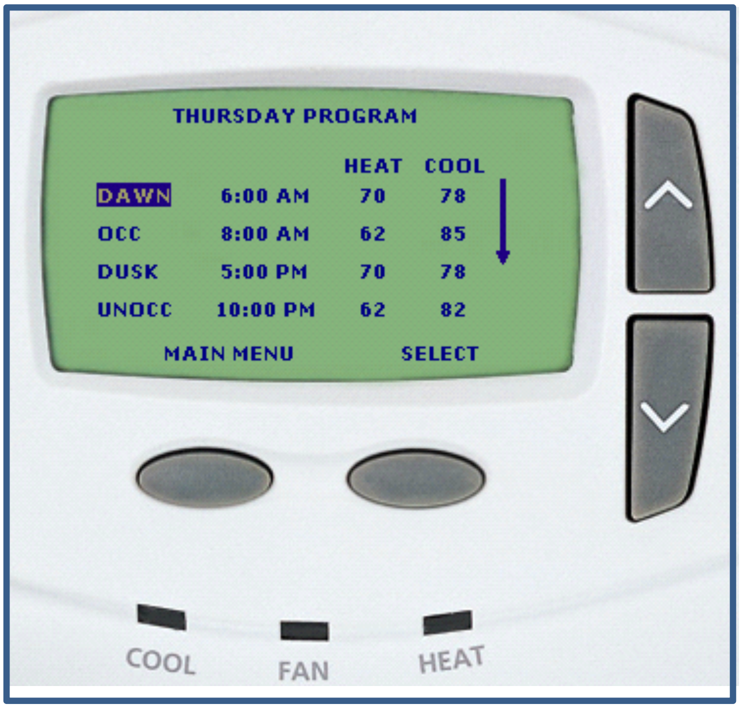


Figure 18: PT showing an overview of programs
(Source: http://www.about-i-series.com/9900i/default.asp?languageID=1#)

A summary or overview feature would be useful because it is very difficult to understand the global settings of the system from a single screenshot (Figure 16). An overview feature would clarify the status of the settings and would probably increase user confidence, thus facilitating selection of energy-saving features. Indeed, several manufacturers try to provide this overview--their user manuals include a table to show the default settings (Table 2) and a blank table to help users to create their own programs. Alternatively, a global overview could be presented graphically (Figure 19) or as a calendar (Figure 20); both representations could help users quickly grasp the whole range of settings.

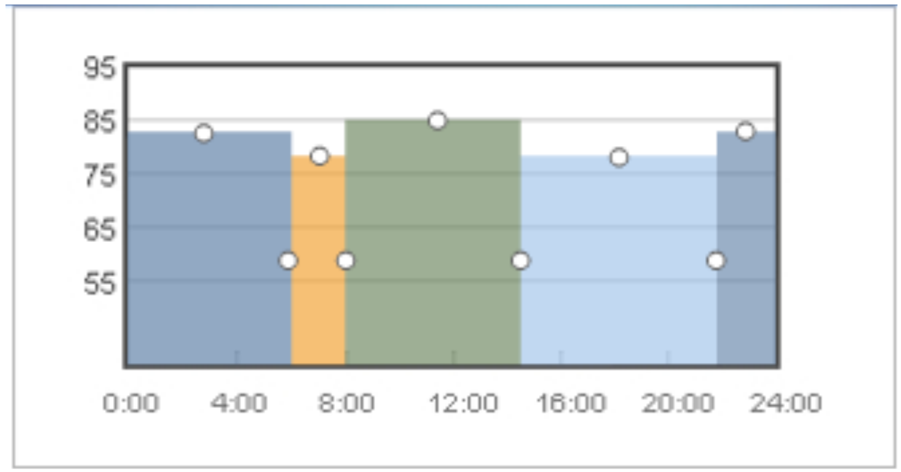


Figure 19: Programs Overview, Graphical Representation
(Source: http://www.ecobee.com/product/smart-portal-features/today)

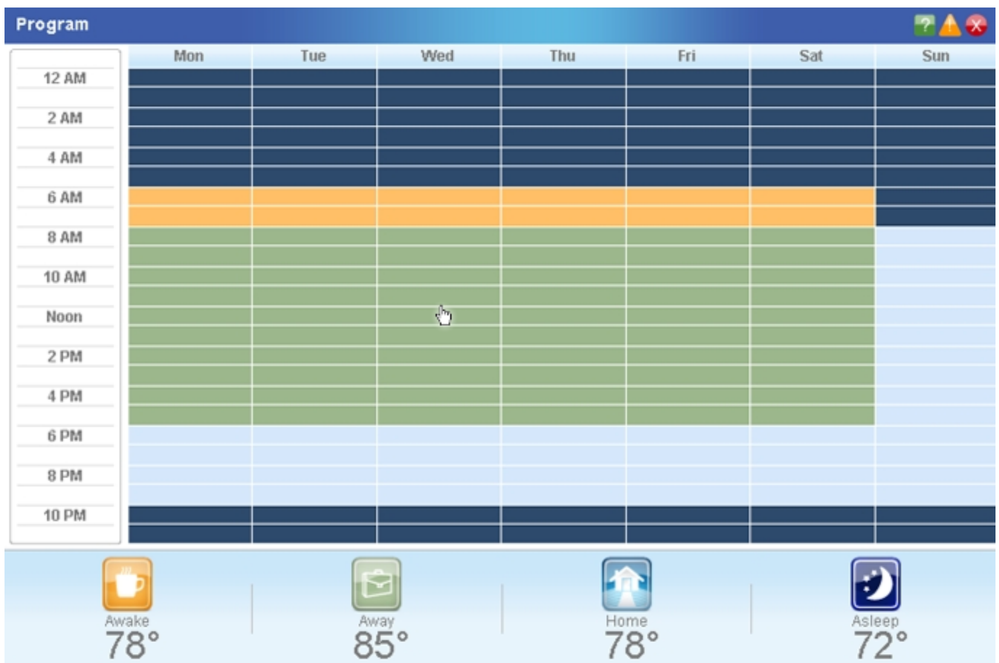


Figure 20: Programs Overview, Calendar Representation
(Source: http://www.ecobee.com/product/smart-portal-features/program)

All overviews have limitations when the thermostat controls both heating and cooling and uses different programs for each day of the week (Figure 21).

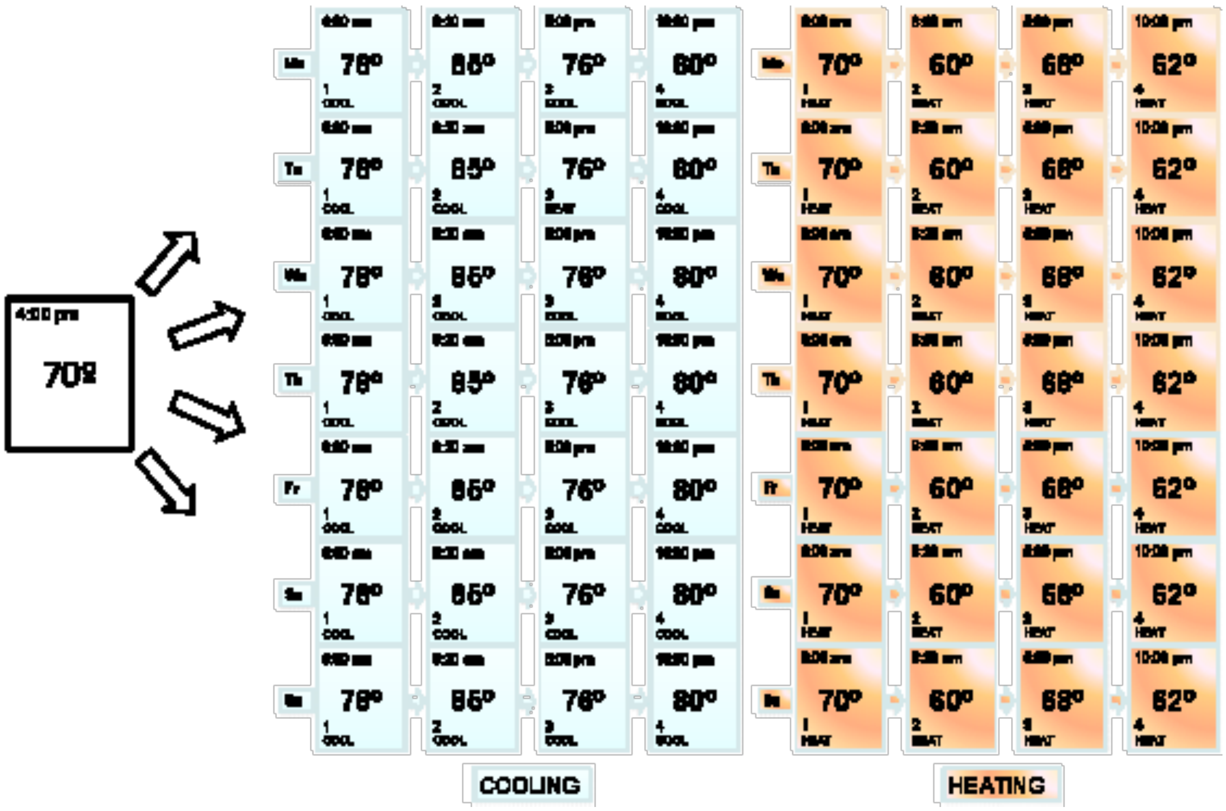

Figure 21: Steps to program a 7-day, heating and cooling thermostat

An increasing number of thermostats incorporate 7-day programs, allowing fine-grained and flexible settings, but it appears that not much attention has been paid to the visual representation of this set of data.

## Other climate controls interfaces

Heating and air conditioning controls have been used in many other applications in addition to buildings. In cars, for instance, for many years the climate controls were not thermostatic. Almost universally, three simple knobs controlled direction, flow, and mix of hot/cool air. Even though keeping a constant temperature inside the car was not easy with this system, these controls were universally understood and easy to operate especially while driving. An example of these controls is provided in Figure 22. One value of this simplified interface is that people interact with their devices because they want to be warmer or cooler. One might argue that since thermal comfort varies with clothing and activity level and over the day and seasons, typical household thermostats are overly number-centric in providing comfort.


Figure 22: Car Traditional Climate Control
(Source: http://www.craigt.co.uk/blog/?p=284)

More sophisticated forms of air-conditioning controls have been installed to allow the temperature of a car's interior to be more accurately controlled (Figure 23). With this system a user can set the desired temperature and the system automatically adjusts the speed and amount of cold air introduced into the cabin. Car thermostats do not need to be programmed (in terms of time) to provide good comfort, thus significantly simplifying the interface.


Figure 23: Car Thermostatic Climate Controls
(Source: http://www.familycar.com/ac1.htm)

# Research Questions

The remainder of this literature review focuses on programmable thermostats (PTs). This choice is based on three major observations: 1) PTs are the latest significant technological evolution in the field of thermostats with a broad market diffusion (Energy Information Administration (EIA), 2005), (California Energy Commission (CEC), 2004); 2) engineering calculations predict that PTs can lead to notable energy savings (Al-Sanea & Zedan, 2008; Nelson & MacArthur, 1978), and for this reason EPA and DOE endorsed their adoption (i.e., ENERGY STAR labeling); and 3) a growing body of studies have focused on PTs in the last two decades. We discuss certain issues concerning the diffusion, usage, and efficacy of these devices by formulating research questions and analyzing how they have been addressed in the available literature.

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

### Diffusion of PTs

The previous sections described three types of thermostats: mechanical or manual thermostat (rectangular or similar to the Honeywell round), clock setback thermostat (can automatically change the setpoint at night), and programmable thermostat (can automatically change the setpoint at night and day).[4] In the 2005 Residential Energy Consumption Survey (RECS), 14% of U.S. households reported having no thermostat, 30% (34.6% of thermostat owners) had a programmable thermostat (PT), and 56% had a manual thermostat[5] (Energy Information Administration (EIA), 2005). According to the American Home Comfort Survey, 36% of households had programmable thermostats in 2004, and the percentage increased to 42% in 2008 (Decision Analyst, 2008). In California, the 2005 RECS reported 19% of households with no thermostat, 44% (54% of thermostat owners) with a PT, and 37% with a manual thermostat. The percentage of houses in California without thermostats differed from the national percentages probably mostly due to milder weather, whereas the increased number of PTs in California versus nationwide may have been due to the last 30 years of energy code requiring a setback or PT. Of those that used central air conditioning in California, 68% had programmable thermostats; this most likely reflected the fact that homes built in the past 30 years were more likely to have central air conditioning. The Residential Customer Characteristics Survey 2009 conducted in Seattle reported that PTs were installed in ~51% of households (Tachibana, 2010).

[4] Definitions by others differ. Manual thermostats have often been called standard or mechanical. The American Home Comfort Survey mentioned in this section used the terms mechanical, digital/electronic (this may refer to the display/actuation function rather than automatic setback features), and programmable/setback.

[5] In both the national RECS and California-based Residential Appliance Saturation Survey (RASS), the authors noted problems with people understanding the term programmable thermostat. In RECS, the authors noted that the response varied depending on how the question is asked—if asked "can you set it so that the temperature setting automatically changes at the times of the day or night that you choose?" the households reporting a programmable thermostat nearly dropped in half compared to the previous survey. RASS also noted that the numbers listed were most likely lower than expected (e.g., the response rate for post-1995 houses was expected to be 100% due to energy code, but was underreported).

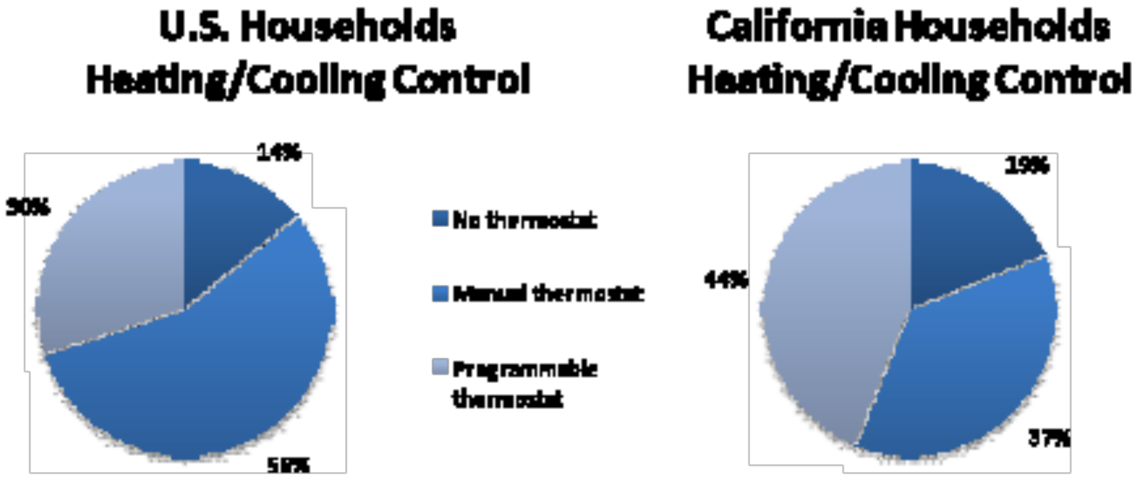


Figure 24: Types of thermostat ownership, from data in (Energy Information Administration (EIA), 2005)

No national survey is yet available reporting the adoption of more advanced devices like programmable communicating thermostats or home energy displays. We can speculate that the distribution of such innovative technologies will be broad when utilities implement demand-response programs and if other communicating appliances become available in U.S. homes. Recently utilities have begun offering web-linked thermostats and home energy displays as an inducement to switch providers; these incentives will also accelerate adoption.

From the available data we conclude that although PTs have been available for more than 20 years (and their prices have been progressively decreasing), less than 50% of U.S. households have installed them. Thus, residential energy savings still depend largely on homewoners setting their manual thermostats. Furthermore, an open question is if and how PT users program their thermostats.

## Use of programming features

Programmable thermostats can be programmed to change temperature setpoints on a schedule. During the heating season, the temperature setpoint is reduced (setback) when the house is empty or at night; in the cooling season, the temperature setpoint is increased (setup) to prevent the cooling system from running when not needed. According to the 2005 RECS, 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 (Energy Information Administration (EIA), 2005). According to the 2003 Residential Appliance Saturation Survey (RASS), only 28% of households in California actively set up the temperature for air conditioning (AC) during the day, and the presence of programmable thermostats did not appear to dramatically affect setback behaviors (California Energy Commission (CEC), 2004). Of the recent buyers of HVAC equipment, the American Home Comfort Study (AHCS) reported that 56% of homeowners always program their thermostats, 32% sometimes program, 9% never program their thermostats, and 3% do not know how (Decision Analyst, 2008). In a study that compared the energy consumption of manual thermostats versus programmable thermostats in CA households, PTs were set slightly higher (i.e., 0.7-1.2 degrees F) than manual thermostats in the cooling season (which would save energy), but were not in OFF

mode as often. In the heating season, PTs were set higher than manual thermostats (which would use more energy), and far fewer were placed in OFF mode than manual thermostats (Haiad, Peterson, Reeves, & Hirsch, 2004). A consumer survey conducted in Seattle revealed that the night setback was adopted by 86% of people with PTs and only by 60% of people with manual thermostats (Tachibana, 2010). A study in California found that setpoints in Title 24 energy code compliance software (similar to those required for ENERGY STAR eligibility) overestimated the cooling setpoint and underestimated the heating setpoint (Woods, 2006), and found that households in the study on average used a lower setpoint for cooling (used more energy) and a higher setpoint for heating (used less energy) than the Title 24 setpoints. However, in our survey of the literature, we did not find any extensive research on the percentage of thermostats actually using ENERGY STAR suggested setpoints.

Similarly, outside the U.S., setup and setback behaviors were not a common habit, as reported in several international studies. A cross-cultural study of energy behavior in Norway and Japan (Wilhite, Nakagami, Masuda, Yamaga, & Haneda, 1996) reveals that less than 50% of Oslo's households set back temperature at night and 28% did not lower thermostat settings during weekends or vacations. Another northern European survey on 600 homes (Linden, Carlsson-Kanyama, & Eriksson, 2006) showed that only 38% of the houses with thermostats lowered their temperature during the night.

One limitation of these surveys, as pointed out by their authors, was that respondents may not have known if they had programmable thermostats nor how they worked (e.g., setup and setback functions). Furthermore, responses may have varied depending on how questions were asked.

### Hold and temperature override modes

Most PTs have two additional operating modes that suspend the programmed schedule: *hold* and *override* (sometime called temporary hold or temporary override) mode. *Override* 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. We found very few studies that looked at the use of these two features. A study conducted by thermostat manufacturer Carrier looked at the operating mode of installed programmable thermostats in households within the jurisdiction of four utilities, LIPA, ConEd, SCE, SDG&E. Of the 35,471 thermostats monitored overall, only 47% were in program mode, in which the thermostat used the schedule previously input by the occupant to control temperature setpoints. The rest were in hold mode. The households within the two southern California utilities (SCE and SDG&E) showed a higher percentage (65%) in program mode, although it was unclear why (Archacki, 2003). This study plus the previously mentioned studies indicated that approximately half of programmable thermostats are not used as designed, which is to change temperature setpoints based on a schedule. In the AHCS, no distinction was made between override and hold. One question asked about the frequency of overrides for recent HVAC buyers (All the time 8%, Often 12%, Sometimes 36%, Rarely 35%, Never, 9%) (Decision Analyst, 2008). It is difficult to know whether overriding "all the time" means the thermostat was in hold mode or not.

Figure 25 represents a qualitative breakdown of the type of thermostat and thermostat use collected in the survey of the literature. Further investigation is needed to quantify the exact percentage in each category.

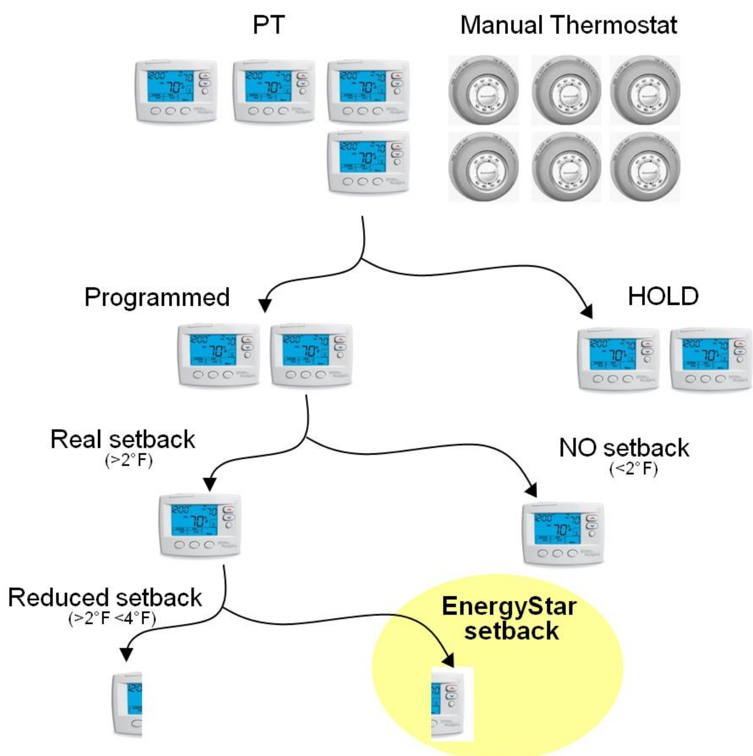


Figure 25: Breakdown of thermostat type and use
(Source: http://www.emersonclimate.com/en-US/products/thermostats/Pages/thermostats.aspx, http://compare.ebay.com/like/290465804506?ltyp=AllFixedPriceItemTypes&var=sbar, M.Pritoni)

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

Several studies have looked at temperature swings and thermostat behavior in homes (Hackett & McBride, 2001; Kempton & Krabacher, 1987; Lutz & Wilcox, 1990; Lutzenhiser, 1992; Weihl & Gladhart, 1990; Woods, 2006). These indicated that thermal comfort at home was very different from that in offices: there was a wider temperature range, because of greater control (i.e., occupants opened windows, and had greater freedom to change thermostat settings, clothing, and activity level) (Ubbelohde, Loisos, & McBride, 2003) and because of costs (Fishman & Pimbert, 1981). A recent national survey found that 49% of homeowners were very much satisfied with their home comfort systems, 43% somewhat satisfied, and 8% not at all satisfied (Decision Analyst, 2008). There was a slight correlation between programmable thermostats and satisfaction: 45% of those very much satisfied had PTs compared to 32% of those who were not at all satisfied (Decision Analyst, 2008). A preliminary study indicated that socio-economic class may have affected the distribution of these complaints: in a recent weatherization study in progress by one of the authors in low-income households, the top two complaints were mechanical ventilation and using the programmable thermostat (Meier, 2010). However, thermal comfort throughout the home tended to be problematic--68% of homeowners found at least one room too hot in the summer and 60% found at least one room too cold in the winter (ibid) When asked about seeking improvements to their home comfort system, 89% of homeowners listed greater energy efficiency as very important, but many listed issues with thermostat as very important as well: more even temperature (65%), better temperature control (68%), faster heating and cooling (64%) (ibid). Other issues were listed as very important—such as better air

purification (76%), improved air flow (69%), and better humidity control (64%) (ibid). However, most commercially available thermostats (the main device to affect house thermal environment) controlled only air temperature, leaving all other parameters unmonitored and uncontrolled. Recently, Moon and Kim designed a thermal control logic (still in development) based on artificial neural networks for creating more comfortable thermal environments in residential buildings (Moon & Kim, 2010). This method allowed control of temperature, humidity, and predicted mean vote – a criterion to assess thermal comfort by predicting the mean comfort response by a large group of people (Fanger, 1970).

There are no set standards for thermal comfort in residences, although a few have suggested the Adaptive Comfort Standard described in ASHRAE 55-2004 as most appropriate (Lovins, 1992; Ubbelohde, et al., 2003). Thermal comfort has been defined and studied both in the lab and field, primarily in the commercial sector (Arens, et al., 1998; Brager, Paliaga, & de Dear, 2004; de Dear & Brager, 1998; Fanger, 1970; Humphreys & Nicol, 2002; Leaman & Bordass, 2001). Many factors have been found to 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 influences (Beshir & Ramsey, 1981; Brager & de Dear, 1998; Humphreys & Nicol, 1998; Karjalainen, 2007; van Hoof, Kort, Hensen, Duijnstee, & Rutten, 2010). For example, Bae and Chun reported that in Korea comfort temperatures have been increasing in winter and decreasing in summer in the past 25 years due to improvement of the HVAC systems (Bae & Chun, 2009). Several studies indicated control as a major issue in thermal comfort at home (Emerson Climate Technologies, 2004; Hackett & McBride, 2001; Lutzenhiser, 1992; Ubbelohde, et al., 2003). Other studies have argued that thermal comfort was perceived as the main concern in the interaction with the thermostat because users perceived it instantly, whereas they became aware of its cost on a longer time frame (Darby 2006). Prepayment might become a viable option if thermostats were designed as vending machines (Figure 26). However, most of the thermal comfort testing and surveys in residences has been of small sample size and not representative of all socioeconomic and demographic classes; even surveys such as AHCS, RECS and RASS still struggled with definition of terms (i.e., programmable thermostat, setpoint, zones).

Figure 26: Prepay Thermostat

## Are the owners of programmable thermostats achieving expected energy savings?

PTs were designed to save energy by automatically relaxing temperature setpoints when people are sleeping and when they are away from home. Studies on PT efficacy were performed in the 1970s and were based on models of energy flows through a dwelling. Model simulations suggested that on average a daily eight-hour nighttime setback could bring ~ 1% reduction in natural gas consumption for each degree Fahrenheit offset (Nelson & MacArthur, 1978). This result became and remains the rule of thumb that guides much of the discussion on the effectiveness of programmable thermostats in situations involving gas- and oil-fired heating systems. The simulation results also suggested that daytime setbacks typically yield lower energy savings. Further, the volume of energy savings tended to be directly related to the severity of climate conditions: the colder the weather, the

greater the energy savings from using a programmable thermostat, especially if the offset (or setback) period was assumed to be at night. However, savings as a proportion of energy use tended to be higher in milder climates. Finally, the volume of energy savings tended to be inversely related to the quantity of insulation used in the structure: greater energy savings were recorded for structures with lower assumed quantities of insulation (Plourde, 2003). An integrated mathematical model including residence, heat-pump, thermostat, weather and energy cost data confirmed that night setback in residential heat-pump systems can significantly reduce heating season costs (Rutz & Moran, 1990).

The adoption of PTs has been strongly supported by the Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA). The predicted savings were typically presented in different forms, such as percent savings per degree setback, or annual dollars saved. For example, the Department of Energy estimated that the average homeowner can save between 5 and 20% of heating and cooling costs by using a programmable thermostat. (U.S. Department of Energy, 2009) The Department of Energy also stated, “You can save as much as 10% a year on your heating and cooling bills by simply turning your thermostat back 10% to 15% for eight hours. You can do this automatically by installing an automatic setback or programmable thermostat.” ENERGY STAR claims suggested that homeowners could save about $180 a year with a programmable thermostat. (Environmental Protection Agency (EPA), 2009) Both sources qualified these predictions with terms like “effectively used” or “properly setting and maintaining those settings.” Other estimates rely on a calculator that included the specific conditions of the user. An EPA ENERGY STAR program on thermostats had been in place since 1995 and was recently discontinued in December 2009. One of the reasons for this decision is that several recent field studies have shown no significant savings in households using PTs compared to households using non-programmable thermostats. (Cross & Judd, 1997; Haiad, et al., 2004; Nevius & Pigg, 2000; Shipworth, et al., 2010) Some of these studies have been summarized in a document by Shiller in Table 4. A few argue that homes relying on programmable thermostats consumed more energy than those where the occupants set the thermostats manually (Sachs, 2004), especially with heat pumps (Bouchelle, Parker, & Anello, 2000). According to this analysis, a programmable thermostat itself does not guarantee reduction in energy consumption, because the latter depended on how the device is programmed and controlled by the household. In other words, the availability of a programmable thermostat did not change setback behaviors: people who were accustomed to setting back with a manual thermostat kept doing so, and did not increase their energy savings; those who had not previously changed the temperature setpoints did not setback with PTs. Further, Lutz et al. reported that half of those who controlled their heating system manually produced load shapes which were so regular as to be indistinguishable from those produced by automatic operation (Lutz & Wilcox, 1990).

A more recent larger scale (about 7,000 households) billing analysis study concluded that savings of about 6% in energy consumption were attributable to programmable thermostat use (RLW Analytics, 2007). This research speculated that other studies had different results because of small sample size and, probably more critically, they were not in heating-dominated climates (which was not entirely accurate). In Quebec 90% of houses are electrically heated and temperature can be changed in each room with a different thermostat; a billing analysis study (> 25,000 households) estimated that the use of PTs reduced the energy consumption by 3.6% (Michaud, Megdal, Baillargeon, & Acocella, 2009). In a survey conducted in Seattle with 2,300 respondents, houses with PTs had on average a 9% reduction in electricity consumption (Tachibana, 2010). A small-sized experimental study on air conditioning usage in part-day occupied buildings in Kuwait showed that PTs allowed 25 to 46% energy savings (Maheshwari, Al-Taqi, Al-Murad, & Suri, 2001).

| Organization | Investigators | Location & Year | Sample size | Conclusions |
|---|---|---|---|---|
| Southern California Edison | Paul Reeves<br>Jeff Hirsch<br>Carlos Haiad | CA 2004 | N/A | Energy savings depend on behavior and can be + or - |
| Energy Center of Wisconsin | Monica Nevius<br>Scott Pigg | WI 1999 | 299 homes | No significant savings. PT's don't change behavior. |
| Connecticut Natural Gas Corporation | David Cross<br>David Judd | CN 1996 | 100 homes | PT's cause no significant behavior change. |
| BPA / PNNL | Craig Conner | NW 2001 | 150 homes | No significant behavior change / savings. |
| Florida Solar Energy Center | Danny Parker | FL 2000 | 150 homes | No savings, some increases. |

Table 4: Summary of thermostat behavior and energy savings studies (Shiller, 2006)

One of the barriers of using PTs to save energy is that users often fail to use these devices as they were designed. Indeed, several interviews pointed out that 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, an investigation into human factors and usability (see next section) 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." (Vine, 1986)

It should also be noted that it is experimentally difficult to directly observe the PT-induced energy savings. Energy savings cannot be observed directly; instead one must examine the *difference* in energy use between two periods. The predicted savings from improved thermostatic controls are in the same range as those caused by seasonal variations; thus, the technique of weather adjustment becomes crucial. Gas and electricity are also used for purposes other than space heating/cooling, so changes in those activities must also be taken into account. Finally, heating and cooling behaviors can vary from one year to the next as occupants or economic conditions change.

## What difficulties do people experience when using thermostats?

Several U.S. and European studies have collected a curious list of complaints and unexpected beliefs held by users, as by-products of other investigations on thermostats. Table 5 summarizes the misconceptions about energy and thermostats, complaints of customers dealing with PTs and PT manuals, and the main barriers to the adoption of PTs. Among those, Boait and Rylatt reported the example of a thermostat that required a total of 28 steps to enter heating times, which were identical for each day of the week (Boait & Rylatt, 2010). Complexity is a barrier, especially for the elderly

(Critchleya, et al., 2007; Freudenthal & Mook, 2003; Rathouse & Young, 2004b). Indeed, Freudenthal and Mook (2003) observed that PT owners do not use all functions, even the ones they find valuable, due to poor interface design. The poor usability of PTs and the necessity to improve their ergonomics was highlighted almost thirty years ago by Dale and Crawshaw, who stated that "it is easy to blame them [PT users] for stupidity, but is slowly being realized that the problem of efficiency in practice properly belongs to the engineers or the system designers," (Dale & Crawshaw, 1983). An earlier report illustrating the application of human factors techniques to heating controls interfaces listed several flaws, such as small lettering and knobs, difficulties reading in poor lighting and distinguishing the current mode of the device (e.g., programming vs. visualization) and lack of feedback on program sets, etc. (Moore & Dartnall, 1982). Although the technology of the interfaces has greatly improved over the past decades, little has been achieved in overcoming these problems.

| 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 consequences) | (Diamond, 1984a, 1984b; Karjalainen, 2008; 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, et al., 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) |
| If interface properly designed, manual is not necessary | |
| **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, et al., 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 | (Bouchelle, et al., 2000; Diamond, et al., 1996) |

| | |
|---|---|
| thermostat setting | |
| High priority for heating in people's expenditures | (Rathouse & Young, 2004b) |
| Renter/Owner problem | |

Table 5: List of user complaints about Programmable Thermostats

In some studies, functions like the "boost button" (an additional hour of heating (Rathouse & Young, 2004b), a timer (Kempton, Feuermann, & McGarity, 1992), and indication of the time needed to reach the desired temperature (Karjalainen, 2008) were considered useful to customers. These features are not currently available in any of the surveyed U.S. thermostats. Figure 27 shows the implementation of a feature to automate frequent operations (adding a minute to the cooking time) for a microwave.

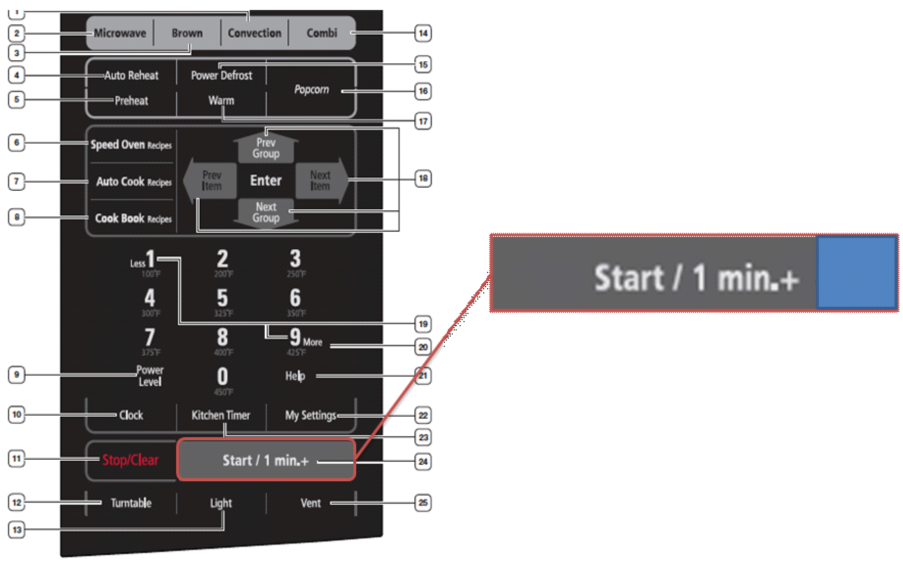


Figure 27: Micowave +1 minute button

Other human factors play a role in limiting the effectiveness of PTs. For example, gender differences in thermal perception or different needs/schedules of people in a household made it more difficult to find an agreement on the programmed temperature (Beshir & Ramsey, 1981; Karjalainen, 2007, 2008; McCalley & Midden, 2004). Some researchers have proposed the development of goal setting strategies for occupant interactions with PTs (McCalley & Midden, 2004). While some studies indicated residents enjoyed "fiddling" with their thermostats (Emerson Climate Technologies, 2004; Hackett & McBride, 2001), other studies found that most people do not have interest in tinkering with their thermostats to optimize performance (Diamond, 1984a, 1984b; Diamond, et al., 1996; Kempton, Feuermann, et al., 1992; Lutzenhiser, 1992). In some cases, discomfort upon entering a cold house discouraged people from setting back temperatures when they are away during the day (Linden, et al., 2006). In fact, in some countries a warm house is cozy and socially recognized (Wilhite, et al., 1996).

Although a wide range of studies has been conducted on temperature settings, thermal comfort, and efficiency of HVAC systems, little quantitative information is available on how people deal with temperature and environmental controls. Such quantitative analysis appears needed to understand the large-scale impact of these problems.

## Have usability issues been adequately investigated and measured?

In the International Organization for Standardization (ISO) Guidelines on Usability (ISO 9241-11 1998), usability refers to the extent to which a product can be used by specified users to achieve specified goals with *effectiveness* (the accuracy and completeness with which users achieve specified goals), *efficiency* (the resources expended in relation to the accuracy and completeness with which users achieve goals) and *satisfaction* (freedom from discomfort, and positive attitudes toward the use of the product) in a specified context of use (International Organization for Standardization (ISO), 1998).

The concept of usability originated in the field of human factors and ergonomics during World War II (Wickens & Hollands, 2000). Prior to this war, it was often simply assumed that humans should be trained to fit machines, rather than designing the machine to fit the human. The invention of the aircraft and its military use in World Wars I and II, along with safety concerns, drove the development of the fields of aviation psychology and human factors. It became evident from accident studies that highly trained pilots were crashing due to poor control configurations (Fitts & Jones, 1947). Seminal work, mostly in aviation and military research, conducted during the forties and fifties led to the emergence of human factors as a discipline, which then expanded into computer hardware in the 1960s and software in the 1970s. The 1980s saw an increase in the popularity of the term "user-friendly;" however, in the early 1990s, Jakob Nielsen noted that the term was not appropriate because users didn't need friendliness; they just needed to get their work done (Nielsen, 1993). He favored the use of the term "usability," defined as how well users can utilize a system's functionality. Nielsen's definition of usability was distinct from that of utility, or whether the functionality of the system in principle can accomplish its tasks, and incorporated such elements as learnability, efficiency, memorability, errors, and satisfaction. In Nielsen's authoritative book, *Usability Engineering*, he also lays out the foundations for the quantitative study of usability (ibid).

In the early 1990s there was an upsurge of interest in defining new usability criteria that led to the formulation of numerous distinct approaches to test product usability (B. Bordass, Leaman, & Willis, 1994; Cooper, Reimann, & Cronin, 2007; Nielsen, 1993; Norman, 2002; Polson & Lewis, 1990; Shneiderman & Plaisant, 2005).

Few researchers have performed usability tests on PTs. Karjalainen completed qualitative and quantitative surveys on thermostat use in homes and offices in Finland, and then developed a prototype thermostat interface with usability guidelines and a user-centered design approach (Karjalainen 2008), i.e. a series of methods for product development with active involvement of users (Table 6).

As an example of user-centered methods, six focus groups were conducted in the UK (Rathouse & Young, 2004b) to investigate issues in use of heating controls. Based on user experiences and complaints, a series of recommendations for manufacturers and installers was formulated to improve the next generation of thermostat interfaces. Rathouse and Young recommended that manufacturers offer a variety of products of different complexity to suit different needs.

| | |
|---|---|
| Methods for focusing on users | Talking with users<br>Visiting customer locations<br>Videotaping users<br>Learning about the work organization<br>Trying it yourself<br>Ethnographic observation<br>Contextual inquiry<br>Card sorting<br>Focus groups<br>Participatory design<br>Use task analysis<br>Use surveys and questionnaire<br>Scenario development |
| Methods for usability testing | Early user manuals<br>Mock-ups<br>Simulations<br>Early prototyping<br>Early demonstrations<br>Thinking aloud<br>Hallway and storefront methodology (collecting user responses in public areas)<br>Computer bulletin boards, forums, networks, and conferencing<br>Formal prototype tests<br>Field studies<br>Follow-up studies<br>Expert reviews |
| Methods for carrying out iterative design | Collect the requirements improvements during usability testing<br>Organize the development work in a way that improvements can be made<br>Have tools that allow you to make the needed improvements |

Table 6: Examples of user-centered methods (Karjalainen 2008)

Similarly Freudenthal and Mook (Freudenthal & Mook, 2003) developed a PT interface with vocal messages that guide the users through the programming steps. This thermostat was part of a smart home system developed by the Intelligence in Products group of TU Delft (The Netherlands). The objective of this study was to design an interface usable for people with no knowledge of the device, even for elderly users. To test the device usability, a lab test was performed by videotaping the interactions with a touchscreen computer (simulating the thermostats) of 14 people randomly selected among the population of Delft. The interactive feature conferred high usability on the device, and even the oldest subjects could accomplish complicated programming tasks.

Sauer et al. (2009) investigated various types of enhanced user support on user performance. Different thermostat interface options providing different support information (status, history, predictive, instructional and warning displays) to the user were simulated as well as the system performances in response to the user actions. Seventy-five subjects were asked to evaluate them, while their score in simulated comfort level and energy efficiency was recorded. The highest scoring interface was the predictive display, which predicted the impact of heating setups on certain parameters, such as energy consumption, efficiency, and comfort level, thus helping users make

informed decisions. This interface had the benefit of relieving users of the cognitive effort of calculating the effects of their actions (Sauer, et al., 2009). The more interactive and rich information displays (e.g. warnings) appeared to be useful for less experienced people. The results of this study suggested that different levels of support were appropriate for specific situations and groups of users.

Peffer (Peffer, 2009) developed a user interface for a PCT as part of the Demand Response Electrical Appliance Manager (DREAM), which was a central control and user interface hub that manage domestic appliances and communicates bidirectionally with the utilities. The objectives were to develop an easy-to-use interface that enabled demand response by informing the occupant of price changes and electrical energy consumption. A user-centered approach was implemented. Starting from the initial paper prototype (which was mostly based on informal questionnaire and anecdotal evidence from experience), the prototype was refined via an iterative process of heuristic testing and user testing of the interface. This process led to the final design.

To our knowledge, the only comparative usability study on commercially available PTs was conducted by Consumer Reports (Consumer Reports, 2007).[6] Twenty-five different thermostats were lab-tested to assess their energy performance and their usability. As a result, PTs were ranked according to these criteria and a series of problems with using thermostats were highlighted (and reported here in Table 5). Consumer Reports did not explicitly state what parameters were considered to assess thermostat usability, and it did not appear that quantitative tests were performed.

A recent publication by the UK Building Control Industry Association (Bill Bordass, et al., 2007) focused on the implementation of user interfaces of control devices for heating, cooling, and ventilation, analyzing the flaws of existing interfaces and providing usability guidelines for new products. The authors affirmed that usable controls improved not only user satisfaction and comfort, but also they provided higher energy efficiency (use of HVAC only when needed), helped to building management (local control versus central control) and provided users with faster response of the system (due to perceived control and feedback). Problems connected with lack of communications between designers and users were also highlighted.

## Can new features address the aforementioned problems?

New products like PCTs, web-enabled thermostats, and In-home energy displays are introducing new features to those already available in current PTs. To what extent will these new features address or exacerbate problems and complaints discussed in the last secton? This section addresses this question.

### Improved feedback

Recently energy consumption feedback has received a great deal of attention (Allen & Janda, 2006; Anderson & White, 2009; Bell, Greene, Fisher, & Baum, 1996; Darby, 2000, 2006; Egan, Kempton, Eide, Lord, & Payne, 1996; Fischer, 2008; Lutzenhiser, 1993; Neenan, Robinson, & Boisvert, 2009; Stein & Enbar, 2006; Wood & Newborough, 2003, 2007). Cost and energy feedback can be obtained by HEDs or PCTs from interval meters, user-installed sensors on meters or appliances, smart appliances, and other intelligent systems. This information, if not directly useful to promote

[6] While PT manufacturers affirm they perform usability tests for their products, they do not disclose results because they consider the user interface a key feature for sales.

energy conservation, can at least raise awareness. Carbon dioxide emission calculation (available in some new devices) can help users understand the connection between HVAC use (and temperature settings) and the environment. Cialdini suggested that showing waste or loss instead of savings can be a better incentive to conserve energy (Cialdini, 1993). In recent studies, the indication of the time expected to reach the selected temperature emerged as a very useful indication for users (Gupta, et al., 2009; Karjalainen, 2008). To implement this feedback information requires some intelligence; the devices needed to store historic internal and external temperature and HVAC cycles, and use the information to predict how quickly the room temperature is going to change. This feature may also enhance the users' perception of control of the system and discourage the use of the thermostat as a valve (i.e., turning it all the way up does not decrease time needed to reach a target temperature). Figure 28 describes how improved feedback on energy cost and consumption and time needed to reach desired temperature can inform the users much more promptly. This real-time feedback not only provided the users with more information more rapidly, but also improved the user reaction time.

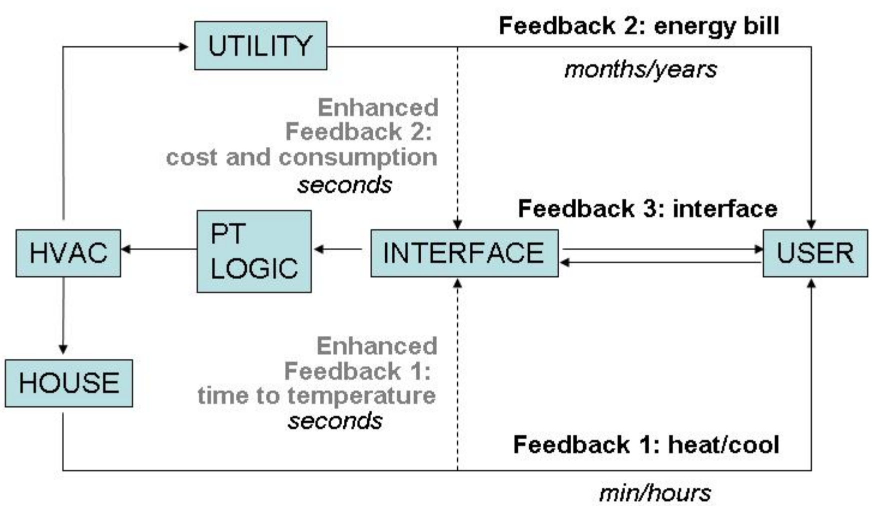


Figure 28: Human-thermostat interaction

## Intelligent systems

Other studies and products proposed automated systems which limited the need for human interaction. Some examples of information needed to operate a system without human input were occupancy and thermal preference. Different original solutions have been suggested to monitor the location of household members ranging from occupancy sensors (BAYweb; Fountain, Brager, Arens, Bauman, & Benton, 1994; Peffer, 2009; RCI Automation LLC; Telkonet) to Mobile GPS (Gupta, et al., 2009). Occupancy data could also be predicted from historic energy consumption of water boilers with the addition of cheap sensors in the tank (Boait & Rylatt, 2010). In order to operate the system autonomously, these sensors must be complemented by an intelligent controller using learning algorithms to recognize patterns and take into account other important variables (e.g., preference in temperatures and characteristic of HVAC and house) (Boait & Rylatt, 2010; Moon & Kim, 2010; Peffer, 2009). Intelligent systems can theoretically overcome some of the problems associated with

human-thermostat interaction, although some users may be reluctant to give up on their control of the system. A more equilibrated approach was the use of intelligent systems to complement user actions rather than eliminate them. Thus, the strategy for future developments should be a balanced mix between user control and automated features (Peffer, 2009).

## Communication features

Figure 29 provides a general scheme of the interaction between the thermostat and other devices inside and outside the house. In this common architecture the thermostat uses the home gateway to communicate with most of the devices in the HAN such as smart appliances, HEDs, and energy detectors and to exchange data with utilities and other service providers. In alternative, less common, architectures the network is more decentralized and devices communicate with each other directly and PTs are capable of communicating directly with utilities via two-way radio communication.

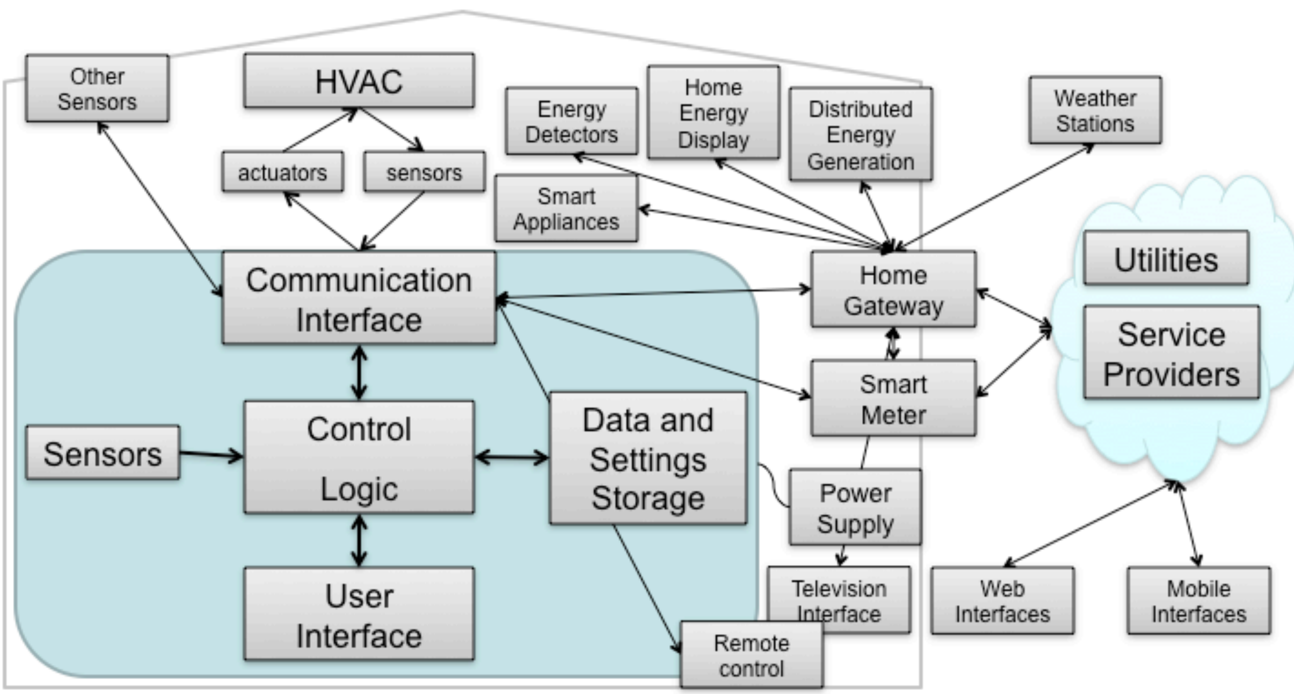


Figure 29:PT Communication Network

PCTs and HEDs feature higher communication capabilities than traditional PTs. Web/mobile interfaces enable controlling thermostat configurations from personal computers, cell phones (also remotely), and potentially Internet-connected television. This feature allows cost reductions because the interface is external to the thermostat and in multifunction devices, and a more flexible environment to develop usable interfaces (as use experience with other devices may result in more usable interfaces). These communication systems enable utilities to implement demand response programs, which will provide economic incentives to users to save energy during peak hours in exchange for economic benefits.

## Other improvements

Talking Thermostats.com and Innotech produce a voice-controlled thermostat which can improve thermostat usability for elderly or motion-disabled people (Innotech System Inc.; Talking Thermostats). Timers are not currently included in available U.S. PTs. Voice-activated devices could dramatically simplify the interaction with thermostats, especially in the case of out-of-schedule requests (Rathouse & Young, 2004b). In response to demands to simplify the interfaces, a single button push triggering an energy saving mode has been suggested in ENERGY STAR Program Requirements. Aesthetically improved interfaces are suggested by several studies to improve social acceptability and increase likelihood of adoption.

A recent interface development is the "Green Machine" (Marcus and Jean, 2009), a mobile application that is an example of *persuasive technology*--defined by Stanford's BJ Fogg as technology created for the purpose of changing people's attitudes or behaviors (Fogg, 2002). The Green Machine interface provides a visualization of energy consumption in comparison to user goals and utilizes social networking to motivate users to reduce their energy consumption.

## Standardization

In the long term, standardization can improve usability, because people have to learn a system only once. In our survey of thermostats currently available in the market we found a substantial lack of standardization not only in the interaction design, but also in symbols, icons, and text. The most basic functions and concepts are implemented in different ways.

Table 7 shows some of the findings.

| CONCEPT | Alternative definition |
|---|---|
| **Period labels** | (MORN,DAY,EVE,NITE), (morning, day, evening, night), (1,2,3,4), (WAKE, LEAVE, RETURN, SLEEP), (AWAKE, WORK, HOME, SLEEP), (WAKE, LEAVE, RETURN, SLEEP), (Dawn, Dusk, occupied, unoccupied). |
| **Programs** | Schedules, events, program schedules, program events, program periods, periods |
| **Override** | Temporary hold, temporary override, programmable extended hold. |
| **Vacation Hold** | Hold until, extended hold |
| **Temperature differential** | Hysteresis, swing settings or swing adjustment |
| **Adaptive recovery** | Smart recovery, adaptive intelligent recovery™, energy management recovery, energy efficient recovery™, adaptive recovery mode (ARM™), progressive recovery, recovery, early start, early recovery.[7] |

Table 7: Alternative definition of elements in Thermostat

[7] Slightly different functions.

Standardization of interfaces symbols and icons has been successfully implemented in other sectors such as in car dashboards (SAE standard) and in power controls for electronic equipment (IEEE 1621) (Figure 30).

**Table 1. Power Symbols**

| Symbol | Name | Usages in addition to use within power control panels |
|---|---|---|
| I | On | On a switch, best used in conjunction with the Off symbol, as on a rocker switch. |
| ○ | Off | On a switch, best used in conjunction with the On symbol, as on a rocker switch. |
| ⏼ | On/Off | For use on a power switch that always switches to *hard-off* in the *off* state. For use with a power indicator if the off indication is always *hard-off* and the distinction from *soft-off* is important. |
| ⏻ | Power | For use on a power switch or button if the *off* state is *soft-off*, is variable, is not known, or the distinction from *hard-off* is not important. Also for use with a power indicator, or as the icon for the power control panel. |
| ⏾ | Sleep | For use on a sleep button, or with a sleep indicator. |

Figure 30: Power symbols in IEEE 1621 standard

## Conclusions

Thermostats play a vital role in providing comfort to people in homes and other buildings. The thermostat acts as an interface between the occupants' thermal preferences and the operation of the heating and cooling systems. For that reason, it is important to understand the effectiveness of the interface from the perspective of the users, the manufacturers, and policymakers. Residential thermostats also have an important role in consuming—and conserving—energy, since they control about 11% of the nation's energy use. We surveyed the research and literature pertaining to residential thermostats. The goal of this survey was not to resolve any disagreements but to determine the extent and quality of research before undertaking our own research. We focused on *programmable* thermostats because, while present in less than 50% of American homes today, PTs are expected to be the dominant model in the future.

We organized the literature review around six broad questions. The questions and a summary of the conclusions from the literature for each of them follow below.

*What thermostats are present in today's homes and how are they used?* About 86% of American homes have thermostats and at least 30% (some surveys show 40-50%) of American homes have programmable thermostats. As many as 60% of those homes with programmable thermostats actually use the scheduling features, although usage appears to be higher in homes with new HVAC equipment. The occupants often place programmable thermostats into a permanent hold mode; one study, involving thousands of homes, found 65% of the programmable thermostats were in permanent hold.

*How successful are modern thermostats at achieving the occupants' thermal goals?* Curiously little research has addressed this question. One survey of homeowners found that about half are very much satisfied with their home comfort systems, which could either be interpreted as the glass being half full or half empty. It also ignores the 30% of rental households. But there appears to have been little exploration of which factors—heating, cooling, controls—occupants find satisfactory.

*Are the owners of programmable thermostats achieving predicted energy savings?*

The evidence suggests that savings are less than predicted and may even result in increased energy use. However, verifications are difficult to perform. It is not possible to calibrate the predicted savings (based on initial conditions) to the observed change in energy use. Most of the studies compared the energy use of homes with programmable thermostats to those without. This raises problems of self-selection and bias in the two groups. High income users might, for example, be more likely to select a programmable thermostat. A more revealing comparison of energy use would be of the same homes before and after they installed programmable thermostats. Unfortunately, this experiment is more difficult to arrange (and suffers from other weaknesses). Additional research is nevertheless important to determine the energy savings from programmable thermostats and linking the amount of savings to initial conditions and usage of the thermostat's features.

*What difficulties do people experience when using thermostats?* Anecdotal information points to widespread user difficulties with programmable thermostats – nearly all of us have encountered problems with one – but the open literature contains relatively few detailed studies (although some proprietary surveys may have been undertaken). User complaints culled from the open literature cover misconceptions about energy use, the thermostats themselves, the operating manuals, and barriers to using programmable thermostats. The user misconceptions are particularly important since they may cause incorrect usage that cannot be easily overcome by better interfaces. These misconceptions range

from not realizing that turning down the thermostat setting will save energy to treating the thermostat as a valve (rather than a thermostatic device). When users complained about the thermostats themselves, they noted in particular their complexity, small size of buttons and writing, confusing terms and symbols, and the steps needed to program the devices. The literature also revealed some functions that would be desirable to some users but are not available in U.S. models, such as a "boost" feature that would provide an extra hour of operation (sort of like the "plus one minute" feature on a microwave oven). One study found that users liked a feature that would indicate how long it would take to achieve the desired temperature. (This would also address the misconception about the thermostat as a valve.)

The literature also revealed disparate attitudes towards thermostats. Some users preferred never to adjust their thermostats—to the point of being afraid of touching them—while others tinkered with it almost daily. These groups will have different priorities for top-level features.

*Have usability issues been adequately investigated and measured?* Even if one takes into account the proprietary research undertaken by thermostat manufacturers, usability has not been thoroughly investigated. Lack of usability studies is a critical weakness in the design of advanced thermostats because usability is among the most frequent complaints about them. Many opportunities for improved usability are now appearing, including access through a web portal and use of audible commands and even voice recognition. At the same time, the functionality required of thermostats to control heating, cooling, ventilation, humidity, and time of use, point to increasing usability challenges.

*Can new features address the problems described?*

Yes, they can certainly address the problems, although probably not completely solve them. Clearly, a goal of future thermostats will be to overcome the misconceptions about thermostat operation and to minimize the number of interface-related complaints. At present, however, designers lack the foundational research to determine which thermostat features succeed or fail. Another issue entirely is addressing motivation to use the thermostat to save energy.

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# Appendix A: Thermostat Dictionary

**AC**: Air conditioner: a device or system that cools the air.
**Adaptive Recovery**: This thermostat algorithm starts the heating or cooling system in advance of the programmed time to reach the comfort setpoint at or near the programmed time. Different algorithms use different feedback information (such as the outside temperature) to determine the optimal initiation time. Also known as Intelligent Recovery.
**Advanced Metering Infrastructure (AMI)**: A utility network that measures, collects, and analyzes metering data. AMI systems consist of hardware, software, and communications. Typical implementations include advanced communicating energy meters, meter data management (MDM) systems, and associated communications infrastructure. AMI systems may also include consumer energy displays and web portals for purposes of displaying energy usage data and facilitating remote control and energy use scheduling.
**Anticipator**: This is a mechanism or algorithm to turn off AC/furnace before the setpoint has been reached, to avoid heating/cooling overshooting.
**Auxiliary Heat**: Electric resistance heat is used to supplement the heat pump during periods of low temperature or rapid recovery. In certain systems, natural gas or other fuels will provide the supplemental heat.
**Climate Control**: Evolved from the programmable thermostat, Climate Control refers to not only control of temperature but extends usability and adds communication features to the traditional programmable thermostat.
**Comfort (Thermal Comfort)**: Human thermal comfort is defined by ASHRAE Standard 55 as the state of mind that expresses satisfaction with the surrounding environment (ASHRAE Standard 55).
**Cycle Rate settings**: This is an adjustable setting of the cycle rate (how many time HVAC can turn on/off, usually between 3-6 time per hour) to prevent damage to the cooling or heating equipment.
**Demand Response (DR)**: Load management activities –such as reducing energy consumption at peak times of the day—aimed at supporting electrical grid and market health. DR can be utilized to reduce overall consumption in response to market conditions or periods of critical peak demand. Since residential energy consumption is dominated by HVAC energy consumption, DR implementations typically provide mechanisms for shedding HVAC load as a fundamental tool to reduce energy load. Secondary targets for DR control include electric hot water heaters and pool pumps.
**Event:** Event refers to a message from a utility in a Demand Response program, for example, a price event – a change in the price of energy due to demand/supply interactions.
**Heat Pump:** A heat pump is a mechanical apparatus that normally consists of one or more factory-made assemblies that include an indoor conditioning coil(s), compressor(s), and a reversing mechanism to transfer heat to the premises from the outside air, ground, or water in heating mode and from the premises to the outside air, ground, or water in cooling mode.
**Hold**: This feature suspends the thermostat program schedule and allows a user to set a fixed target temperature until the user cancels it.
**Home Area Network (HAN)**: An HAN is used for communication between digital devices typically deployed in the home: personal computers, peripherals, mobile computing devices, smart appliances, and other network electronics. The HAN is connected to the Internet via a residential gateway.
**Home Energy Display (HED)**: Also known as In-Home Energy Display (IHED) or (IHD). An HED provides prompt, convenient feedback on electrical or other energy use. Some devices may also

display cost of energy used, and estimates of greenhouse gas emissions.

**Home Automation System (HAS)**: An HAS integrates the control of security, HVAC, lighting, and other systems to enhance safety, comfort, and convenience. An HAS can have different architectures (centralized or distributed) and can include the scheduling and automatic operation of landscape irrigation, heating and air conditioning, window coverings, security systems, lighting, and food preparation appliances. Home automation may also allow vital home functions to be controlled remotely from anywhere in the world using a computer connected to the Internet.

**Home Gateway (router)**: A residential or home gateway connects the external network to the rest of the HAN. This enables multiple devices to connect to the Internet simultaneously.

**HVAC**: Heating, ventilating, and air conditioning system.

**Mode**: Mode describes the status of the thermostat (set program mode, set time mode, run mode, etc.) or the status of the HVAC system (cooling or heating mode).

**Multi-stage HVAC system**: Multiple-stage heating or cooling systems allow two or more rates of heating or cooling, depending on the difference between the target temperature and the current temperature. Typically, a large difference (e.g., 5 degrees Fahrenheit) will trigger the high level (e.g., both compressors, highest fan speed), whereas a small difference will trigger the low level (e.g., one burner, low fan speed). Since the low setting is adequate to meet household heating/cooling demands most of the time, a multiple-stage unit runs for longer periods and produces more even temperatures. Longer cooling cycles also translate to quieter, more efficient operation and enhanced humidity control.

**Override (Temporary Hold)**: This thermostat feature temporarily overrides the program setpoint when the user sets a temporary target temperature. Override is active only until the next scheduled program begins.

**Period (Time Interval)**: Period represents the time interval of each program (e.g. 6am-9am is the period in the morning program in Figure 31)

**Period Label**: Manufacturers often use labels to describe the periods of a program. Labels commonly used for a four-period Programmable Thermostat are MORN, DAY, EVE, NITE (Figure 31); others are WAKE, AWAY, SLEEP.

**Program:** A program refers to the mode (heating or cooling), schedule (day and starting time), period, and associated desired temperature.

**Programmable Communicating Thermostat (PCT):** A PCT can communicate with sources external to the HVAC system for energy management and remote control. External sources include but are not limited to: (1) customer signals from home computer or mobile device, (2) utility price signals and display messages, and (3) home energy management device signals.

**Programmable Thermostat (PT)**: A PT automatically adjusts the temperature according to a series of desired temperature targets at different times of the day; the temperature targets and times are entered or "programmed" by the user.

**Schedule (Program Schedule)**: Schedule is the day and starting time of a program (e.g. Mon-6 am is the beginning of the morning program in Figure 31).

**Setback (set-back) Temperature**: The Setback Temperature is a lower temperature setting than the comfort setpoint. This is used during the heating season, and is the temperature setting for the energy-savings periods, generally at night and during unoccupied hours.

**Setpoint**: Setpoint is the desired or target temperature setting in degrees Fahrenheit or degrees Celsius for any specified time period.

**Setpoint, Comfort**: Comfort setpoint is the desired or target temperature setting in degrees Fahrenheit

or degrees Celsius for the time period during which the house is expected to be occupied (e.g., the early morning and evening hours for a residence).

**Setpoint, Energy-Saving:** The Energy-Saving Setpoint is the temperature setting in degrees Fahrenheit or degrees Celsius for the time periods during which the house is expected to be unoccupied or during which occupants are sleeping (e.g., workday hours and nighttime for a residence).

**Setup (set-up) Temperature**: The Setup Temperature is a higher temperature setting than the comfort setpoint. This is used during the cooling season, and is the temperature setting for the energy-saving periods, generally at night and during unoccupied hours.

**Smart Grid**: The automated electric power system that monitors and controls grid activities, ensuring the two-way flow of electricity and information between power plants and consumers—and all points in between. The "Smart Grid" has the technical capability to sense, monitor, and, in some cases, control (automatically or remotely) how the system operates or behaves under a given set of conditions to optimize use of electricity.

**Smart Meter (Interval Meter)**: A Smart or Interval Meter is an advanced meter (usually an electrical meter) that measures and records energy consumption on a time interval (typically 15 minute or hourly). Generally it communicates that information via some network back to the local utility for monitoring, billing, and other purposes.

**Temperature, Current (Displayed, Actual, Internal)**: Current indoor temperature.

**Temperature, Outdoor:** Current outdoor temperature.

**Temperature, Target: Also referred to as the Set, Goal, or desired temperature for a particular time period**. See *Setpoint.*

**Thermostat**: A Thermostat is a device for regulating and maintaining the temperature of a system near a desired setpoint or temperature setting.

**Time (Program Time)**: Time refers to the starting time of each program (e.g. 6:00 am is the program time for the morning program in Figure 31).

**Zone/zonal control**: Zonal control refers to independent temperature settings for different rooms or areas (zones) of a building. Residential zoning systems typically use dampers in ductwork, which are opened and closed as needed to control the air flow to a zone. The zonal thermostat controls the process.

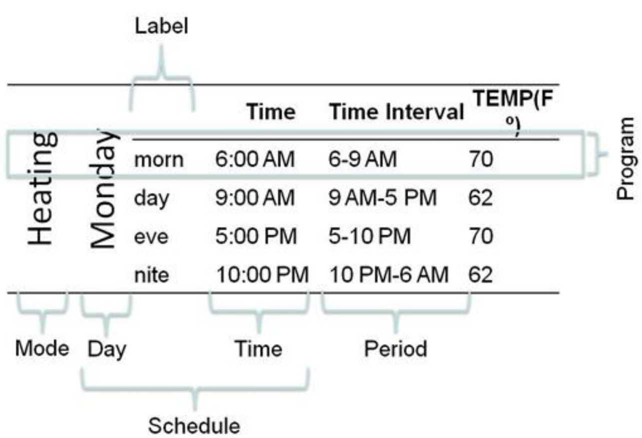


Figure 31: Program terminology

# Appendix B: List of features found in residential thermostats

In the course of maintaining temperatures at desired levels, residential thermostats rely on other features and functionalities. A partial list of these features is presented below. The list was compiled through inspection of numerous models, their operating manuals, and other sources. The organization of this section is based on Figure 32.

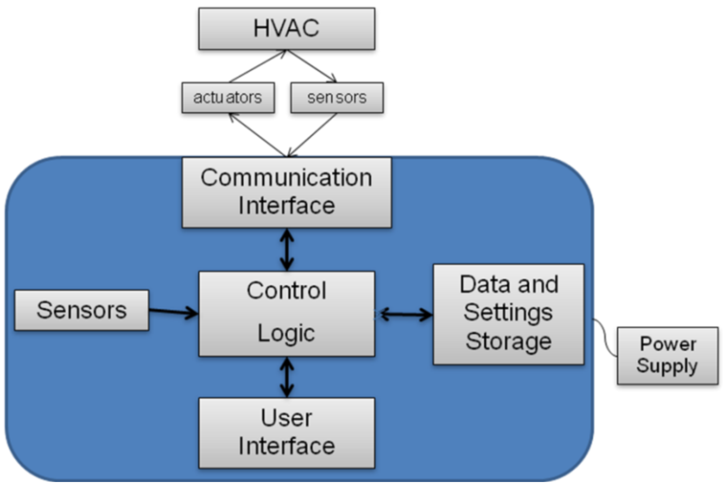

Figure 32: Programmable Thermostat architecture

Note that some features and names are either copyrighted or patented; these are indicated when known.

| SENSORS | |
|---|---|
| **Room temperature sensor** | (usually within +/- one degree F)<br>Physical implementation can be:<br>Bimetallic mechanical or electrical sensors<br>Expanding wax pellets<br>Electronic thermostats and semiconductor devices<br>Electrical thermocouples |
| **Remote indoor temperature sensor** | |
| **Remote outdoor temperature sensor** | A sensor installed outdoor with wired or wireless connection to the thermostat |
| **Relative Humidity sensor** | Sensor displays relative humidity percentage |
| **Occupancy sensor** | Wired or wireless |
| **Door entry sensors** | Wired or wireless |

| CONTROL LOGIC - a) TIME | |
|---|---|
| **Internal clock** | Minimum requirement to be a programmable thermostat, Set time of day and day of week |

| | |
|---|---|
| **Real-Time Clock** | Keeps time during power failures and automatically updates for daylight savings. It is synchronized with radio signal |
| **CONTROL LOGIC - b) HEAT-COOL MODE** | |
| **Heat-Cool manual control** | Typically a physical switch (HEAT-OFF, COOL-OFF, HEAT-OFF-COOL), the thermostat controls heating/cooling according to the position of the switch |
| **Heat-Cool automatic changeover** | Automatically switches between heating and cooling system |
| **CONTROL LOGIC - c) FAN ACTIVATION** | |
| **No Fan control** | In heating-only systems or system without forced air |
| **FAN ON-AUTO** | Typically a physical switch; can turn on the blower fan when the air conditioning is off (for air circulation), or leave in AUTO mode that turns on the blower fan automatically with the AC/heating system |
| **Circulating FAN** | Fan runs randomly (e.g. 35%) not counting any run time with HVAC |
| **Programmable Independent Fan Control** | Fan runs continuously during a selected time period, such as MORN, EVE, etc. |
| **Pre-occupancy fan purge** | |
| **Residual Cool** | In order to get greater efficiency from the cooling system, the fan can be programmed to run for a few minutes after the air conditioner has shut off; this same effect may be achieved with a fan delay relay, instead of with the controller (Robertshaw, Braeburn) |
| **Variable Speed Fan Control** | |
| **CONTROL LOGIC - d) PROGRAM and HOLD** | |
| **1-day program** | same program every day |
| **5+2 program** | weekend vs. weekday |
| **5+1+1 program** | weekend + Saturday + Sunday |
| **7-day program** | different settings each day |
| **366 day Programming, multi-year scheduling** | Set from a Web interface, as an electronic calendar |
| **Special Day Groups** | Set from a Web interface, as an electronic calendar; days can be grouped and have common settings |
| **2-7 periods** | Set temperature "goal" for two - six different times per day, usually four; time of day: morn, day, eve, night/sleep |
| **Default energy saving settings (temperature and schedule)** | Preprogrammed settings for an easy configuration |
| **Cool Savings™** | White-Rodgers feature to reduce energy use of HVAC in period of high demand |

| | |
|---|---|
| **Override** | Temporarily change heating or cooling setpoint that lasts until next program; in some thermostats the temporary hold can be set for a fixed/variable number of hours; usually activated by up/down buttons |
| **Hold** | Press to change heating or cooling setpoint, takes precedence over programmed settings. Usually a physical button. Hold can be a generic name for slightly different functions |
| **Vacation Hold** | As hold but with ending time/date |
| **Planned Hold** | As hold but with a starting AND ending time/date |
| **Home Today™** | Patented by Hunter; allows quick and temporary change of settings when occupant is at home to increase comfort; functions for one day, but can be extended |
| **Quick Save™** | EcoBee one-button feature that automatically increases (in cool mode) or decreases (in heat mode) set temperature to save energy |
| **CONTROL LOGIC - e) HUMIDITY** | |
| **Dehumidifier** | Control the max target humidity and run the conditioner/dehumidifier to reduce humidity when needed |
| **Humidifier** | Increase humidity when necessary |
| **CONTROL LOGIC - f) MULTI-DEVICE & MULTI-AREA** | |
| **Zonal Control** | Zoning systems use dampers in ductwork, which are opened and closed as needed, to have independent temperature settings for different zones or areas of the house; when a particular zone attains the desired temperature, the dampers close to save energy; the zonal thermostat controls the process |
| **Multiple Unit** | Multiple system for different floors or rooms (ex: 3 H 2 C), but managed by the same thermostat |
| **CONTROL LOGIC - g) DEMAND RESPONSE** | |
| **Default price offset temperature settings (Demand Response)** | Automatically changes settings according to the pre-set price preferences |
| **CONTROL LOGIC - h) INSTALLATION SETTINGS** | |
| **Temperature differential** | The difference between target temperature and current temperature that triggers the system operation (usually a few degrees F) |
| **Setpoint Temperature Limit** | Maximum target temperature for heating and minimum target temperature for cooling |
| **Low Temperature "Freeze" Protection** | Minimum target temperature for heating to prevent freezing pipes |

| | |
|---|---|
| **Override Adjustment Limits** | Limits how much the thermostat can be adjusted from the program set points when the thermostat is used in the programmable mode |
| **Deadband Setpoint** | Deadband is used with the automatic changeover feature; the deadband is the temperature difference from the setpoint temperature during which the heating or cooling will not be turned on |
| **Temperature recalibration** | Used to recalibrate the thermostat temperature with an external device |
| **Compressor Power Outage Protection** | Provides cold weather compressor protection for heat pumps by locking out the compressor stage(s) of heating for a period of time after a power outage; during that period of time, the auxiliary heat stage will still be available to maintain the set point temperature |
| **Compressor protection** | This feature forces the compressor to wait a few minutes before restarting, to prevent equipment damage, e.g. a four-minute minimum off period for AC is typical for preventing damage to AC equipment |
| **Cycle rate** | Adjustable setting of the cycle rate (around three - six cycles per hour) for AC and furnace based on equipment minimum off period. (Max five cycles/hr under NEMA DC 3-2008); this affects the temperature swing within the house—long cycles are associated with better energy efficiency but greater temperature differential, while short cycles are less efficient but provide more even temperature |
| **Anticipator** | Adjustable setting to turn off AC/furnace before setpoint reached, based on equipment to prevent overheating/overcooling |
| **PreComfort recovery** | When switching from setback/setup setpoint (unoccupied/energy savings mode such as day, night, vacation setpoints) to comfort setpoint (morn, eve setpoints), start AC or furnace ahead of time, so that the appropriate temperature is reached at the start of the comfort period; system "learns" recovery time based on measuring the rate of decay/change and outdoor temperature over several cycles (depends on house and temperature differentials)<br>Controversy over whether to include this, or disable it: some people set the time periods for the equipment, not comfort and don't want to hear equipment come on too early |
| **Auxiliary Heat** | Control the use of auxiliary heat (either electric or fossil fuel) to help heat pumps to reach the target temperature faster |

| | |
|---|---|
| **Multiple Stage parameters** | Time intervals or temperature differentials to activate the second or third stage of the system |
| **Economizer Control** | Economizers are mechanical devices intended to reduce energy consumption using pre-heated/pre-cooled air, typically using outside air |
| **Clean Cycle®** | Lux patent: helps improve air quality |
| **USER INTERFACE - a) TYPE OF INFORMATION** | |
| **Current temperature (F or C)** | |
| **Target temperature (F or C)** | |
| **Current external temperature (F or C)** | |
| **Current Relative Humidity** | |
| **Target Relative Humidity** | |
| **Local Weather Forecast** | Requires a remote connection |
| **Time of the Day** | Sometimes with AM/PM or 12/24 hr. |
| **Day of week** | |
| **Military time** | |
| **Whether the thermostat is ON/OFF** | |
| **Whether the system is in heat mode or cool mode** | (word and/or icon) It does not mean the system is actually running. |
| **Whether heating or cooling is currently on** | (word and/or icon) |
| **Whether the fan is on or in auto** | AUTO means the fan turns on and off as needed by the AC; ON means the fan is continuously on, to be used for air circulation |
| **Whether the backup heat (heat pumps) is working** | (word), Emergency (Auxiliary) heat is generally more expensive |
| **Whether in hold mode** | (word) Different words are used for different hold options |
| **Current program on (i.e., morn, day, eve, night/sleep)** | (word and/or icon) |
| **Keypad lock/unlock** | To prevent changes or to clean the device (in particular for touch screens); some thermostats use passwords to unlock the keyboard<br>The most sophisticated devices have multi-level passwords |
| **Alert: low battery indicator** | (icon) |
| **Alert: replace filter indicator** | (word and/or icon) |
| **Alert: other systems indicator** | UV lamps, dehumidifier |
| **Alert: system malfunction** | Malfunctioning indicators to signal problems in heating and cooling systems |
| **Help** | Show tips and other information for easy setup; some models have a built-in instruction manual |
| **Energy usage and cost reporting** | Energy and cost feedback, calculated with different systems |
| **Messages from Utilities** | Show messages from the Utilities |
| **Current Price Tier (actual energy price)** | Show the current price tier in demand response programs |
| **USER INTERFACE - B) FORMAT** | |
| **Analog display** | (Honeywell Round, etc.) |
| **Digital (segmented numbers vs. pixels)** | |

| | |
|---|---|
| **Size of display** | |
| **Liquid Crystal Display (LCD)** | |
| **Touchscreen** | |
| **Multiuse or single use buttons** | |
| **Display on screen vs. moving arrow that points to day of week printed on thermostat** | |
| **Menu driven interface** | |
| **Monochromatic vs. multicolor** | |
| **Backlight** | |
| **Multiple languages** | |
| **Custom naming** | Customized names for programs, zones, sensors |
| **Separate Installer and User Setup Modes** | |
| **Separate Residential or Commercial Program Modes** | |
| **Audible touch confirmation** | Audio prompt to confirm entries |
| **Up/down arrows for temperature** | When a program is running they usually activate override mode |
| **Next button** | Skip to the next program anticipating its beginning |
| **Reset button** | Reset all the saved changes (except for the built-in settings) |
| **Save button** | It saves the changes |
| **OK (confirmation) button** | It confirms the settings |
| **Back button** | It goes back to the previous window/mode |
| **One button override** | Access to a pre-set program (either to get energy saving or comfort) |
| **Unoccupied until button press** | To start the HVAC only when needed. Particularly useful for conference rooms |
| **Scroll Wheel** | |
| **Switch between F and C display** | |
| **Copy schedule button** | To avoid replicating the same steps for all the programmable days |
| **+1 Hour heat/cool boost** | (European systems) |
| **1-touch daylight savings time key** | To quickly switch to DST. The switch can be automatic in some thermostats |
| **Installer Clear Button and Reset Button** | |
| **Soft touch key** | |
| **Speed Dial®** | Lux patent; easy access to the different setting modes |
| **Voice control** | |
| **COMMUNICATION INTERFACE** | |
| **Infrared connection to the Remote Control** | |
| **Wired connection to the TV** | |
| **Wireless connection inside the house: ZigBee™** | |
| **Wireless connection inside the house: Z-Wave®** | |
| **Wireless connection inside the house: WiFi™** | |
| **Wireless connection inside the house: RedLink™** | Honeywell |
| **Wireless connection inside the house:** | |

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|---|---|
| **FlexNet™** | |
| **Wireless connection inside the house: other protocols** | |
| **Wireless/wired connection inside the house: X10™** | Open source standard; powerline carrier communication or wireless |
| **Wireless/wired connection inside the house: INSTEON™** | Powerline carrier communication or wireless |
| **Wired connection inside the house: N2** | |
| **Wired connection inside the house: LonWorks** | Powerline carrier protocol |
| **Wired connection inside the house: HomePlug** | Powerline carrier protocol |
| **Wired connection inside the house: Ethernet** | Ethernet Cable |
| **Wired connection inside the house: R232** | |
| **Wired connection inside the house: RS485** | |
| **Communication outside the house: Radio Frequency (RDS)** | One- or two-way communication |
| **Communication outside the house: Telephone control (using telephone touch pad or voice)** | |
| **Communication outside the house: Page network** | |
| **Communication outside the house: Text messages (SMS) activation** | |
| **Communication outside the house: Web Interface via Gateway** | TCP/IP communication, Web interface |
| **Communication outside the house: E-mail** | |
| **Communication outside the house: Smart Phone applications** | iPhone, iPad, Android, etc. |
| **USB port for setup** | To upload saved settings |
| **U-Snap™ port** | |
| **Plug-N-Go Networking ™** | Quick network installation |
| **POWER SUPPLY** | |
| **Battery only** | |
| **Hardwired (24vac, 240 vac, 120 vac)** | |
| **Hardwired (millivolt)** | |
| **Hardwired and Battery** | |
| **DATA AND SETTINGS STORAGE** | |
| **Volatile memory** | |
| **Volatile memory (with battery backup)** | |
| **Nonvolatile memory** | To backup all the settings and programs |
| **SPECIFIC CONTROL TO OTHER EQUIPMENT** | |
| **Heat only** | |

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| **Heat and cool** | |
| **High efficiency furnace** | |
| **Heat pump** | |
| **Heat pump with backup heat/cool** | |
| **Multistage** | Take advantage of a multi stage HVAC: A multi stage heater or air conditioners contains more than one burner or compressor (or a single unit with different speeds)<br>As demand increases, the multi stage unit can respond by bringing extra capacity online to meet the demand<br>A multistage thermostat can trigger the higher capacity based on setpoints, time or using algorithms |
| **Line Voltage** | |
| **Cooling with Reheat** | The thermostat controls reheat coils which heat the air delivered to areas which do not require the full cooling capacity of the air |
| **Radiant floor** | |
| **Steam Heating** | |
| **Radiant ceiling** | |
| **Radiators** | |
| **OTHERS** | |
| **Mercury-free product** | |
| **ENERGY STAR compliant** | |
| **Meets California title-24** | |
| **FCC Class B compliant** | |
| **UL, CSA certified** | |
| **Energy use monitor** | Records system ON (run) time; this feature can store and display info in different ways such as today, yesterday, cumulative, etc. |
| **Program Lock** | Blocks any possible change to programs, to prevent resets or changes of settings; it allows temporary temperature changes |
| **Instruction in the back of the door** | |
| **Detachable device** | Thermostat can be detached from its base in order to enter schedules from the comfort of a chair |

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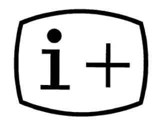
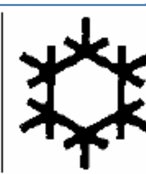
| **Integrated solar generation management** | |
| **Algorithm to average temp from different sensors** | |

## Appendix C: List of Standard Symbols

Various international standards organizations have assigned specific meanings to symbols and icons. This approach allows users to understand controls even when they are not familiar with the language. Hundreds of symbols have been adopted; however, this list consists only of those symbols that may have relevance to residential thermostats. Note that ISO stands for International Organization for Standardization, CEN for the European Committee for Standardization, and IEC for the International Electrotechnical Commission.

| Number/ Name | Definition | Symbol |
|---|---|---|
| 5005<br>Plus; positive polarity | To identify the positive terminal(s) of equipment which is used with, or generates direct current.<br>*Note – The meaning of this graphical symbol depends upon its orientation.* | + |
| 5006<br>Minus; negative polarity | To identify the negative terminal(s) of equipment which is used with, or generates direct current.<br>*Note – The meaning of this graphical symbol depends upon its orientation.* | − |
| 5510<br>Additional information on screen | To identify the control to display additional information for the user, for example input source, selected function, warning, time, etc. |  |
| ISO 7000<br>n° 027 | COOLING; AIR CONDITIONING<br>This snow flake differs from snow flake n°10, intended to avoid ambiguity/mix-up with frost. |  |
| ISO 7000<br>n° 2614 | FROST, ICY<br>This snow flake differs from snow flake n°8, intended to avoid ambiguity/mix-up with cooling. |  |
| ISO 7000<br>n° 543 | AIR COOLING |  |
| ISO 7000<br>n° 2626 | Air conditioning OFF, not available |  |

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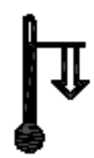
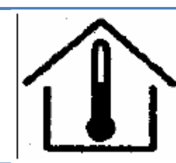
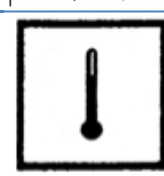
|---|---|---|
| ISO 7000 n°535 | TRANSFER OF HEAT IN GENERAL, HEAT, HEATING |  |
| ISO 7000 n° 0537 | AIR |  |
| ISO 7000 n° 0089 | VENTILATING FAN ; AIR CIRCULATING FAN |  |
| ISO 7000 n° 034 | TEMPERATURE |  |
| ISO 7000 n° 035 | TEMPERATURE INCREASE Heating or cooling control function Room, air, or water temperature |  |
| ISO 7000 n° 036 | TEMPERATURE DECREASE Heating or cooling control function Room, air, or water temperature |  |
| Industry practice (CEN/N719) | INSIDE TEMPERATURE |  |
| Industry practice (CEN/N719) | ROOM TEMPERATURE |  |
| Industry practice (CEN/N719) | OUTSIDE TEMPERATURE Outside building (or outdoor) measured temperature. |  |

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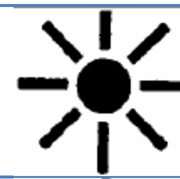
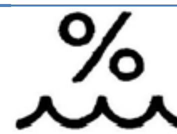
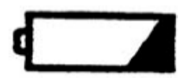
|---|---|---|
| Industry practice (CEN/N719) | COMFORT, NORMAL OR DAILY OCCUPANCY<br>A nominal mode, for a normally occupied room for daytime.<br>On ISO and IEC, the sun symbol is used for different meaning (camera, photography), e.g. 508. |  |
| Industry practice (CEN/N719) | PRECOMFORT<br>A reduced mode. The mode allowing the room temperature to quickly reach the nominal temperature as the final room state upon changing to the nominal operating mode. |  |
| Industry practice (CEN/N719) | OCCUPIED<br>A nominal mode. The mode for a normally occupied house. |  |
| Industry practice (CEN/N719) | SLEEPING<br>A reduced mode. The mode for a temperature satisfying sleeping conditions or for a nighttime. |  |
| Industry practice (CEN/N719) | WEEK-END or special days<br>A nominal mode. The mode for extend a nominal mode, overriding reduced modes for a week end duration. |  |
| Industry practice (CEN/N719) | VACANCY, HOLIDAY<br>A reduced mode. The mode for extend a reduced mode, overriding nominal modes for some days, e.g. for a holiday period. |  |
| ISO 7000<br>n° 0505 | RELATIVE HUMIDITY, MOISTURE CONTENT |  |
| IEC 60417-1<br>n° 5546 | BATTERY CHECK<br>To identify a control to check the condition of a battery or to identify the battery condition indicator. The size of the darkened area may vary with charge |  |
| IEC 60417-1<br>n° 5181 | VARIABILITY IN STEPS<br>To identify the device by which a quantity is controlled. Device or function user interface Step-by-step quantity value input. |  |
| IEC 60417<br>n° 5004 | VARIABILITY<br>To identify the control by means of which a quantity is controlled.<br>Device or function user interface Progressive quantity value input.<br>(see also IEC 60417 n° 5183) |  |

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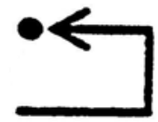
|---|---|---|
| IEC 60417-1<br>n° 5569 | LOCKING<br>To identify on a control that a function is locked or to show the locked status Device or function user interface<br>See an other lock symbol on ISO 7000 n° 1656 |  |
| IEC 60417-1<br>n° 5570 | UNLOCK<br>To identify on a control that a function is not locked or to show the unlocked status Device or function user interface |  |
| IEC 60417-1<br>n° 5495 | RETURN TO AN INITIAL STATE<br>To identify the control which returns a device to its initial state Device or function user interface programming. |  |
| ISO 7000<br>n° 96 | MANUAL CONTROL |  |
| Industry practice (CEN/N719) | AUTOMATIC MODE<br>The mode of operation when control functions are not overridden by the user. Text could be put in a rectangular frame. | **AUTO** |
| ISO 7000<br>n° 0908 | OPERATOR'S MISTAKE Device or function user interface |  |
| IEC 60417-1<br>n° 5184 | CLOCK ; TIME SWITCH ; TIMER<br>To identify terminals and controls related to clocks, time switches and timer. |  |
| IEC 60417-1<br>n° 5440 | PROGRAMMABLE TIMER, GENERAL<br>To identify the control for a programmable timer, for instance the operating element for a programmable function |  |
| IEC 60417-1<br>n° 5417 | PROGRAMMABLE DURATION<br>To identify the control of a programmable timer for the ON-condition of a part of equipment at a present point of time and for a determined duration. |  |
| Industry practice (CEN/N719) | MENU<br>Program, function or mode selection. Text could be put in a rectangular frame. | **MENU** |
| Industry practice (CEN/N719) | PROGRAMMING MODE<br>Program or parameter introduction. Text could be put in a rectangular frame. | **PROG** |

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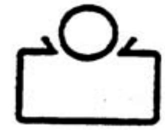
|---|---|---|
| IEC 60417-1<br>n° 5581 | SAVE, ECONOMIZE<br>To identify a control whereby an economy program become activated, for example to save energy or water. Energy-saving mode for a room that does not need to be in a nominal mode. |  |
| Industry practice (CEN/N719) | LOAD SHEDDER<br>Function for peak load limitation of energy in accordance with energy supply tariff (electricity, natural gas, heating or cooling network…) |  |
| ISO 7000<br>n° 0422 | READY (to proceed) |  |
| IEC 60417-1<br>n° 5307 | ALARM, GENERAL<br>To indicate an alarm on a control equipment. |  |
| IEC 60417-1<br>n° 5308 | URGENT ALARM,<br>To indicate an urgent alarm on a control equipment |  |
| ISO 7000<br>n° 2301 | URGENT ALERT INDICATOR |  |
| ISO 7000<br>n° 093 | Remote control |  |
| 0094 | Control; controlling |  |
| 0095 | Feedback control |  |
| 0175 | Temperature control |  |

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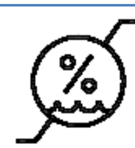
|---|---|---|
| 0224 | Measure humidity |  |
| 0533 | Upper limit of temperature |  |
| 0534 | Lower limit of temperature |  |
| 0559 | Cooling control |  |
| 1603 | Malfunction, general; failure |  |
| 1628 | Setting too high |  |
| 1629 | Setting too low |  |
| 1962 | End of data entry; data collection terminator |  |
| 2017 | Insert |  |
| 2026 | Help |  |
| 2620 | Humidity limitation |  |