Occupancy Sensing Adaptive Thermostat Controls – A Market Review and Observations from Multiple Field Installations in University Residence Halls

Jonathan Woolley, Western Cooling Efficiency Center, UC Davis
Therese Peffer, California Institute for Energy and Environment, UC Berkeley

ABSTRACT

While both occupancy sensors and the Internet have been around for many decades, recently both have been applied to programmable thermostats to reduce energy consumption and to improve usability and control. This paper explores the implications of coupling these technologies, and the role the added capabilities play on the efficiency and effectiveness of building conditioning. The research focuses on various installations of occupancy-sensing mesh-networked web-programmable thermostats in university residence halls, with a focus on the results from installation in multiple dormitories at the University of California, Davis.

Occupancy sensors have been used in commercial lighting controls for a few decades, but have only recently been applied to manage conditioning systems. Occupancy sensing for climate control may have the greatest impact in hotels, residence halls, and conference or assembly halls. The appropriateness of occupancy sensing thermostats in various applications depends on user motivations, regularity of occupant schedules, total occupied time, and the extent to which a space setback is already managed manually, or programmed to align with occupancy schedules.

The type of mechanical system to which an occupancy-sensing thermostat is applied will have enormous effect on its potential for energy savings. We present two installations: one successfully saved energy and the other did not. In retrospect, the latter represented an inappropriate application of an otherwise functional occupancy sensing thermostat technology. Upon review of this energy savings failure, the authors were surprised to find that facility managers were keen to install the technology in many other residence halls. Added facility management services such as wireless communicability, web-based global control, and insight into residence thermal preference, user behavior, and occupancy trends were at least as motivating as the potential for energy savings.

Introduction

Houses, hotel rooms, and university residence halls are often mechanically conditioned to a constant set-point, regardless of whether they are occupied. In commercial and high rise residential buildings, the same is true for mechanical ventilation. This is a waste of energy and money, but has historically been the only way to manage temperature and indoor air quality without zealous manual regulation by users or facilities managers. Programmable thermostats that vary temperature set-points and ventilation according to pre-defined schedules do offer added system control, though research has shown that the solution rarely results in energy savings since the devices are generally not setup properly (Peffer, et al 2011)

The newest thermostat technologies capitalize on the recent development of standardized wireless communication protocols, the proliferation of wireless communicating components, and the infusion of the Internet into many aspects of personal life and facility management. They leverage these factors to enable much more sophisticated control sequences that manage conditioning and ventilation to respond to actual occupancy trends and thermal comfort preferences. These newest thermostats promise to improve usability, and offer added functionality such as a global management and integrated system monitoring.

The occupancy control schemes are of particular interest to this research since they offer potential for significant energy savings, especially in circumstances where mechanical systems operate without regard to dynamic facility use. The technical approaches employed by these thermostats are varied: some monitor occupancy using infrared motion sensors, and allow space temperature to drift to a set-back temperature until the devices senses occupancy once again. Other systems incorporate historical patterns of occupancy into a learned schedule; in addition to allowing temperature drift when a space is unoccupied, these systems anticipate occupancy and pre-condition a space in order to return to comfort before an occupant arrives. Some approaches allow a system to learn from user temperature preference, while others learn about diurnal thermal load patterns, mechanical system capacity, and temperature response and adapt the driving duty cycle accordingly.

Although these technologies are market available, and have been conceptualized for many years, there are few academic and trade studies that predict or document the savings for these control schemes in various applications. This paper presents a framework by which we can characterize the various adaptive thermostat technologies and lays a foundation for prioritizing the most appropriate applications. Focusing in on a single technology, the paper discusses the specific capabilities of the Telkonet EcoInsight Energy Management Thermostat, and documents the authors' experience with two pilot demonstrations that saw the device installed in 224 rooms in two residence halls at the University of California, Davis. While the trial period is not yet complete, and measured annual energy savings has yet to be determined, the interim results presented here do provide many intriguing insights.

Framework for Technology Characterization

Standard programmable thermostats can theoretically relax temperature set-points at night or during unoccupied periods of the day, but these depend on the occupants having fairly regular schedules and actually programming the thermostats correctly. Programmable thermostats are well-known for poor usability which may discourage energy saving behavior (Meier et al. 2011). Evidence suggests that only 50-60% of U.S. households actually program their thermostats (Peffer et al. 2011) and a recent informal survey suggests that at least half of the respondents have variable schedules for which regular programming does not work. (Peffer 2012). For hotels and dormitories, schedules are even less predictable; an informal survey of college students showed only 25% had regular schedules (Peffer, 2009). Moreover, even when programmable thermostats are scheduled accurately, research has shown a take-back effect due to user behavior that can negate the energy savings achieved by daily set-backs (Lopes, 2010).

Table 1: Four major categories for adaptive set-back thermostat control logic.

Type	*Occupancy measured*	*Set-back temperature determined by …*	*Return to set-point when …*
1	Yes	User/manager programs set-back temperature	Occupancy measured
2	Yes	User/manager programs allowable recovery time	Occupancy measured
3	Yes	User programs absolute allowable limit	Occupancy anticipated or measured
4	No	Learned allowable preference at different times	Occupancy anticipated or user input

In response to these shortcomings, more sophisticated thermostat control techniques have recently emerged that provide adaptive set-point adjustment and scheduling to more accurately follow occupancy trends. Most of these solutions are based in part on occupancy sensing, but apply various algorithms to adjust and schedule temperature set-backs during vacant periods.

These solutions generally communicate wirelessly with Internet gateways and provide the option of a web-based user interface for programming, data logging, and control. Some products even allow networked control of other devices to enable demand response, or merely for the luxury of system automation. These adaptive thermostats can employ a wide range of different control logics to choose a set-back temperature; some of the major technologies can be categorized by the types described below, and summarized in Table 1.

1. Measured occupancy triggers set-point adjustment. A static, user programmed set-back temperature is used for vacant periods, and temperature returns to set-point once the space is again occupied. This approach will achieve different degrees of energy savings based upon how aggressive the user selects a set-back temperature.
2. Measured occupancy triggers set-point adjustment. The set-back temperature is determined according to a user programmed allowable recovery time and a learned rate of temperature recovery for the building and conditioning system. The energy impact of this approach hinges on the system conditioning capacity, and on the user's willingness to tolerate transition periods.
3. Measured occupancy triggers set-point adjustment. The set-back temperature is determined according to an anticipated time of re-occupancy, which is derived from a learned regular occupancy schedule. Depending on the scenario, this could allow space temperature to drift further than the previous two approaches, but is penalized when the actual length of the unoccupied period is misjudged. Returning to a normal set point too early will cost energy, and late return from a large set-back if the room is re-occupied earlier than expected could impact user comfort.
4. Occupancy is not measured directly, but user input is used as a proxy. In this case, the thermostat logic attempts to widen the set-point bandwidth until it receives user input about comfort preference. This input is interpreted to develop a map of user schedule and acceptable set-points.

The exact algorithm applied for each of these control schemes will impact how flexible an adaptive thermostat is to user behavior and preference changes. If a learning algorithm is too stiff it would shift a regular set-point schedule according to sporadic occurrences (e.g., a window left open, or a short visit). If the algorithm is too elastic, an initially learned set-point schedule would have trouble adjusting over time, even after a users regular schedule shifts (e.g., at semester change in a university residence hall).

In all of these cases, the set-point temperature during occupied periods may be determined in various ways. The thermostat could:

1. Choose the set-point adaptively according to learned user preference
2. Follow a baseline pre-programmed occupied set-point and allow for temporary user override
3. Automatically attempt to stretch occupant comfort to save energy and rely on feedback to learn acceptable user tolerances.

Research has indicated that occupant satisfaction is improved merely by having some control over the proximate thermal environment (Brager, 2004). Interestingly, since occupant comfort is based to some extent on the psychological experience of the user, the last adaptive set-point control strategy could automatically push the allowable comfort threshold, while still maintaining user satisfaction on the basis of perceived control. Arguably, user comfort is also impacted by ergonomics of a thermostat, an aesthetic and usable interface may improve user satisfaction, similar to the way it improves proper use of standard programmable thermostats. However, attributing energy savings specifically to the quality of human-device interaction would be difficult to measure.

Market Assessment

Thermostats that use occupancy information to reduce energy consumption have been used for over the past two decades, especially in hotels (and especially abroad, in Europe, and Japan). Some examples include a thermostat with a built-in motion sensor; simple models have been around for 20 years (the Honeywell Ultrastat was reviewed in 1994). Other approaches use a different proxy for occupancy, such as using a key card inside a hotel room to keep lights on and to enable conditioning systems. As described, the technology is advancing toward much more sophisticated adaptive control techniques, and is being applied more broadly than hotels. The range of mechanisms to determine occupancy is expanding, for example, using one's personal mobile phone as a Global Positioning System (GPS) to inform the home thermostat of occupancy and one's proximity to home (Gupta, Intille, and Larson 2009). Somewhat tangentially, the newly adopted 2013 Commercial Building Energy Efficiency Standards specifically call out occupancy sensing as a strategy to provide demand-controlled ventilation.

It is expected that the energy and demand savings potential for these adaptive thermostat strategies will vary broadly by application. Buildings that have a continuous thermal demand or uninterrupted occupancy, such as a data center or 24-hour service facility, will not benefit much from these techniques. Figure 1 presents one approach to characterize the appropriate markets for these devices. The authors consulted a small group of experts to describe various building types by two different qualitative metrics:

1. The predictability of vacant periods
2. The relative occupancy rate

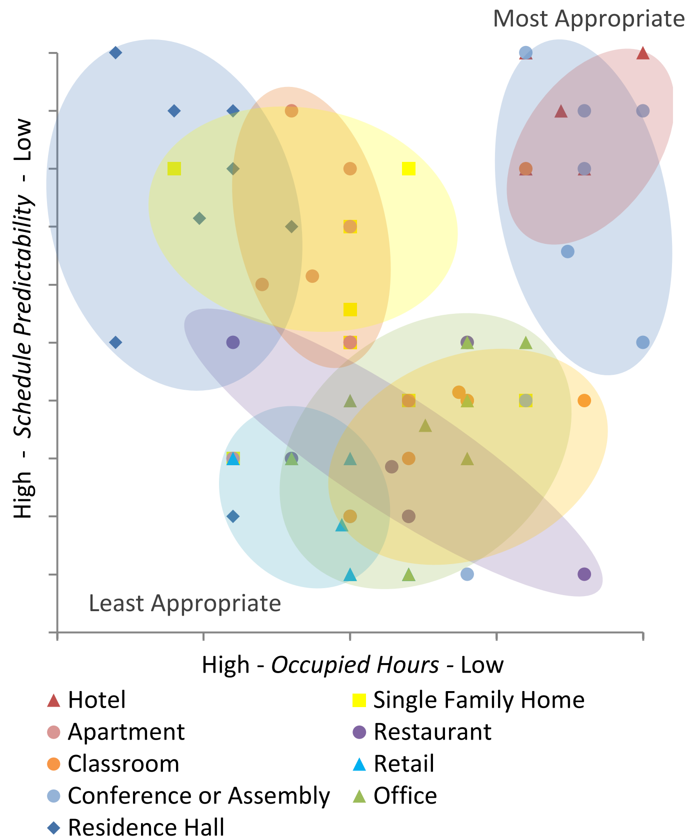
In theory, building types with highly predictable schedules could be served well enough by a programmable thermostat, and buildings with high relative occupancy would have little room for benefit from an occupancy sensing control. Alternatively, buildings with unpredictable occupancy schedules and relatively low occupancy rates have much to gain, and constitute the most appropriate market segment. Figure 1 orients hotels and conference or assembly halls as the most appropriate market. University residence halls have a comparatively high occupancy rate, but also one of the least predictable schedules, making them a likely candidate for cost effective energy savings.

The qualitative assessment presented in Figure 1 does not paint a complete picture of appropriateness of each market segment. For example, while residence halls have fewer unoccupied hours than homes and apartments, they are also burdened with a principal-agent problem that shields the end user in a residence hall from the financial incentive for energy-wise system management. This would increase the relative appropriateness for savings in residence halls.

Additionally, Figure 1 does not account for efficiencies, typical thermal load characteristics, and mechanical system design constraints for each facility type. For example, some offices have highly variable occupancy rates, yet unless the associated mechanical equipment has part-load operating capability, and zone-by-zone thermostat control, an occupancy sensing thermostat will not save energy on a low-occupancy day.

In general, anything that affects the overall run time of the heating and cooling system will affect energy savings; the more the system runs to begin with, the more potential for reducing when the room is unoccupied. This includes climate, building insulation, equipment efficiency, and previous set-points. Thus, milder climates (where the heating and cooling systems are used less often) show fewer savings than more extreme climates. Older construction usually has poor insulation compared to new construction. Some HVAC types are inherently more efficient than others, such as water source heat pumps and four pipe fan coil systems. Since another feature of these systems is to limit the available heating or cooling temperature set-point range, the previous allowable set-points affect the savings. In addition, occupancy affects the savings—rooms with single occupants have more chance of being unoccupied compared to rooms with two, three or more occupants.

Figure 1: Applicability of occupancy sensing thermostats in various building types



According to the Energy Information Administration, the energy used for HVAC in U.S. lodging facilities accounts for 30% of the total building energy consumption. In many scenarios HVAC represents the single largest energy expense for these facilities (EIA 2003). Hotels and dormitories typically have low occupancy rates during the day. Occupants want to be comfortable while in their rooms—especially since they are typically not charged separately for heating and cooling. There is no incentive to reduce heating and cooling costs, and typically occupants leave heating or cooling systems on when they leave so they are not uncomfortable upon return. However, dormitories differ from hotels in that their occupants stay in the same room longer, and have more investment or perceived ownership of the space; thus educating and engaging students in the use of the thermostat may be more effective.

A dormitory room's occupancy is variable, depending on the school's in-session schedule, each student's individual schedule of classes, work, and social engagements, and the number of students per dorm room. During winter and spring breaks, dorms are typically completely empty for several days, and during the summer, many dorms are only partially occupied. One manufacturer claims that dorm rooms are occupied about 60% of the time on average (New York University and Telkonet 2011). However, the individual rooms may show a wide range of occupancy. A quarterly report from a selected dormitory showed a average range of 60-85% occupancy depending on the month, with a low of 3% and high of 100% (INNCOM 2010).

Many manufacturers of occupancy sensing thermostats claim 30-45% savings in hotels (US Energy Solutions website, personal correspondence with INNCOM), and 20-32% reduction in HVAC runtime in dormitories (New York University and Telkonet 2011). The amount of savings depends on the existing baseline, specific climate, efficiency of heating/cooling equipment, and the environment. Note that calculating this savings is typically difficult since weather and the price of utilities change from year to year; in addition, often the heating and cooling systems are not sub-metered, so savings due to thermostat controls is difficult to separate from overall gas or electricity consumption. There are cultural and behavioral influences as well, which affect the operation of the heating and cooling systems.

Cost Assessment

The cost of these systems varies depending on the technology and the installation, but has generally decreased in recent years. The simplest occupancy-sensing thermostat with on-board sensor costs approximately $100 before installation; this technology is not networked, does not offer a web interface, or global management of many devices. According to INNCOM, the current installed price for a non-networked system is $245 per room; the price for this system in 2009 at Harvard Law School was $365. The first installation of a networked Telkonet system in the New York University dormitories in 2009 was over $500 per room, and subsequent installations were closer to $300. The most recent installations of fully networked wirelessly communicating Telkonet systems at UC Davis cost roughly $250 per door before installation.

Figure 2: Projected simple payback for occupancy sensing thermostats in dormitories

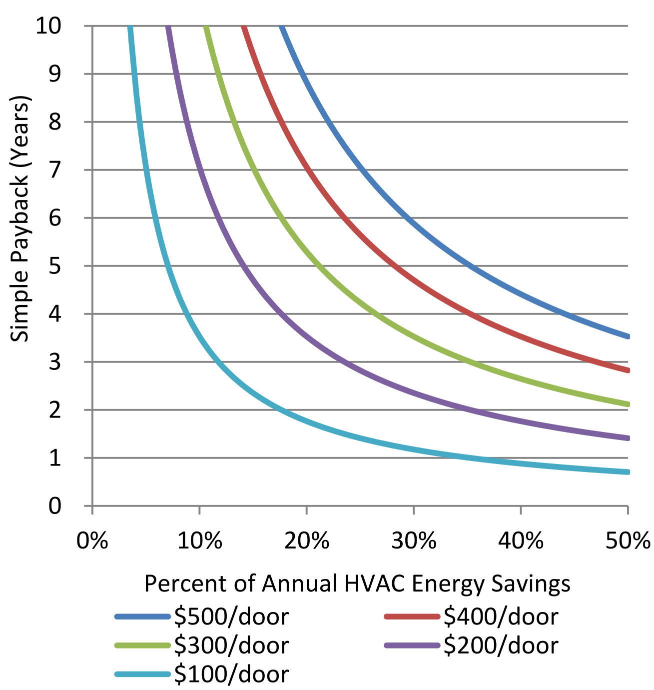


Figure 2 presents an evaluation of the simple payback for these systems as a function of the percentage of HVAC energy saved, and the installed cost of the devices. The analysis is based on the California Energy Commission's Commercial Building End Use Survey data for annual heating, cooling, and ventilation energy for lodging facilities in Sacramento, CA. For simplicity the calculation assumes energy costs of 0.10 $/kWh, and 1.00 $/therm, and uses the floor area and equipment layout for a 114 room residence hall to determine total energy use and equipment costs. For the sake of comparison, the end use energy intensities used for this analysis were: 0.89 $kWh/ft^2/yr$ & 12.02 *kbtu/sqft/yr* for heating, 2.53 $kWh/ft^2/yr$ for cooling, and 1.56 $kWh/ft^2/yr$ for ventilation.

The analysis assumes that an occupancy sensing thermostat is installed in every residence room, and that the cost includes installation and all auxiliary devices such as wireless networking components, and external occupancy sensors.

The results are presented as a function of the "percent of annual HVAC energy consumption savings", to demonstrate the trend in payback and value for various degrees of energy savings. Depending on the occupancy rates for different dormitories, one might expect to achieve a range of different savings. For example, our evaluations have observed average room occupancy rates that range from 50-90% for regular operation. During weekends and breaks, the average room occupancy rate is significantly less.

For context, an installation of occupancy sensing thermostats at New York University has claimed a return on investment for projects between 1-5 years. Similarly, an installation at Harvard Law School recorded a simple payback of 1.5 years. However at CSU Northridge, the installation of non-networked thermostats in a new building with a relatively mild climate, the payback was estimated to be 4 years.

In general it seems reasonable to expect at 10%-30% annual HVAC energy savings for application in most dormitories, though the value will vary depending on the building and HVAC type. If a dormitory is used as conference housing during the summer period, it might achieve savings nearer what has been demonstrated for hotels. In fact, during the summer period of 2011 when Potter was utilized as conference housing, the average occupancy rate of all 114 rooms was less to 20%, compared to roughly 75% during the following two academic quarters.

Overview of Field Evaluation

As part of a program that demonstrates and evaluates emerging technologies for California Universities, the authors collaborated with Student Housing at the University of California, Davis to monitor and analyze the field performance of one occupancy-sensing adaptive thermostat technology. The thermostats were installed in several different residence halls, covering more than 313 rooms in all.

All four of the buildings use two-pipe fan coil systems for heating and cooling; where each building is manually switched between heating and cooling modes during the shoulder seasons. Chilled water and steam for heating hot water is provided to these building by the campus central plant. Fresh air for these buildings is generally provided by central exhaust or by natural window ventilation, except Potter, where each fan coil unit also has an outside air supply. Every room has a thermostat, even in Potter and Webster, where fan coils serve groups of rooms. Each room in Sereno and Bixby has a dedicated fan coil.

The authors observed retrofit of each of these buildings with the Telkonet EcoInsight system, an occupancy-sensing adaptive thermostat solution described fully in the following section. A monitoring plan was developed in coordination with UC Davis Student Housing and the UC Davis Energy Management Office, data was drawn from the building's energy management system, as well as from points trended by the Telkonet thermostats.

Potter and Bixby were selected for monitoring, since they have independent chilled water and heating hot water circuits that are monitored and controlled separately from neighboring buildings in each complex.

Potter Hall is a newly constructed four-story residence hall with more than 114 shared student bedrooms. The building is one of three in the Tercero complex that was commissioned and first occupied in September 2010. The thermostats replaced in each room were snap-acting manual devices that allowed residents to increase or decrease the desired set point, but without any feedback about actual room temperature or desired set point. Since each fan coil in Potter serves a group of rooms, room thermostats control actuation of dampers, while the fan speed responds to maintain a constant static pressure. Bixby Hall is a five-story high rise dormitory constructed in 1965. Prior to the study, each room had unrestricted manual thermostats that allowed students to drive the room temperature as they preferred.

For Potter, the thermostats were allowed to run in an occupancy sensing mode continuously, whereas in Bixby the thermostats were controlled to shift between an occupancy sensing mode, and a standard scheduled mode in two week intervals for the purposes of evaluation.

Thermostat Description and Installation

The SS6000 Energy Management Thermostat is the heart of the Telkonet EcoInsight system, which includes all of the networked components to integrate an entire array of the occupancy-sensing adaptive thermostats. Each thermostat has an on-board infrared motion detector that senses when a room is occupied. Vacancy in a room triggers adjustment of the active set-point, which allows temperature to drift and results in a reduced duty cycle for the conditioning and ventilation systems.

In applications where the thermostat is not ideally located to sense occupancy, the system can incorporate a remote occupancy sensor that communicates wirelessly with the thermostat. Additionally, the system incorporates an on-board light sensor and logic to distinguish between vacancy and a nighttime condition where occupants are sleeping.

Telkonet applies a learning algorithm called Recovery Time™ which continually adapts the set-back temperature for unoccupied periods such that a room can recover quickly upon the occupant's return. Facility managers are able to program an acceptable recovery time, and the thermostat learns how quickly the associated mechanical system is able to respond, allowing the room temperature to drift only so far that it can return to the occupied set-point within the allotted time. The algorithm is designed to adapt to changes in season, and in mechanical system characteristics such as a switch between heating and cooling mode. The set-back response can also be tiered such that after a long period of vacancy, temperature is allowed to drift even further; achieving added savings over unoccupied weekends or vacations. In addition to these adaptive control strategies, facility managers can select absolute limits for the set-back temperature to avoid damage to building materials and equipment. During occupied periods, users are allowed temperature control, although facility managers may limit the selectable set-point bandwidth to avoid excessive heating or cooling by residents.

Beyond the thermostat, every component in the EcoInsight system communicates wirelessly in a ZigBee mesh network that ties through an Internet gateway to a web-based user interface. The web application allows facility managers to adjust thermostat schedules and set-points, call up real time status details for each thermostat, or review historical data and statistics such as average occupancy trends for each room.

Results

In general UC Davis Student Housing has been pleased with the thermostat systems and currently intends to install the equipment in all of their facilities. Interestingly, while the system has significant benefits as an energy efficiency measure, the asset management functionally provided seems to be the major driving factor for Student Housing. The potential for room-by-room insight to support diagnostics and troubleshooting, as well as global control of set-points and schedules for thousands of rooms in more than 30 buildings are invaluable capabilities.

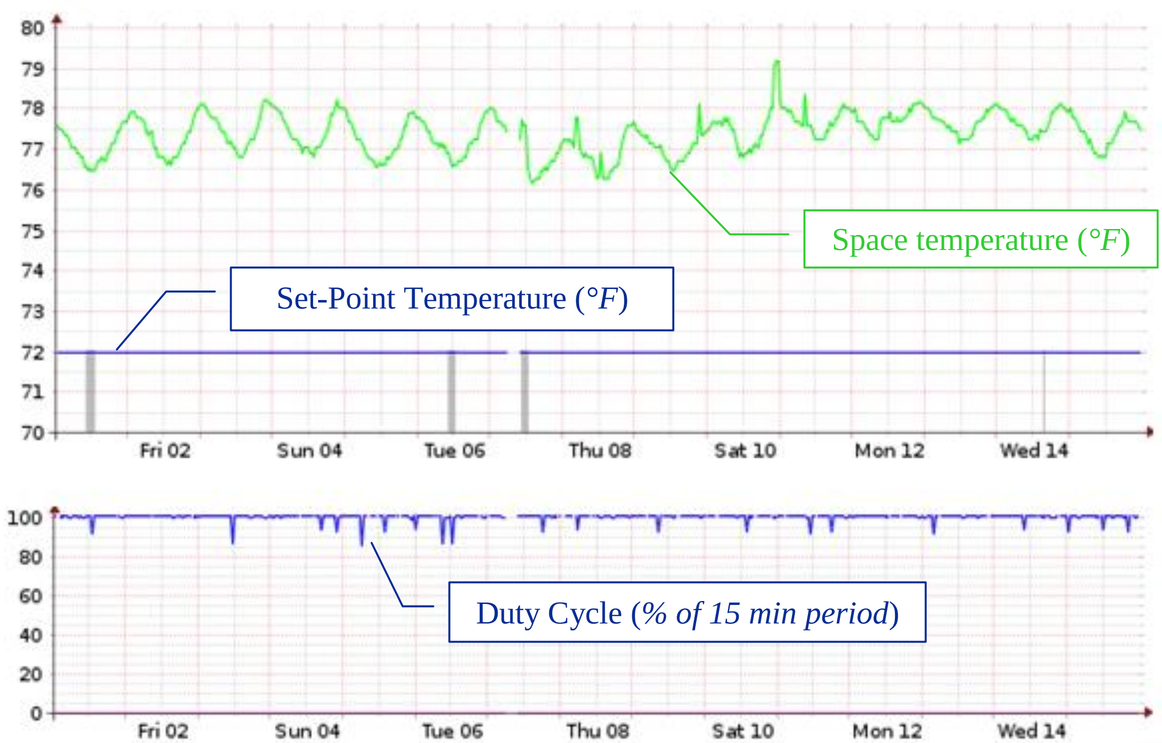
There were some small commissioning issues with the thermostats themselves, but no major failings were observed. Some minor issues included mesh network connectivity, and troubles changing between programmed schedules. The authors have observed multiple firmware updates since installation, these changes have mostly addressed nuanced technical details to increase reliability, but have also expanded functionality and usability of the systems.

Although field evaluations are still in process, the following sections present data from both Potter and Bixby, and discuss some observations about each application. Importantly, our monitoring of the Potter installation indicates that while the Telkonet systems functioned as expected, the project did not achieve any energy savings because the thermostats were not integrated appropriately into the existing control scheme for the building mechanical system. On the contrary, the Bixby application shows a significant reduction in average fan coil run time, and annual HVAC energy savings are estimated to be between 10-30%.

Potter Hall – Lessons Learned from a Failure

Each fan coil unit in Potter serves a group of five rooms. The fan coil draws return air from the building corridor, as well as some air directly from outside to provide fresh air to each room. Supply air from the fan coil is ducted through five separate branches, and a motorized damper in each branch allows regulation of airflow to each room. The position of each damper is controlled by the associated room thermostat. If additional heating or cooling is desired, the damper opens. Each fan coil has a variable speed fan, which is controlled to maintain a constant supply plenum static pressure. Thus, if all five dampers are open, the supply fan will run at a maximum speed, then will slow as dampers close. The minimum position of each damper is such that some ventilation will always be delivered to each room. Since return air is drawn from the building corridor, each room operates at positive pressure relative to the corridor.

Figure 3: Temperature response to continued call for cooling in Potter Residence Hall



The Telkonet thermostats were installed to directly replace existing snap-acting manual devices. These devices were not integrated into the building control system, rather, they actuated each damper position directly. It was expected that the adaptive thermostat set-back would reduce total conditioning requirements in each room, cause each damper to remain closed for longer, reduce the average fan speed for each unit, and reduce the total thermal energy consumed in the building. However, the overarching sequence of operations for the building was not consulted, and some important facts were overlooked which caused the system to respond differently.

While the thermostats functioned exactly as they were designed, it turned out that chilled water valve position, and supply air temperature for each fan coil were controlled to maintain a set-point temperature measured in the building corridor. The amount of thermal energy delivered to the building, therefore, was a function of the corridor set-point temperature, and the room occupancy sensing controls had almost no bearing on the operation of each fan coil. In fact, since the occupied set-point temperature for each room was typically lower than the corridor cooling set-point, application of these new thermostats actually caused the damper position to remain open longer.

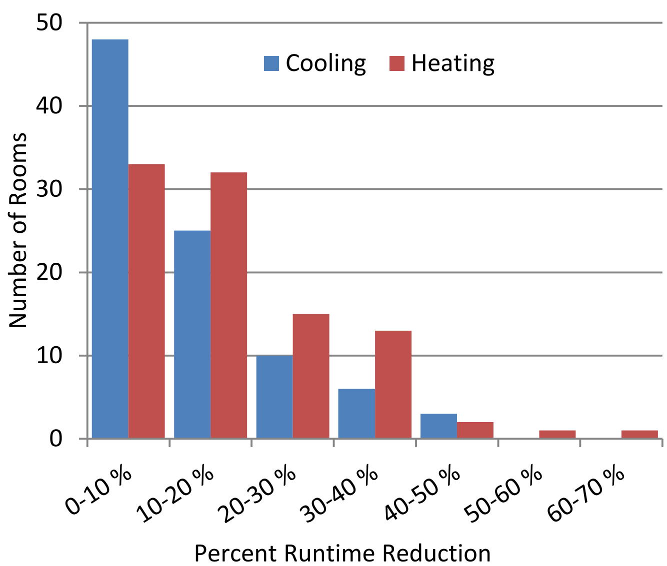
Upon observation, it was clear that the mechanical system did not respond to calls for conditioning from each thermostat. Figure 3 shows one room in Potter that was demanding cooling for 15 continuous days, though the space temperature never responded. Unfortunately, this installation stands as an example of inappropriate application for the technology. The experience does offer some valuable lessons – namely a reminder that as the complexity of buildings increases, minor specifics in a sequence of operations, and small misunderstandings about system function can have broad impacts on building function, and may completely counteract energy savings potential.

On the bright side, it should be noted that the Telkonet hardware is BACnet integrable, and that Student Housing is currently pursuing a redesign of the HVAC sequence of operations that will drive fan coil operation according to the occupancy-based conditioning demand in each room.

Bixby Hall – A Success Story

In Bixby Hall, however, the thermostat in each room has direct control over the operation of fan coil. Thus, application of the occupancy sensing thermostats in this building yielded more obvious energy savings. Figure 5 plots the occupancy, user selected set-point, actual room temperature, and fan coil duty cycle for two similar rooms across one Friday-Sunday period in March 2012. In Room 302, the occupants leave the thermostat on but depart for the weekend, whereas in room 312, the room remains occupied for most of the three days period. If the thermostats were not sensing occupancy, these two rooms should follow similar

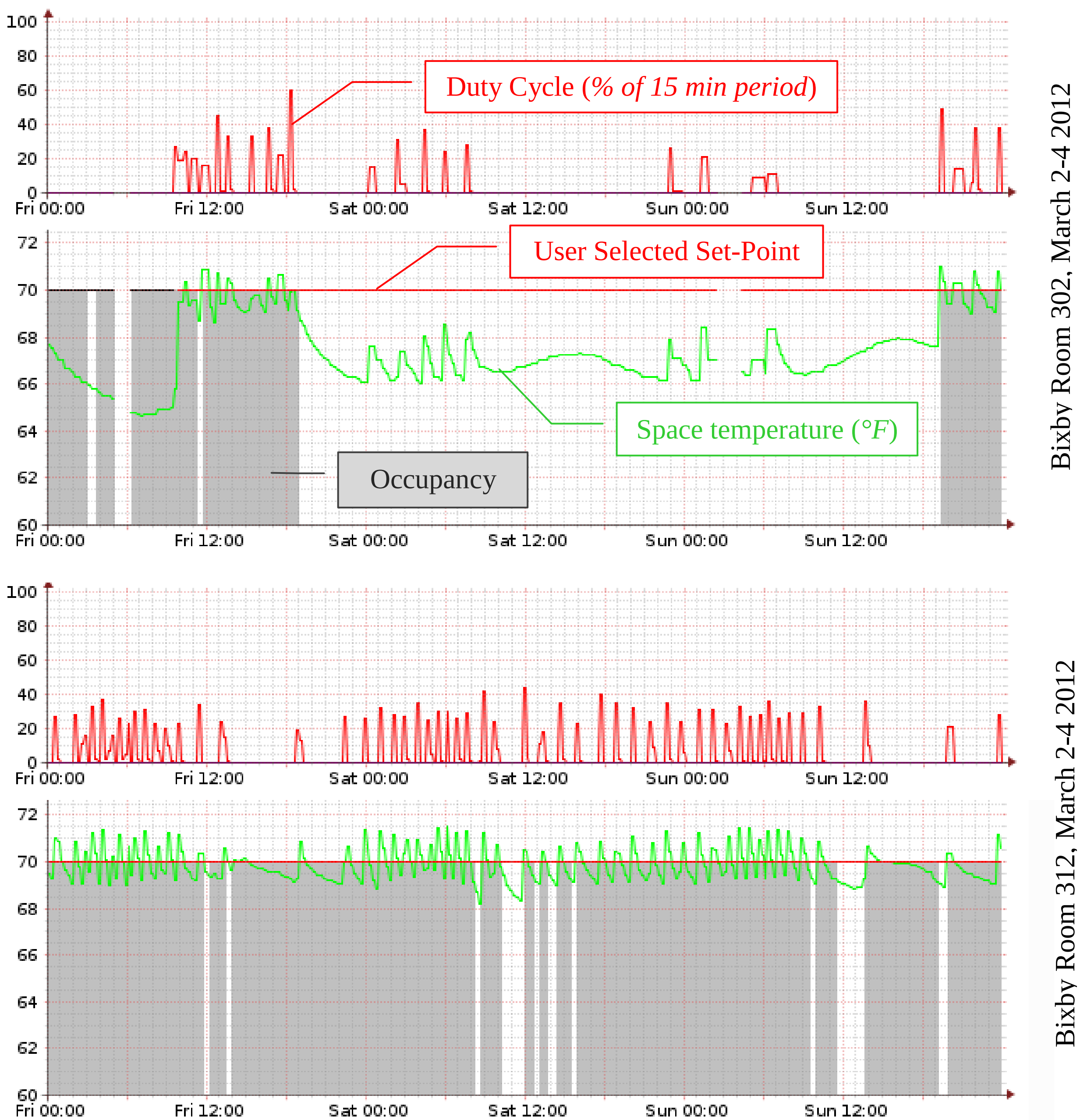
Figure 4: Runtime reduction for Bixby Hall



temperature fan coil cycle patterns. However, since room 302 is unoccupied, the thermostat allows the temperature to drift by a few degrees, and the cumulative cycle operation is reduced dramatically for the weekend period. Upon re-occupancy on Sunday afternoon, room 302 returns to comfortable set-point within 10 minutes.

Monitoring for Bixby Hall will continue for the next several months, and measured energy consumption will be used to develop a complete analysis of savings due the Telkonet system. For the period of evaluation thus far, cooling runtime for rooms in Bixby was reduced by 7% on average, while heating runtime was reduced by 15%. The data is drawn from roughly one month in the heating season and one month in the cooling season.

Figure 5: Set-point, occupancy, duty cycle, and temperature response for two similar rooms in Bixby hall over one three day period



Conclusions and Lessons Learned

Occupancy-sensing adaptive thermostat controls and Internet connected systems management for this type of HVAC system is a relatively new technology, especially as applied to university residence halls. A review of a number of installations throughout the U.S. shows the promise of significant energy savings in this application, with a sensible return on investment. In various case studies at UC Davis, the authors have observed mixed results in regard to energy savings. One building currently under evaluation is likely to achieve annual energy savings of up to 30%, but another showed no energy savings because the thermostat technology was not fully integrated into the building's complex sequence of operations.

Through our experiences and observations of these innovative systems, we draw the following conclusions:

- Communication with all building stakeholders is critical for successful deployment of these systems in residence halls. This includes the students who ultimately interact with the devices, facilities management and maintenance personnel, manufacturers, engineers, and installers. Like other advanced controls systems, these devices risk misuse, or ultimately abandonment, if any of these stakeholders don't understand the basic implications.
- Seemingly minor details within complex systems designs can have major impacts on actual operating characteristics. Small oversights in system application might eliminate the anticipated energy savings benefit from this efficiency measure.
- Proper placement of the occupancy sensors for these systems is critical. False readings can be caused by furniture placement or other obstructions, thermal flow within the sensors' field of vision, or activity outside a window such as passing cars. Experience from installation at NYU suggests that the ceiling is the best location to install sensors.
- Occupancy sensing thermostats can have provide significant HVAC energy savings, especially in applications where schedule predictability is low, or where there are many unoccupied hours. Hotels are likely the best application for this technology, and residence halls are probably a more cost effective market than apartments and homes. Arguably, offices assembly halls, and typical residential buildings could benefit significantly from occupancy sensing thermostat controls, depending on the mechanical system that serves the space.
- There are many non-energy benefits that motivate application of occupancy sensing and communicating thermostats. These characteristics may or may not have measurable economic value, but definitely provide significantly increased level of service for factors such as asset management, maintenance, and system control.
- The energy savings potential for occupancy sensing thermostats varies significantly between building applications, depends on occupant behavior, and is tied inextricably to the design of the mechanical system which it controls.
- The baseline conditions in a building will make a significant difference for the degree of energy savings achieved. For example, some of the best paybacks demonstrated may be in part due to the fact that the thermostats replaced were unconstrained operated lavishly.

References

Brager, G. S., Gwelen Paliaga, and R. J. de Dear. 2004. *Operable windows, personal control, and occupant comfort*. ASHRAE Transactions 110 (2):17-35.

California Energy Commission. *California Commercial End Use Survey*. CEC-400-2006-005. 2006. [online]. http://www.energy.ca.gov/ceus/

Energy Information Administration. *Residential energy consumption survey*. Table hc14.5: Space heating usage. 2005.

Gupta, M., Intille, S. & Larson, K. 2009. *Adding GPS-control to traditional thermostats: An exploration of potential energy savings and design challenges*. Pervasive Computing. Haiad, C., Peterson, J., Reeves, P. & Hirsch, J. *Programmable thermostats installed into residential buildings: predicting energy savings using occupant behavior & simulation*. Southern California Edison; 2004.

INNCOM. *Energy Savings and Operations Report*. Queens College, The City University of New York, QC-2010-04-12, Version 1.41. 2010.

Lopes, J, & Agnew, P. *FPL residential thermostat load control pilot project evaluation*. Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings, 2010. Vol. 2.

Meier, A., Aragon, C., Peffer, T., Perry, D. & Pritoni, M. *Usability of residential thermostats: Preliminary investigations*. Building and Environment, 46 (10), 1891-1898. 2011.

Michaud, N., Megdal, L., Baillargeon, P. & Acocella, C. *Billing analysis & environ- ment that "re-sets" savings for programmable thermostats in new Homes*. IEPEC. Portland. 2009.

Nelson, L., Macarthur, J. *Energy savings through thermostat setbacks*. ASHRAE Transactions, 83 (AL-78-1 (1)), 319-333. 1978.

New York University & Telkonet. *Webinar on occupancy sensing thermostats*. [online]. http://www.telkonet.com/resources.php. 2011.

Nevius, M., Pigg, S. *Programmable thermostats that go berserk: taking a social perspective on space heating in Wisconsin*. Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings. 2000:8.233e44.

Peffer, T., Pritoni, M., Meier, A., Aragon, C. & Perry, D. *How people use thermostats in homes: A review*. Original Research Article. Building and Environment, Volume 46, Issue 12, December 2011, Pages 2529-2541

Peffer, T. 2009. *California DREAMing: the Design of Residential Demand Responsive Technology with People in Mind*. University of California Berkeley, Berkeley, CA.

Peffer. 2012. People and Energy at Home: Information Display and Thermal Comfort Development for Residences. Sacramento: California Energy Commission PIER

Sachs, H., *Programmable thermostats*.Washington, D.C: American Council for an Energy Efficient Economy. 2004.

Shipworth, M., Firth, S., Gentry, M., Wright, A., Shipworth, D., Lomas, K. *Central heating thermostat settings and timing: building demographics*. Building Research & Information 2010;38:50e69.

Tachibana, D. *Residential customer characteristics survey – 2009*. Available from: www.cityofseattle.net/light/Conserve/Reports/Evaluation_15.pdf. Sept 23, 2010.