Thermostats Can't Fix This: Case Studies on Advanced Thermostat Field Tests

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ABSTRACT

The technology for thermostats has changed significantly in the past decade. More advanced features such as programmability offer great potential for energy savings. But with this increased technical complexity has come a corresponding complexity in the user interface. Some manufacturers have attempted to deal with this by adopting a deployment model that transfers to the installing contractor responsibility for the initial setup and user instruction.

This paper describes a study of advanced thermostats installed in three non-residential locations. A baseline survey was conducted to measure pre-installation comfort, satisfaction and usability of existing thermostats. The advanced thermostats were installed by contractors, and their usability was assessed by assigning usability tasks to end users and conducting a post-installation survey. Effects on HVAC electricity usage were estimated using SmartMeter and meteorological data collected from comparable pre- and post-installation periods.

There were many problems with study implementation, due mostly to weaknesses in the deployment model. Once operational, occupants' responses to the thermostats were almost universally negative. Most users surveyed were unsure of how the thermostat worked, and had little confidence in their effective management of it. It was found that significant training and support would be needed to enable occupants to effectively operate the advanced thermostat and optimize their energy use. Estimates of the thermostats' effect on HVAC-related electricity consumption ranged from modest but positive energy savings to negative energy savings. Recommendations are made on how to improve the deployment model to make advanced thermostats such as those tested in this study appropriate for utility-funded thermostat replacement programs.

Background

In theory, there is great potential for energy savings from thermostats. Even inexpensive programmable ones have the potential to save 30-50% of energy use from heating, ventilation and air conditioning (HVAC) (Nguyen and Aiello, 2013; and Maheshwari et al., 2001). But actual savings falls substantially short of that, ranging from modest savings (see RLW Analytics, as cited in Peffer et al., 2011) to negative energy savings (see Meier et al., 2011).

The failure of programmable thermostats to deliver substantial energy savings is due in large part to the fact that many users simply do not program their thermostats. In California, estimates show that as few as 50% households program their programmable thermostats (see Archacki, 2003, as cited in Peffer et al., 2011; and Meier et al., 2011).

There are many reasons for this. In fact, a study by Meier et al. (2010) provides a two-page list of barriers to using programmable thermostats, including misconceptions about energy and thermostats, and complaints/issues about programmable thermostats and thermostat instruction manuals.

So-called advanced thermostats aim to deliver energy savings by providing the ability to grant different levels of access, improving access through web portals, improving users' ability to control the thermostat settings and schedules through more user-friendly web interfaces and contractor engagement, and promising energy (and cost) savings. Realizing the latter requires that a more conservative schedule is implemented upon the change. The implicit assumption is that the thermostat it replaced was not programmed (nor operated manually in a way that conserved energy) and that the added features mentioned above will increase the likelihood of programming a conservative schedule.

Most advanced thermostats that offer these features are sold to the customer by an HVAC contractor, who is expected to program the thermostat or instruct the customer how to do so. This business model essentially circumvents the problem of users' lack of ability or motivation to program a schedule, but the extent to which it actually plays out that way is unknown. This study provides some indications of how such a thermostat is utilized and functions in reality.

Study Design and Methodology

The study was conduct as a sub-project as part of a larger effort to investigate advanced controls and sensors for commercial building packaged HVAC. The authors worked with California IOU Emerging Technology departments to conduct a scaled field placement of advanced system control sequences, sensors, and displays for small and medium commercial packaged HVAC applications.

Advanced wireless thermostats promise improved programmability and control through a web portal, energy savings through better programming and remote access, and real-time and historical energy use data to facilitate better system management. The aim of the study was to empirically test those claims by field testing the thermostats at three non-residential sites.

Specifically, the primary objectives of the study were to determine whether users can engage with an advanced thermostat's interfaces as desired, and whether or not they use the thermostat features in ways that save energy. As the study progressed, the initial scope was expanded to include a preliminary assessment of the wireless thermostat deployment model and its impact on users.

The field study was conducted between June 2013 and February 2014. Pre- installation surveys were conducted in June 2013. Thermostat installation took place in June and September of 2013 (with re-commissioning in October due to errors in the initial installation at the school). Post- installation surveys were conducted in October. Energy use data was collected for the pre-installation period of September/October 2012, and the post- installation period of September/October 2013. Long delays between the baseline survey and initial energy data collection resulted from inadequate setup upon installation (a problem that stems from flaws in the deployment model rather than the study itself).

Thermostat Selection and Installation

The thermostat selected for the field tests is a web-connected "advanced" thermostat with a basic user interface on the device and a more comprehensive user interface on its web portal, accessible by computer or smart phone through a website or application. In addition to setting schedules, the web portal provides access to temperature settings, schedules, real-time and historical energy usage and temperature settings data.

According to the business model (typical for similar thermostats), the thermostat is sold to customers through HVAC contractors who install the hardware and (presumably) instruct customers on how to use it. Ongoing support for usage of the device is offered by the manufacturer, and the contractor retains responsibility for responding to system issues, as indicated by the data output and communicated either to the contractor directly, the customer or both.

The study differed from the typical process in that the hardware was offered to participating study sites free of all charges, including installation by HVAC contractors, by the researchers. However, the numerous challenges experienced during and after installation are not solely attributable to the unique circumstances of the study. For example, the availability and reliability of the Wi-Fi network within the facility (although critical for online access and control) are not considered within the scope of thermostat manufacturers nor is it within the realm of expertise of the HVAC contractor.

As the installation of the thermostats progressed, a number of technical and instructional failures and misunderstandings occurred affecting all the actors involved, including the participants, the installing contractors and technicians, the thermostat manufacturer and service providers, and the research team (which was treated as a tech support service by some users). All sites experienced problems, but especially the school. Some specific examples of the issues are presented in the case studies below.

Site Selection and Participant Engagement

The study took place in 3 non-residential buildings: a school (CA CZ 04), a restaurant (CA CZ 12) and a clubhouse (CA CZ 12). Each of these buildings had facilities managers, although the level of responsibilities and tasks of these managers differed across sites (as described below in the case studies). Because of the differences in management and use structure in the three sites, the number of study participants per site varied widely. The study initially targeted 14 users in the school (teachers and facilities manager), 1 participant in the restaurant (owner/facilities manager) and 3 participants in the clubhouse (facilities managers and operators).

Targeted participants were recruited to the study via email (in the case of the restaurant and clubhouse), and in person (in the case of the school). They were offered monetary incentives to participate in the study.

Communication between study participants and researchers was conducted via email and a message board. The latter was also used to assign thermostat tasks to gather empirical data on thermostat usability, while the former became the primary mode for asking questions and expressing frustrations about the thermostats.

Initial Evaluation Survey

Before installation of new thermostats, researchers conducted a survey of occupants of the zones to be controlled by the new advanced thermostats. This survey was done online, using the internet survey manager SurveyMonkey. Participants were sent the web link for the survey via email, and given a period of time during which they could respond, after which a reminder was sent by email.

This initial survey was intended to provide a baseline of user experience with their "old" thermostats, to be later compared with user experience with the newly installed thermostats. The first survey addressed the following key topics:

- Perceived product usability: ease with which users can manipulate the "old" thermostats
- Perception of efficacy: users' perceived effectiveness of the thermostats in doing what the occupants want to do
- Barriers to use: technical and non-technical aspects of thermostats which make them difficult to use effectively
- Comfort: self-report of thermal acceptability using sensation (very cold > very hot) and comfort (very comfortable > very uncomfortable) scales

Data from the first survey was collected from 14 respondents (10 from the school, 3 from the golf club, 1 from the restaurant). Key results from the pre-installation survey are presented below in the case studies.

Usability Tests

Twice the research team posted thermostat task requests which the participants were asked to complete. Through the message board, respondents reported on the results of their attempt, discussed difficulties they had completing the task, and posed questions.

Final Evaluation Survey

Follow-up surveys were conducted after the users had a chance to operate the thermostats for at least a month. Again using SurveyMonkey, respondents were asked about the usability and efficacy of the advanced thermostats. Only respondents from the school responded to requests to participate in the online survey. Respondents from the clubhouse and restaurant were contacted by email and telephone but did not respond.

Monitoring Usage and Modeling Energy Savings

Through the advanced thermostats' web interface, researchers had access to the thermostats' actual functioning logs. These logs included the outdoor and zone temperatures, setpoints, current operating mode, and user interactions. Through this, the researchers were able to monitor whether and how users operated the thermostats after installation.

Electricity usage[1] was monitored by gathering pre-install and post-install data from the utility Smart Meter (1 meter per site). Data on hourly outdoor air temperatures was gathered from CIMIS weather stations. Data was collected for the post-install period of September/October 2013 to February 2014 and the corresponding (pre-installation) dates in 2012-2013.

[1] Initially researchers planned to model energy savings from electricity and gas usage, but the latter proved unfeasible. Gas usage for heating was largely irrelevant for the school (which relied on electric heating) and the restaurant (which used little gas for heating, but lots for cooking). Gas Smart Meter was not available for the clubhouse, and monthly gas data was insufficient. Thus, the scope of the energy savings analysis in this study is limited to electricity usage for heating and cooling.

Calculating the energy savings of the advanced thermostat involved:

1. Determining a baseload schedule for each site, and thus isolating HVAC power draw by subtracting the baseload prediction from the total smart-meter measured power draw;
2. Normalizing the HVAC power draw by outside air temperature to account for annual differences between the pre-install and post-install period; and
3. Comparing the normalized HVAC power draw in pre-install and post-install periods to determine if there was an overall energy savings attributable to the advanced thermostat.

The latter was done using a 'hockey stick' regression to relate ambient air temperature to the HVAC kW consumed. Two regressions were performed - one for pre-install and one for post-install - and the resulting difference between the slopes in the HVAC operating region of the plot (> approx. 65F), less the standard error, represents the energy savings attributable to the advanced thermostat. Greater details about the methodology used to calculate energy savings will be presented in a forthcoming report, while results of the analysis are presented in the case studies below.

Case Studies

The key findings of the field tests are illustrated through a set of case studies on each site. The case study of the school is the most comprehensive. Having started with more study participants (14) and yielding both pre- and post-installation surveys[2], the school provides the most details on the process and results of data collection efforts. Mini case studies on the restaurant and clubhouse highlight key differences in the process and/or results to illustrate the range of experience across field sites.

School

Pre-installation conditions. The school had 9 nearly identical RTUs, which were jointly controlled by several different types of thermostats located in nine classrooms and six communal spaces. The facilities manager had access to thermostat management but it was not her exclusive responsibility to regulate them or control any policy regarding their use. Rather, the teachers in each of the thermostat-controlled rooms had complete control over the thermostats of the rooms they were using at a given time.

To establish a baseline for usability, respondents were asked to report on their level of confidence in their ability to perform a number of basic tasks on their existing (non-identical) thermostat. Half or more of those who responded (N=10) reported they were mostly or completed sure they could do the following tasks: find the current room temperature, change the date and time, find the current setpoint, and change the current setpoint. Only two were confident they could schedule the thermostat. Figure 1 below presents the details. The results highlight this common problem with programmable thermostats, one that the advanced thermostat installed later attempts to address.

Installation experience. The advanced thermostats were installed by a contractor in June 2013,

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[2] The other sites had fewer participants and had incomplete post-installation survey data, although feedback on the new thermostats was collected via email communication.

in nine classrooms.[3] When the school session began it was discovered that the contractor had locked out all end users, except via the web portal. This was not the researchers' intent, nor that of the manufacturer. The researchers received complaints and re-commissioned the thermostats in September 2013.

User access and control. Control over the classroom thermostats remained with the teachers assigned to each room. In the early months after initial installation, there was a problem with shared control that stemmed from organization dynamics. The facilities manager had assumed that she would be granted access to monitor usage of all the advanced thermostats through the web portal. A dispute ensued between the facilities manager and classroom teachers. The researcher remained agnostic, as it was not the aim of the study to influence the specific form of thermostat oversight. The power struggle highlights one of the ways in which advanced thermostats can complicate, rather than resolve, institutional circumstances.

Usability. Users of the advanced thermostats at the school reported a generally negative experience with usability and efficacy. As Figure 1 below illustrates, respondents were less sure of their ability to perform basic tasks on the advanced thermostat than they were with their previous one, which was already quite low.

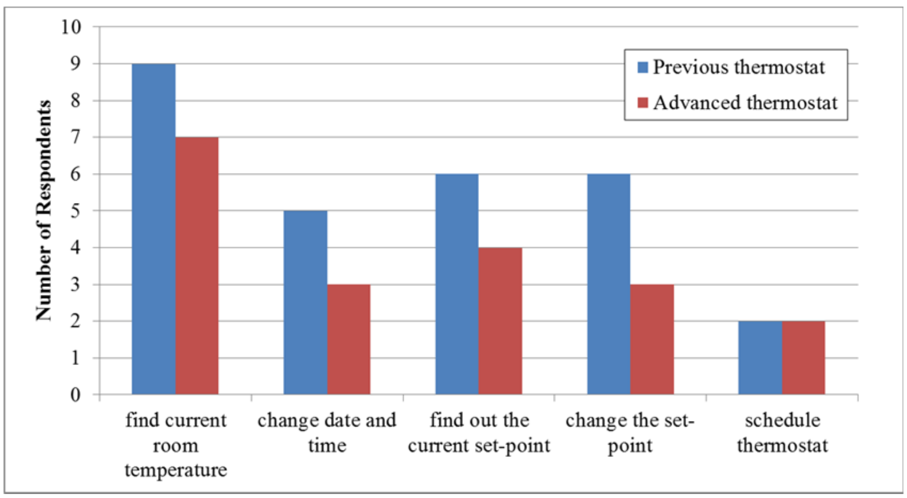

Figure 1. Number of respondents who were confident in their ability to perform various thermostat tasks with old versus new thermostat (N=10). The remaining respondents were "mostly" or "completely" unsure.

In addition to self-reported levels of confidence, respondents were also asked to complete a set of tasks that the researchers could verify using the thermostat log data. The first set of tasks required participants to check the mode the thermostat was in, set it to HEAT (it was winter time, and it had been detected that many thermostats were on COOL mode), and check/modify the date and time. Date and time were correctly displayed in all cases. However, several participants were unsuccessful in reporting and changing the mode.

The second usability task assigned focused on online access, since this had been problematic for some users, and was required for easy access to traditionally difficult tasks, like

[3] Thermostats were also installed in five communal use areas, but were excluded from the usability survey due to erratic usage patterns.

scheduling. Even with the researchers setting up accounts for respondents, there were usability obstacles at every step of the process: login, access to relevant information, and operation. After trying to program a thermostat schedule, one user reported: “I clicked all over it, and nothing I did changed it…I thought it would be easier.” Overall, participants judged the online portal as frustrating and unappealing, and manifested little interest in accessing it or using it again.

Uncertainty about their ability to accomplish basic tasks with the thermostat may have been due in large part to the fact that very few users received training or instructions on using the new thermostats. Indeed, 9 out of 10 respondents reported that there no information or training had been provided at all (i.e., no general information, personal training, hands-on training, written materials provided, or direction towards online materials). As the thermostat manufacturer designed it, this was the job of the installing contractor. In practice, however, such services were rarely, if ever, provided to the field sites.

The lack of training or instruction translated into a lack of even the most basic understanding of how the thermostat works. In a comment echoed by others, one teacher said: “[I don’t like] having people from the outside deciding what [the] temperature should be in my classroom”. This misunderstanding most likely stemmed from the expectation that the “hold” setting was indefinite, as with the previous thermostat, whereas the new ones had been programmed to either two or four-hour hold settings.

Lack of confidence in and understanding of (and possibly interest in) the new thermostats translated to lack of use of advanced features. By accessing the web portal, the researchers were able to verify that in fact none of the occupants at the school logged in to the system to set a schedule or make a change, even when they are “locked out” of the wall devices.

User experience. One aspect of user experience is thermal comfort. Before and after installation, participants were asked how often they felt too cold, too hot or comfortable at the workplace. Overall, ratings under the old and new thermostats indicate a middling level of comfort, with little change between the two.

Another aspect of user experience is perceived efficacy, that is, the perception that the thermostat accomplishes what the user desires it to do. Only one out of ten respondents was “mostly unsure” that the old thermostat did what the user wanted it to do when used. By contrast, that fraction was six out of ten with the new thermostat, and four of them were “completely unsure” the new thermostat operated as they directed.

These results are consistent with some findings in the open ended section of the post-installation survey. When asked to describe, in their own words, their experience with the new thermostats, at least half of the participants mentioned things like “the thermostat seems to have a mind of its own”; “it does not do what I want it to do” or “it turns on and off at will”. Another asked “how can the thermostat be put back into a mode where it operates like a normal thermostat?”

Occupants had frustrating experiences, such as arriving at the site in the morning and finding it very cold and with no heat on. In one instance there was actually a problem with the furnace, but it was not discovered for some time because the occupants assumed that was how the new system was supposed to work. The occupants weren’t sure if the inadequate heating was part of the study, reflected what the thermostat was supposed to be doing, and whether or not they should do something about it. In general, they suffered through the cold temperatures rather than trying to change things, although it’s not entirely clear whether that was due to inability to operate the thermostat as desired, or confusion about whether they ought to.

Altogether, poor usability, low perceived efficacy and lack of improvement in comfort led to broadly negative feelings about the advanced thermostats. Eight or more respondents out of ten said the advanced thermostats made them feel confused, frustrated or out of control (compared to two or three out of ten with the old thermostats).

Energy savings. The regressions for the school were the worst fit of all three sites, which is assumed to be attributable to the non-standard operating hours of the church portion of the facility. An attempt was made to correlate the school's event calendar with hourly power usage based on total daily 'event hours'. This appeared to show some correlation but an exact relationship could not be determined and was deemed unsuitable as a predictor of baseload power consumption. This is suspected to be due in part to a combination of: a) inconsistencies between scheduled times and actual operating times of a building (i.e. rooms are often booked longer than they may actually be required) and, b: large variances in the power use of different types of activities (i.e. due to occupancy, ambient light, indoor vs. outdoor activities, etc.).

Not surprisingly, then, analysis of school's energy usage in nine classrooms yielded inconclusive results regarding energy savings, since their power consumption could not be disaggregated from that of the less predictable communal spaces.

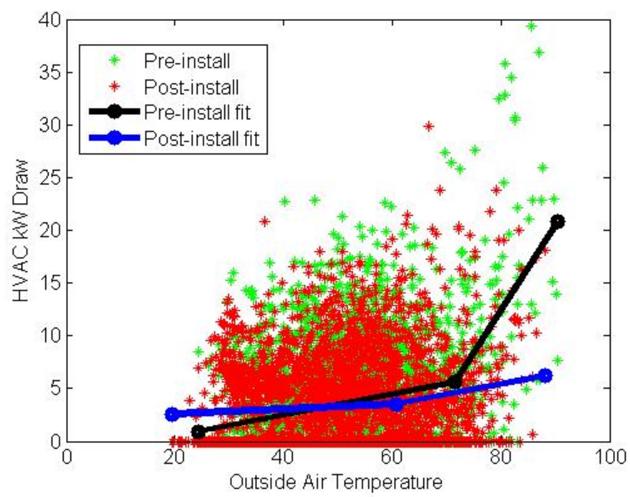

Figure 2. HVAC kW draw versus air temperature at school (October to February, 2012/13 and 2013/14).

Restaurant

Pre-installation conditions. The pre-conditions at the restaurant differed from the school in nearly every way. The restaurant had three operating RTUs, but had little call for heating, as the kitchen generated a lot. Within the last year, the facilities manager (and restaurant co-owner) had installed a programmable thermostat in order to reduce the cost of his substantial energy bills. He had established a schedule of setbacks and conservative setpoints, which had yielded energy savings. He had complete control over thermostat scheduling and it was his exclusive responsibility to manage it. No one else had access to thermostat control.

The restaurant owner was reasonably satisfied with his existing thermostat pre-installation. He reported being "completely sure" he knew how to perform basic tasks including finding the current room temperature, changing the date and time, finding and changing the current setpoint, and scheduling the thermostat, which was markedly better than the average respondent from the school. In addition, he was “mostly sure” it did what he wanted it to do when he used it.

The restaurant owner also reported none of the negative emotions that occupants of the school did (e.g., frustration, anger, confusion) regarding his existing thermostat. In the pre-installation survey, the restaurant owner reported that although he liked his existing thermostat, he would consider upgrading to a thermostat that could be controlled remotely and accommodate deviations from the normal 7-day schedule.

User access and control. Upon initial installation, the restaurant owner set a program that replicated the one he had with his previous thermostat. As before, the restaurant owner remained the sole user of the thermostat, and he controlled it exclusively through the web interface.

Usability and user experience. Despite being an effective and experienced thermostat operator, even the restaurant owner reported errors when using the thermostat. For example, he reported difficulties navigating the thermostat’s web interface when asked to change its settings for the usability task assigned by researchers. Although ultimately successful, he said he had made plenty of mistakes in accomplishing the task because ‘why would [the mode setting] be under "details" rather than "preferences" or "program"?’. Furthermore, the restaurant owner had concerns about usability issues in the future.

> *When ‘time-of-day’ billing hits, just having the choice of occupied or unoccupied won't do. I'm going to have to program in the calendar the hours the system will need to shut-down, completely. However, when the system is set to ‘off’, if the preferences are set to run the fan for a certain number of minutes during the hour, that fan is gonna run. What if I want the whole shebang OFF?*

The restaurant owner summed up his opinion of the advanced thermostat this way: “While really neat [thermostats], they are not user friendly. [There are]…[a]lmost too many choices, and [there is] no quick way to do anything.”

Energy savings. Based upon the methodology described above, it is estimated that the restaurant experienced (negative) energy savings of -6.7% (s.e. 0.43%) of HVAC power draw per degree F (for OAT > 60.6 deg F) with the advanced thermostat.

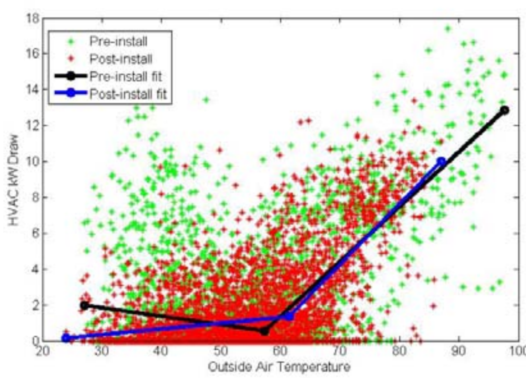

Figure 3. HVAC kW draw versus air temperature at restaurant (September to February, 2012/13 and 2013/14).

This result highlights the fact that the energy savings a thermostat may deliver depends in large part on the baseline. In the case of the restaurant, the owner had established an appropriate schedule with his previous programmable thermostat, which had yielded energy savings over his prior system of manual operation. Despite offering remote access and the ability to create a more nuanced program (accounting for holidays, for example), the advanced thermostat performed worse than the previous, well-programmed thermostat, in terms of energy savings.

Clubhouse

Pre-installation conditions. The clubhouse had 14 RTUs of comparable make and model ranging from 4 to 8 tons of cooling capacity. The original thermostats were extremely old, and when asked, respondents stated explicitly that the thermostats were outdated and needed to be replaced with more advanced models. Two out of three respondents were “mostly sure” the old thermostat did what they wanted it to do when they used it. The other was “mostly unsure”. Only one respondent reported negative emotions about the old thermostat (i.e., it made them feel confused, frustrated, powerless, for example).

The thermostats controlled the heating and cooling in several rooms, a few of which were used sporadically for club functions. A facilities manager oversaw all building operations, and had access to thermostat control and decision making about scheduling. Other employees and visitors to the club were not supposed to have access to thermostat control. However, in practice, thermostats were operated on an as needed basis by clubhouse staff.

User access and control. After the advanced thermostats were installed and commissioned, the facilities manager appointed himself a “super user” and locked others out of the devices. Thus thermostat usage switched from manual operation on an as-needed basis, to a hands-off experience governed by a pre-determined program.

Usability and user experience. One user at the clubhouse reported “no problems with [the] task” after participating in the first usability assignment (checking the date and time and resetting the mode). She reported that in general, the “thermostat [is] very easy to use.” However, another reported that the time was incorrect on one thermostat and missing on two others.

Energy savings. Based upon the methodology described above, it is estimated that the clubhouse saved 3.5% (s.e. 1.00%) of HVAC power draw per degree F (for OAT > 65.1 deg F) over the course of the study period (September 2013 to February 2014). This is largely attributable to the programmed setbacks, which eliminated accidental heating and cooling after hours, although that was not empirically proven. The setbacks were scheduled upon installation and were rarely, if ever, overridden.

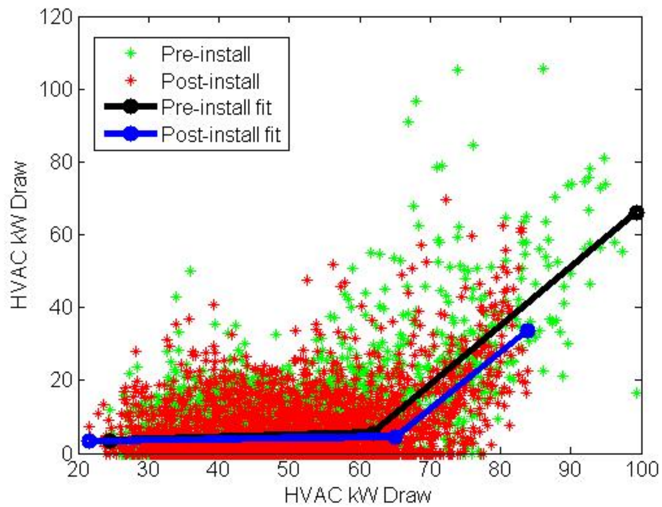

Figure 4. HVAC kW draw versus air temperature at clubhouse (September to February, 2012/13 and 2013/14).

Key Findings

The results of this study were somewhat discouraging, although some lessons were learned that could make future programs more successful.

Usability. Evidence from the, admittedly limited, field tests, suggests that the advanced thermostats posed substantial usability issues for many respondents. The interface on the device itself was not user friendly, and the web interface was difficult to access and not intuitive to navigate. The level of frustration that the occupants experienced, especially at the school, was a surprise. The researchers concluded that the design of the thermostat, which did not provide much information to the user about why it was in the mode it was in, was confusing and frustrating. It is likely that some of these issues would have been ameliorated if end users had been given instructions on how to use the thermostats. None of the respondents at the three test sites received training or instruction, indicating a problem with the deployment model which leaves the provision of this essential service entirely up to the installing contractor's discretion.

Energy savings. Energy savings at the three field sites ranged from modestly positive to negative. The small, non-random sample does not allow for generalization of results, but does indicate that there are certainly many non-residential users for whom the advanced thermostat would not save substantial amounts of energy. It depends enormously on the baseline. Furthermore, evidence from the field tests suggests that the one field site that did garner energy savings did so through the initial programming of the thermostat, not the advanced features. Similar results could have been achieved with a much cheaper thermostat programmed properly.

Deployment Model. The advanced thermostat's deployment, installation and service was full of challenges that highlight the relevance of its service and business model in addition to its technological features. The thermostats were selected by the research team, installed by a contractor selected by the utility, and used by test subjects who had little control over what was happening to them (or at least felt so). Installation did not include troubleshooting of communication issues, and problems in this area did occur when the users attempted to use the web portal. After installation, when the users encountered difficulties, they did not know who to call: their building facilities manager? the contractor? the thermostat manufacturer? The manufacturer had no on-site support capabilities, and was not able to be of much help. Contractors did not have the motivation (or responsibility) to return to the site to address issues such as Wi-Fi malfunctions and missing usernames on the website.

In some cases, the contractor was set up with a “Super User” access to the thermostat, to facilitate support. End user autonomy was not the focus. End users were given no training, instructions, or materials (such as a manual) by their installing contractor. The vast majority of end users never accessed the web portal. End users in the school (a larger organization) were extremely confused about who was controlling their thermostat, and who should be controlling their thermostat. Utilities considering a broader installation of smart thermostats in a program should consider the (significant) support requirements.

Role of Contractor. The deployment model, in which the thermostat communicates back to the contractor or service provider, implies that this choice of thermostat is made to facilitate use by the contractor. This model worked well when the role of owner and facility manager overlap (small restaurant), moderately well when the facilities management structure was well established, and disastrously in a complex institution with social control issues. In any case, the technician problem remains. Why make a technician’s life easier, give him more control, and then no incentive to monitor low-return services such as scheduling, alert annoyances, Wi-Fi issues, etc.?

Recommendations

Advanced thermostats are thought of as a drop-in replacement for existing manual or programmable thermostats. They are purchased the same way, they are installed the same way, and they tend to be used the same way. However, they require a more sophisticated deployment process that includes training and instruction, documentation, strategy-setting, commissioning, and ongoing support. If this technology is going to be used consistently for energy saving purposes, and not only remote control, lockout of users, or comfort, then a utility program should consider a model that includes some form of continuous energy commissioning by utility agents that are known and trustworthy to the customers. There is also a need for automated methods of optimizing these thermostats, while respecting the autonomy of the end-user. With these kinds of checks-and-balances, smart thermostats can be one of the most significant energy savings technologies, as well as providing an important amenity to occupants.

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