Advanced Thermostats for Small- to Medium-Sized Commercial Buildings

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Abstract

Large commercial buildings typically incorporate building management systems (BMSs) that facilitate the control of multiple HVAC systems. Such BMSs are not as prevalent in smaller commercial buildings due to their cost and complexity. However, advanced thermostats are emerging that can provide Internet communication and enable the visibility and control of HVAC systems needed to reach higher levels of efficient operation in this smaller class of buildings.

Quick, easy, and ubiquitous communication capabilities create opportunities for energy and demand savings through enhanced HVAC performance management by facility staff. Additionally, the newest advanced thermostats can integrate with and control other energy consuming systems, such as lighting and/or plug loads. The combination of these features suggests that advanced thermostats have the potential to fulfill the original savings promised by programmable thermostats, change the relationship between the HVAC unit and facility staff, and become the central building block of modular and more cost-effective BMSs.

Introduction

An advanced thermostat is a programmable thermostat that can communicate with the Internet or an intranet via a wireless or wired network. The device controls an HVAC unit via existing wires in the same way that a standard programmable thermostat does. Other names for advanced thermostats are “web-enabled programmable thermostat,” “connected thermostat,” and “smart thermostats.” The three key components of an advanced thermostat system are hardware, communications, and software. The following subsections describe the most common technical configurations available and deployed today.

Hardware

The core hardware element of an advanced thermostat system is the actual thermostatic unit, which controls the HVAC system. Advanced thermostatic units operate identically to standard programmable thermostats and replace them one-to-one. Like standard programmable thermostats, they are not designed to control multizone or variable air volume systems. Unlike standard programmable thermostats, advanced thermostats often include supplementary relays that can be used to collect data from peripheral devices, such as occupancy or temperature sensors, or to control other equipment, such as lighting. Input and output channels are capable of delivering and receiving continuous (e.g., temperature) and discrete (e.g., on/off) signals to and from the thermostatic unit. These expanded control and data collection capabilities are foundational elements of the expanded value proposition and market transformation potential offered by advanced thermostats.

Communications

Advanced thermostats communicate, either wired or wirelessly, to the Internet or an intranet. In this context, “communications” does not refer to communications between the thermostat and the HVAC unit, but rather between the thermostat and the Internet or “cloud,” typically via a wired Ethernet, Wi-Fi, or wireless mesh networks such as ZigBee. These communications enable remote control through the web-based interface and also send data back to a server where it can be analyzed and reported. Communications capabilities are essential to the definition of advanced thermostats; without them, these thermostats would not be considered “advanced.”

Software

In most commercial applications, the advanced thermostat is communicating to a web-based software platform that enables remote, account-based access to all the thermostats in the system. This access allows authorized users the ability to remotely view and control the thermostats’ schedules and setpoints, overriding local controls. These abilities have important consequences:

- The act of programming thermostats is made substantially easier through the use of the relatively intuitive and easy-to-manipulate interface of the computer rather than the often challenging interfaces of standard programmable thermostats.
- Maintaining setpoints and schedules is made substantially easier by consolidating the controls of many disparately placed thermostats into one web-based interface that offers one-click resets of all thermostats in the fleet and is accessible everywhere.
- A web-based software allows maintenance staff the option of limiting or disabling local controls. This helps maintain setpoints and schedules by limiting or eliminating local tampering.

In addition to remote visibility and control, the software supports the processing and storage of data. This data can be leveraged in real time to provide automated alerts via email or text when trends are identified, such as when a unit is slow or unable to reach setpoint. It can also be used to operate a unit more efficiently such as when historical usage patterns and outside air temperature are analyzed as part of "smart recovery" to minimize the time a unit runs while recovering from setback periods. In addition, this data can be stored and analyzed on regular intervals.

Value-Added Components

The capabilities described above provide for a range of value-added features in the categories of controls integration, performance management, energy savings, and demand management. The following subsections describe the most common and useful features available and deployed today.

Controls Integration

Integration and interoperability with other control and data collection devices is a major value-added component of advanced thermostats. Advanced thermostats achieve this connectivity to other devices through three main methods:

1. Built-in connectivity – Achieved through auxiliary relays or supplementary system-enabled hardware. Auxiliary relays are attached to the thermostat itself, while the system-enabled hardware that includes relays links to the software system, but does not control an HVAC unit (e.g., a Wi-Fi enabled relay). These two components – auxiliary relays and system-enabled hardware that includes relays – can be used to collect input from control sensors, diagnostic probes, and basically anything that can be controlled by a switch (e.g., lighting or plug loads) or which can emit a discrete (e.g., on/off) or continuous (e.g., a value between 0–100) voltage signal. An example of system enabled hardware is offered by BAYWeb.[1]
2. Open-source interoperability – Hardware control units such as wireless plug-load controllers that are manufactured by companies other than the advanced thermostat vendor can be made to communicate wirelessly with the advanced thermostat and its back-end software.
3. Application programming interface (API) (custom and partnerships) – Most advanced thermostat software suites include an API, which can be customized to meet the needs of specific applications or end users. Many product developers can use their API for demand-response applications or cross-communication to other software systems such as a BMS.

The first advantage afforded by controls integration is the ability to leverage additional data by connecting to sensors such as discharge air temperature or occupancy sensors. These can be used to monitor or control the performance of the HVAC unit.

The second and more transformative advantage of controls integration is the ability of an advanced thermostat to act as a hub for an "internet of things" in the building. Linking up with other energy-consuming systems such as lighting, electric water heaters, plug-loads, or basically any electric-powered device, these devices can then be monitored and controlled in the same way that the HVAC unit is controlled: in response to outdoor temperature, occupancy, or schedules. Acting as a hub, the advanced thermostat transcends its original purpose as a device used to control the output of an HVAC unit and instead becomes the central element of a modular, simplified or "light" BMS that can be scaled incrementally to include essentially any simple energy-consuming system that can be controlled through an electric relay. These systems include lighting, electric water heaters, commercial equipment (e.g., coffee maker at a café), refrigeration, and other generic plug loads (e.g., office equipment). It's worth emphasizing that these systems can then access the same monitoring and controls capabilities offered to the HVAC unit. For example, a refrigeration system could have a temperature probe installed to monitor and

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[1] http://www.bayweb.com/mktg/webintegrator.php

report on system performance, and a door-contact sensor could be installed to alert facility staff when a walk-in refrigerator door has been left open. The possibilities are profound and will be discussed further in the "Market Transformation Potential" section.

Performance Management

The data monitored and collected by the advanced thermostat system enables basic performance management functions that improve the ability of HVAC contractors and facility staff to remotely identify and characterize problems. Automated alerts, remote visibility of real-time system performance, and regular, long-term data logging support the day-to-day efforts of building staff and HVAC contractors:

- Comfort complaints can be investigated and, if necessary, rectified remotely using the web-based interface – often without ever traveling to the facility or the space.
- Automatic emails and text messages can alert the managing staff to problems before they result in complaints or before the equipment suffers permanent damage from malfunction.
- Regular (e.g., monthly) reviewing of performance reports can alert the management staff to problems before they devolve into a crisis. Performance degradation over time is often overlooked, as it happens slowly and thus goes unobserved until it has gotten dramatically worse.

Energy Savings

Advanced thermostats can save energy relative to standard programmable thermostats:

- The most commonly experienced savings are likely to result through the improved usability, which makes it easier and more convenient to view, set, and maintain schedules. If the facility maintained its thermostats poorly or had no thermostats, then the savings could be substantial.
- Advanced control features such as smart recovery or smart staging can glean modest heating and cooling savings in certain circumstances. Smart recovery uses historical data and outside air temperature readings to minimize the time a unit runs while recovering from setback periods. Smart staging uses similar data to achieve a setpoint by prioritizing a unit's more efficient stage (e.g., running the heat pump longer rather than using the electric resistance booster).
- In circumstances where there is intermittent occupancy, additional input from a traditional motion detector, door-contact switch, or key-card sensor can dynamically match conditioning to the times that it is needed. This has been shown to be especially effective in, for example, mobile classrooms and hotel rooms, where savings have been as high as 40% on heating and cooling costs.[2].
- Multisystem controls integration has the potential to yield large savings in cases where large, previously uncontrolled loads, such as lighting, are brought into the control system and put on a schedule or tied to a sensor.

Demand Management

Advanced thermostat manufacturers currently include some features that relate to demand management. Overall, most of these features are manual, and automated demand management still has some way to go before the technology is ready for mass consumption.

Automated Demand Response

Many advanced thermostats were designed specifically for automated demand-response programs, particularly in the residential sector. Nonresidential units with the integration capabilities described above tend not to have automated demand-response capabilities built in, but they can achieve those capabilities by integrating via their API to the software of a demand-response aggregator. As a result, and since most units include APIs, advanced thermostats today are typically capable of facilitating automated demand response.

Market Transformation Potential

Advanced thermostats make it easier and more convenient to view, set, and maintain temperature setpoints by replacing at-thermostat controls with web-based, remotely accessible interfaces. In addition, remote visibility and control fundamentally change the relationship between the HVAC systems and those that maintain them. The ability to instantly view system setpoints, operational schedules, and status from any Internet browser or mobile phone has important implications for the way HVAC contractors and facility managers do their job.

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[2] http://www.techzone360.com/news/2010/03/16/4675008.htm; http://www.magnumenergysolutions.com/case-study.php

However, the most significant impact will be supporting a modular, light BMS. The potential market transformations described are based on the capabilities that exist today and on anecdotal evidence for how installed advanced thermostats are being used.

A Modular Building Management System

The integration capabilities of advanced thermostats are perhaps the features with the potential for the biggest impact on the market. Integration capabilities make it possible for the advanced thermostat to act as the cornerstone of a modular energy management system (EMS) that can achieve most of the capabilities of a BMS at a fraction of the cost.

Advanced thermostats can be easily configured to control lighting, water heaters, and any other equipment controlled by an electric circuit. This can be achieved either directly through the thermostat or through supplemental hardware that leverages the same communications and software platforms. In this sense, the advanced thermostat is a stepping stone to something much greater. Upon installation, customers enjoy the benefit of the advanced thermostat's non-integration features (which are the primary marketing point, at this time), and they are also provided robust software connectivity that allows other equipment to be integrated with relatively little marginal cost. The additional equipment can be integrated iteratively and slowly over the course of time, which makes the system modular. Vendors report that most consumers choose not to integrate non-HVAC equipment into the system at the time of original installation; those that do, though, report satisfaction. It remains to be seen whether consumers will recognize the value of monitoring and controlling non-HVAC equipment, but the advanced thermostat is the entry point by which these light BMSs will take hold if they are to do so.

These authors do not believe advanced thermostat systems will replace BMSs. Advanced thermostats are not intended to control more advanced HVAC systems including variable air volume systems, which tend to be managed by BMSs. Down market, however, the advanced thermostat system can be used as an effective substitute for a BMS in small- to medium-sized buildings where the costs of a BMS cannot be justified. While all vendors suggested that costs vary substantially by installation, self-reported costs ranged from approximately $750 to $1,250 per thermostat installed. While this is two to five times the cost of a regular thermostat, it is a fraction of the cost of a traditional BMS, offering small- and medium-sized buildings an alternative way to control their energy consuming systems.

Barriers to Adoption

Advanced thermostats offer new challenges to HVAC contractors and end users. Overall, the product is intended to be simple and easy to understand. This is primarily accomplished by making it familiar. Nearly all the vendors indicated that in terms of control issues, an advanced thermostat is "just a regular thermostat" with some bells and whistles – all HVAC contractors should be able to connect the thermostat to an HVAC unit without issue once they realize the control wiring works exactly the same behind the wall. Power issues are not entirely new either; nor are they especially complicated. According to the vendors, most HVAC contractors require little assistance in this realm. The most popular power mechanism – power by common wire – is a holdover from programmable thermostats with larger power draws. Ethernet and battery power methods are newer, but are relatively intuitive. Issues with control and power tend to be small and easily solved. Most vendors have developed online support forums or FAQs, which vary in quality, to deal with simple issues, and some offer dedicated tech support call-in numbers that operate 24/7.[3]

All vendors agreed that the biggest knowledge gap surrounds the communications technologies. While setting up advanced thermostat networks is by IT standards a fairly simple task, HVAC contractors are unfamiliar with this type of technology. Most vendors see this issue as an industry-wide learning curve that would eventually be overcome. This gap has contributed to a lack of uptake of advanced thermostats in the retail and distributor market channels. In order to overcome this challenge, most vendors have developed HVAC partner networks that include training on such issues as communications as a condition of joining the network.

Additionally, understanding how to use the thermostat is another potential gap. Most vendors interviewed suggested that end users rarely if ever requested training. They attributed this to "idiot-proof" design and familiarity. Thermostat settings on an advanced thermostat are broadly similarly to those on a standard programmable thermostat, with the key difference being a web-based interface that is simpler to interact with. In order to promote proper operation of the basic functionality, vendors such as Ecobee offer regular webinars[4] and

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[3] http://support.nest.com/customer/portal/articles/197951; http://www.ecobee.com/support/resources/; http://www.bayweb.com/mktg/downloads.php

[4] http://www.ecobee.com/contractors/webinars/

online video resources[5] for interested parties. Other vendors suggested they were developing the same types of material.

Advanced thermostats offer a suite of more advanced features that are not covered by these resources and that may or may not be used properly, regardless of whether customers and installers request training on them. Connecting vendors to actual feedback from users regarding those features (e.g., smart recovery, parameter-based alerts, and integration) that they are using, not using, or potentially misusing is important to ensure that the product category is reaching its full potential. A misunderstanding of the value of advanced features by users and installers alike is holding back key distribution channels such as retail and distribution and seems also to be inhibiting greater uptake of advanced features such as integration. Training sponsored by vendors or program administrators could improve this situation and contribute to an increase in general industry-wide awareness.

Conclusion

Advanced thermostats hold the potential to transform the market for controls of HVAC and other energy-consuming equipment in nonresidential settings. All of the features described are available today and have been deployed already. Similarly, the opportunities for market transformation described above are representative of how the units are being used in some installations today.

Overall, though, advanced thermostats are underutilized in two distinct and important ways. First, the market is not yet deploying these units at much scale. Research suggests that installation numbers have been deflated by installers' lack of understanding of advanced thermostats in general and communications technology in particular. Vendors have reacted by shifting their business models to promote trained HVAC-contractor networks and to rely more heavily on direct sales, rather than distribution or retail. This has led to a growth in overall installations, and we suspect that it will continue and expand as knowledge of this technology disseminates and greater numbers of installers recognize that they can increase revenues by installing these more costly units. We also believe this trend can be further encouraged by program administrators. Utility and state government programs can lend their credibility to the technology and put greater resources behind training the broader market of thermostat installers.

Expanding the number of installations will not, on its own, guarantee that advanced thermostats fulfill the potential described in this paper. Most of those already installed are not being fully leveraged, which is the second way that advanced thermostats are underutilized. On the one hand, interview responses suggest that customers are effectively using the units to better set and maintain their setpoints and schedules, and that one of the greatest added values has been the way that maintenance staff have leveraged remote control to make their jobs easier and more efficient. On the other hand, HVAC contractors have yet to embrace the business model opportunities offered by remote control and visibility. Effective use of the newly available data is still limited at the building level and non-existent at the industry level, and – most importantly – very few customers have embraced the notion of the advanced thermostat as the central node in a light BMS. While use of peripherals, for example to measure discharge air temperature, is quite common, full-scale controls integration of lighting and other energy-consuming equipment is exceedingly rare. We suspect that these unfulfilled market transformation opportunities will be tapped, if slowly, as customers and installers become more comfortable with the technology. That said, we believe that program administrators can accelerate these market transformation outcomes by, for example, incentivizing expanded installations that include lighting and other energy-consuming equipment, encouraging HVAC contractor business model transformation to include advanced thermostats through training and conferences, or requiring that incentivized installations provide data back to the program so that it can develop an industry-wide database of HVAC performance. These sorts of actions are important not only to ensure that advanced thermostats are installed at a much higher rate, but also that those units installed are maximally utilized so that the technology can achieve its full potential.

[5] http://www.ecobee.com/support/resources/tutorials/