INNOVATIVE CONTROL OF ELECTRIC HEAT IN MULTIFAMILY BUILDINGS

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SUMMARY

This paper describes the application of web-based wireless technology for control of electric heating in a large multifamily housing complex. The control system architecture and components are described. A web-based application enables remote monitoring of temperature, electric usage and control of peak demand through a temperature-based duty-cycling algorithm developed specifically for the application. Installed costs and energy savings are discussed. A 16% energy-use reduction was confirmed through the first heating season of operation. The response of occupants and management to changes in temperature regime has been a critical aspect of system start-up and commissioning.

Keywords: electric heat, energy savings, wireless communication, multifamily housing.

INTRODUCTION

This case study describes performance improvement that is possible through enhanced control of electric resistance (baseboard) space heating in a large multifamily complex in the Bronx, New York. Since no central control system existed, one had to be installed. Wireless (RF) and web-based technology for communications was combined with temperature sensors and solid-state relays to establish control over all terminal heating units. The ability to observe and remotely set apartment temperatures, to program night setbacks, and to duty-cycle equipment for peak-demand limiting are relatively standard control functions in commercial building practice that have been adapted by this project to the multifamily environment.

The complex of 731 apartments in 14 medium-rise (5 to 7-stories) buildings serves a low-income and working population. The first phase of the project, which is reported on here, encompassed 169 apartments in three buildings. The rest of the complex is scheduled in a second project phase, authorization of which was contingent upon performance of the first phase. To protect the owner's confidentiality, the complex is referred to as "P-L Housing."

The case experience confirms and documents the energy savings from reduction of overheating as hypothesized and projected based on engineering calculation. Experience in multifamily housing suggests that overheating is common, probably to a much greater degree than in owner-occupied single-family homes. The ability to monitor and control temperature therefore has a significant potential in this market and is part of the basis for AEA's on-going development work in this area.

The success of the pilot described in this case study suggests wider applicability in electrically heated housing. While this project used technology specifically configured for baseboard heating elements, AEA has also developed pilot product configured for use with packaged terminal air-conditioning (PTAC) units, many of which are supplied with electric resistance heating elements. In this case, control could be provided for both heating and air-conditioning with the same devices and programming structure. Air-source heat pumps could also be addressed from the same control platform, especially in northeast climates where heat pump operation must be switched over to resistance heating for much of the heating season.

The project team consisted of AEA, acting as developer and system designer, a technology vendor that provided the wireless networking devices, assumed responsibility for communications and established the website, data acquisition and storage and an electrical contractor who fabricated and installed the control panels during the summer of 2003. The team worked together under AEA leadership to commission the communications and control functions, starting in October 2003. P-L Housing management and maintenance staff were involved in tenant communications, monitoring, and complaint response with an eye towards eventual full operational turnover of the system.

Work was supported by the New York State Weatherization Assistance Program (WAP), administered by the Division of Housing and Community Renewal (DHCR) and by the Assisted Multifamily Program (AMP) of the New York State Energy Research and Development Authority (NYSERDA). An energy audit was performed by lead author Dominique Lempereur, following the protocols of both programs that provided the basis of cost and performance to develop the project.

Both authors have previously worked on temperature control projects in multifamily housing. Mr. Lempereur developed digital thermostats for use in electrically heated apartments in France. Resident heating mode selection was a key feature of that work. Mr. Bobker has applied thermostatic radiator valves in NYC steam-heated buildings as part of system balancing and overheating reduction efforts. Their separate experiences have converged in emphasizing the importance of two-way communication with control devices and the ability to remotely monitor and adjust temperatures. Their experience in this project suggests that a proper appreciation of the feedback potential of two-way communications and full data acquisition with graphic capabilities is a critical success factor for projects of this nature. Project acceptance and performance is strongly supported by the data logging function of the system. However, this function's value cannot be realized unless the project allows for sufficient time and commitment of skilled personnel to make use of the capabilities. The issue of customer support and training and a full system commissioning period must be addressed in the project's design; building operating staffs are unlikely to do this on their own if the system is turned-over prematurely without support. In all likelihood, this would result in the system being deemed a failure and soon abandoned.

Significance of the Project

Electrically heated housing has been a stubborn sector for energy cost control in many parts of the world. The low first-cost of resistance baseboard was to be complemented by low electricity prices. Adjustable temperature control on each baseboard element offered full room-by-room zoning. During the 1960's and into the early 1970's this paradigm was attractive especially for state subsidized low- and moderate-income housing.

Reality has not lived up to the rosy projections. Electricity prices have moved steadily upward, driving heating costs out of control. Especially when combined with master-metering, where the resident has no direct financial responsibility for energy used, room zone controls become largely useless – they will commonly be found at the highest settings with window-opening to control perceived over-heating. Energy audits in the NYC area have found apartment temperatures typically in the 80-85 degree F range. Heating operating costs have become a significant aspect of financial distress for managers.

Naturally, upgrading possibilities have been explored. Converting the domestic hot water from electricity to fossil fuel (usually natural gas) is relatively easy and cost-effective since there is usually a central location for the original water heating equipment that needs to be replaced while distribution piping can remain unchanged. The building is able to maintain its favorable electric-heating rate with this conversion. Space heating is more difficult to address.

The knee-jerk response to high electricity usage has sometimes been to suggest cogeneration. But there is no thermal load to match the electric space heating demand. Without a heat sink to recover the on-site generation's waste heat, there is no efficiency gain and therefore very limited savings opportunity.

Converting to fossil fuel for space heating requires a completely new distribution system, such as installing a hydronic (hot water) system. Expense and disruption are major barriers even if the economics are marginally acceptable (say, 10-15 year payback). Calculation must take into account that the remaining electric loads will shift to a more expensive rate classification. The hydronic heating does now make cogeneration feasible, as the waste heat can be used for space heating. The payback of the system will be somewhat improved but at the cost of much higher capital expense and operating requirements.

An alternative for a gas conversion has been the use of decentralized units. These are direct-vented room units that require only two small wall penetrations. This approach has been somewhat more successful with several installations completed. New gas piping must be extended throughout the building, which is more feasible when mains can be run on the building exterior. Especially in high-rise situations, gas pressure may also become an issue. The expense of the new piping and equipment, on the order of $3-4,000 per apartment, and the addition of mechanical maintenance in apartments have inhibited owner acceptance of this approach.

Faced with this situation and also with a US DOE Weatherization Assistance Program rule that discourages fuel switching, AEA considered a controls-based approach to optimize performance of the existing electric space heating rather than replace it. Installed costs of roughly $1,500 per apartment were estimated with a payback of 5-7 years. Projected savings accrued from improved control to accomplish (a) monitoring and control of apartment temperature (b) night set-back and (c) coordinated duty-cycling to reduce peak load and demand charges. It should also be noted that with this measure, the remaining building electric loads would stay on the lower-cost electric heating rate. Moreover, rather than locking into a single fossil-fuel such as natural gas, the building would retain the long-term flexibility of the electric system to use lowest-cost sources or renewables.

METHOD

The project's method was based on installing a functional system into a significant sample of apartments as a first phase and demonstrating its performance, with the full project contingent upon successful operation. The project has moved through development, procurement, installation, and commissioning phases with AEA as the project manager. The ability to have a fairly large scale first phase installation proved important in understanding behavioral response from all of the parties involved – residents, building management, and members of the project team.

Description of the System Developed

Building Management agreed to keep the existing electrical heaters and install a new type of heating control based on ambient temperature and electrical demand management. Natural gas conversion was evaluated but not deemed cost effective in comparison to this control option.

Equipment list and functions

Hardware	Functions
Apartment level	
cabinet	vandal proofing
- tamper switch	cabinet opening alarm reporting
- solid state relays	heating load switching
- din rail and terminal strips	device mounting, wiring connection
power meter	apartment total electric load measurement, apartment electric usage computation and storage, 2 zones thermostatic function, solid state relays command, 2-way communication with building access point.
temperature sensor	ambiant temperature measurement, send data to power meter
Building level	
outdoor temperature sensor	outdoor temperature measurement, send data to server
Interval meter	building overall electric demand and usage measurement, analog to numeric data conversion
Ethernet communication converter	master meter pulse reading
access point	apartments network wireless communication hub
RS485 to Ethernet communication converter	apartment communication network to building-to-building communication network interface.
Radio transceiver	2-way building-to-building communication transceiving
omnidirectional antenna	communication transceiving hub for the entire building complex
directional antenna	communication transceiving device for the building
local server	data processing, data storage, broadband access gateway

Software	Functions
SQL Database	data management and storage, site configuration
Graphic User Interface	web pages browsing, data reporting and display
Peak Demand Limitting algorithm	duty-cycles heating elements to keep building electric demand below calculated threshold

The primary goal was to suppress overheating and simultaneous operation of heating and cooling elements. To control the ambient temperature in each apartment, temperature sensors with an accuracy of 0.5 °F were installed in each heating zone. Though studios and 1-bedroom apartments have a single heating zone, most of “P-L Housing” apartments are duplexes that are divided into two independent heating zones, one per floor. An advanced power meter regulates each zone around a temperature setpoint adjusted remotely by the Management, but not accessible to the Tenant. This configuration limits the zone temperature to a maximum setting decided by the Building Management. Solid-state relays are installed in a new cabinet for switching heating loads. Temperature control function is stand-alone and is not affected by an interruption of communication with the server. The system also allows a night-setback function, where schedule and temperature settings are managed from the server.

An Outdoor Temperature Reset is implemented to prevent heater over usage and simultaneous heating and air conditioning in the shoulder months. It monitors the outdoor temperature and switches off all heaters when the outdoor temperature reaches a temperature threshold. Management now has control over all heaters so that they will operate in the heating season only.

Another strategic issue is to reduce electrical demand at the building master meter. The Peak Demand Limiting (PDL) algorithm was developed by AEA to address the separately metered and billed monthly peak demand typical in large residential buildings. Demand is analyzed in real time. If it approaches a limit defined by the algorithm, the system will duty-cycle heating elements and shed load based on a temperature prioritized procedure to keep the load below the threshold. PDL parameters include measurement of outdoor temperature, ambient temperatures and regression analysis on historical data. The utility’s demand meter was upgraded to a fully digital interval meter and equipped with pulse-outputs to interface in real time with the new monitoring and control system at the system server.

Wireless network

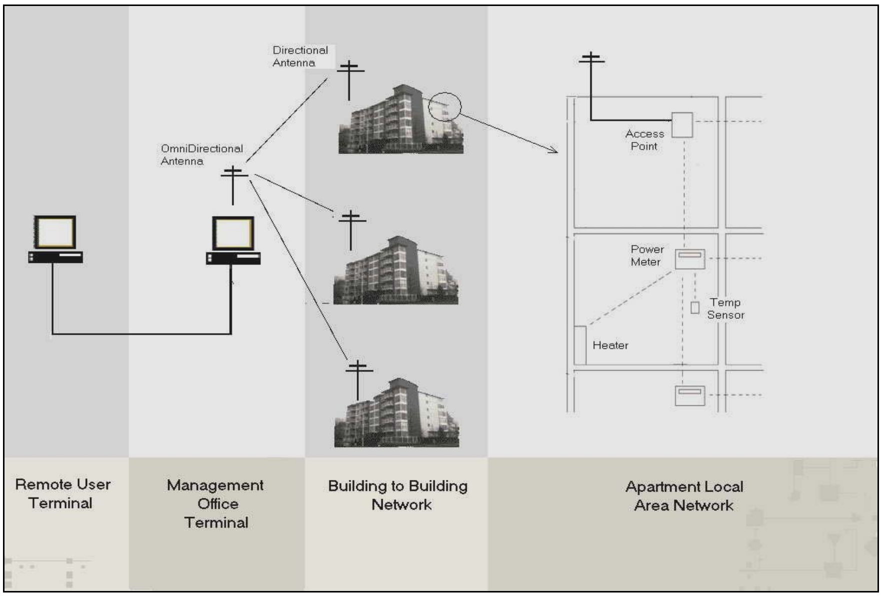

Fig 1. Wireless network infrastructure

The system integrates a wireless communication local network within the buildings to monitor and control heating elements. Apartments power meters communicate in a two-way mode with a building access point installed on the roof of each building. This system operates at the 902-928MHz-frequency band dedicated for non-licensed Industrial Scientific Medical (ISM) applications in the USA. Because "P-L Housing" complex consists of multiple buildings, another set of radio devices and interfaces using 802-11b wireless protocols are installed to ensure building-to-building communication. A server, installed in the Management office receives and stores data and transmits orders to switching device using this network. The server is connected to a Wide Area Network using broadband Internet (DSL). A Graphic User Interface (GUI) uses a web browser to allow remote access to data and controls parameters. Individuals in other locations, accessing website with secure ID and password privileges, may use the GUI to monitor and control data with the same convenience as on-site personnel.

Data is transferred on a daily basis to a monitoring operator. Costumed software was developed to (a) manage operator queries such as selection of period of analysis and apartments (b) to perform calculations of trends that were not available on the GUI and (c) to generate clear and printable reports. This tool assists in data analysis and electrical management strategy.

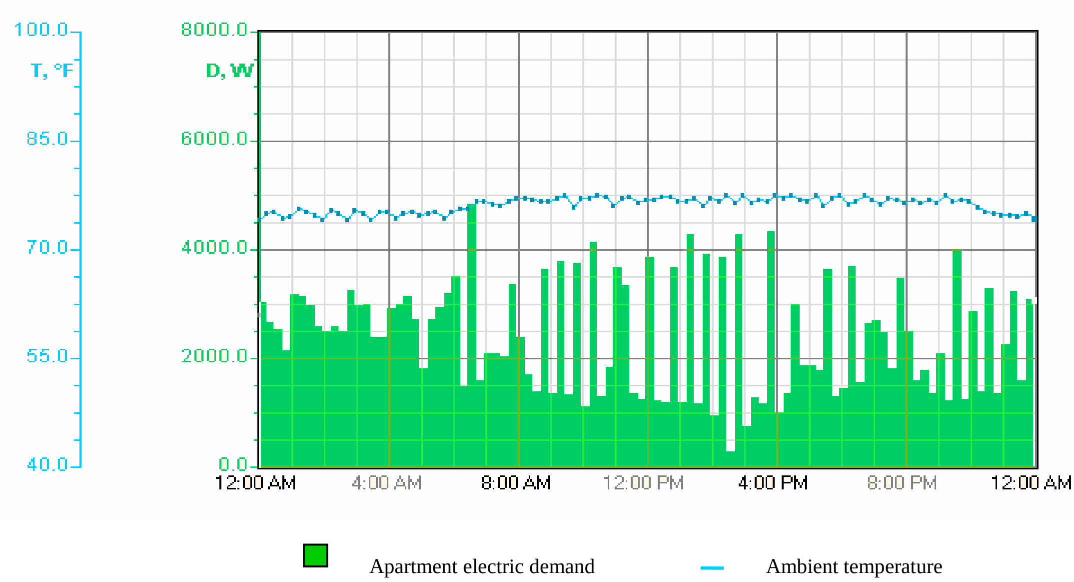

Fig 2. Sample of Internet reporting screen for a 2-bedroom, intermediate floor apartment

Comments: The above graph demonstrates that the ambient temperature is controlled accurately at the temperature setpoint with a deadband of 1°F. Data is recorded every 15 minutes. Nightsetback temperature is set at 74°F. At 6:00am, temperature ramps up to the daytime setpoint of 76°F. At 10:00pm, temperature smoothly drops back down to the nightsetback temperature setpoint. The graph also shows heater cycling during the daytime where solar gain and warmer outdoor temperature condition reduce heating load. The higher load through the night is reflected in the more continuous heater operation, showing as power consumption "blocks" rather than the "bars" created by more frequent heater cycling. The average outdoor temperature of this 24-hour period was 28°F.

Installed costs

Description of Component	**Average installed cost per apartment** (1)
Control panel – solid state relays, power supply, terminal block, assembled in locking NEMA enclosure	$600.00
Apartment power meter – includes RF transceiver	$440.00
Temperature sensors – wired in surface-mount raceway	$313.00
Verification of baseboard operation	$119.00
Master meter KYZ pulse output – pro-rata (2) share of metering and communication interfaces	$43.00
Communication network infrastructure – pro-rata (2) share of antennae and inter-building communication interfaces	$75.00
Server and software (database, GUI, site configuration) – pro rata share	$54.00
Total	**$1,644.00**

Fig 3. Project investment costs

(1) Cost is allocated over 169 apartments
(2) Pro-rata share is based on 731 apartments

Originally in the audit, the projected installation cost for controls, communication and server was estimated at $1,518 per apartment. Final cost per apartment appeared to be $126 over this estimate. This discrepancy is accounted for:

- An under-estimated installation time. Contractor covered costs for potential multiple attempts to access apartment. This appeared to be realistic.
- Installation of vandal proof metal cabinets with additional locks instead of regular enclosures to secure new equipment in common area.
- Hardwiring of master meter pulse output to roof antenna rather than using wireless communication. This solution improved data reliability since master meter appeared to be located in an environment unfavorable to propagation of radio frequency.
- Need for additional wireless nodes to improve communication between devices. Apartments that were not installed with the system created shade zones and kept wireless communication from relaying properly into the network.

RESULTS

The following energy savings analysis was performed on the 169 apartments located on the Eastern cluster of “P-L Housing” complex. The control system was installed over the summer of 2003 and put into operation at the start of the heating season, on October 1, 2003.

Data used for the analysis is based on electric bills available on the local electric utility (ConEdison) website. Weather data for the calculation of the Heating Degree Days is derived from NOAA website, LaGuardia Airport weather station. System performance is evaluated by comparing usage records from the building equipped with the new control system to an identical, non-controlled building also located in “P-L Housing” complex. Usage and demand savings were then computed by comparing the data to the previous year with normalized weather data.

New System performance
(Controlled building compared to identical uncontrolled building)

Month	% Performance difference	Electric usage savings generated
November	+ 15%	51,217 kWh
December	+ 14%	52,679 kWh
January	+ 9%	41,181 kWh
February	+ 9%	38,497 kWh
March	+ 10%	30,845 kWh
April	+ 8%	20,840 kWh
Total	**+ 10%**	**235,259 kWh**

Fig 4. Performance and electric usage savings

% Performance is evaluated on the overall building electric usage (all apartments and common area usage). Total electric usage savings generated by the new system equals 235MWh for the period of analysis, adjusted to the weather conditions. This result corresponds to a **16.3%** energy savings in heating usage.

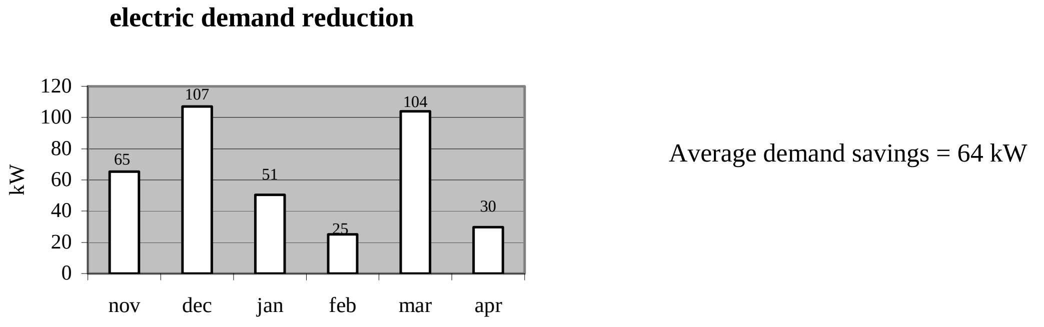

Fig 5. Demand reduction

Electric Demand reduction is based on the peak demand values as recorded by the Utility. For the month of November, the peak demand recorded in year 2002 was 65kW higher than in year 2003.

Electric bills were reduced by nearly $ 28,000 between the heating season 2002-2003 and heating season 2003-2004.

DISCUSSION

The Building Management has decided to implement phase II, encompassing the rest of the complex, based upon the savings generated by this system. Electric prices have risen significantly this past year and Management has appreciated a stabilized bill rather than an increase in the operating costs. Especially since phase II is largely financed through owner debt, their decision is a very promising market indicator.

Although there were significant savings and Building Management responded positively, the initial savings estimate was higher than the outcome. The overall performance for the year was projected at 13% as opposed to the 10% recorded for the period. Even if non-heating measures such as lighting and refrigerators will generate savings during the summer, results are still below the expected savings. Originally, 20% of heating savings were estimated but only 16.3% were recorded. This discrepancy between projection and performance can be accounted for in the following:

- 24 out of 169 apartments did not install the control system or thermostatic function had been set to manual mode. For these apartments, which represent 14% of the total number of apartments, tenants operated the heating system as they had in previous years. The assumption in the energy audit was that 100% of the apartments would participate in the project.
- Targeted temperature setpoint to achieve savings was calculated to be 75°F. A significant number of tenants (46% of the apartments equipped with the new system) started to complain in November that it was too cold at these temperature settings. Setpoints had therefore been re-adjusted remotely to values ranging from 76.0°F to 80.0°F. The resulting average building temperature was calculated at 76.7°F. A 1.7°F increase in temperature setpoint reduces potential for savings of 4% for the period.
- Outdoor temperature reset was not operational until the end of the heating season. Potential savings that could have been generated in the month of March and April if this function was enabled were not realized.

The same consideration is to be applied to the electric demand, where reduction estimates were higher than recorded. The 64 kW demand reduction that did occur was most likely from the overall temperature limiting strategy since the PDL algorithm was not operational during the heating season. We believe that the implementation of PDL will reduce peak demand by several additional percentage points.

System Implementation, Commissioning and Behavioral Responses

We originally suggested a strategy of introducing the new control function with high set-points and very gradually decreasing them as the heating season wore on. In this way we hoped to acclimate residents, long-used to full control and high temperatures, to a new temperature and comfort regime. Management did not see things this way and took a very hard-line position, that 74 degrees was all that they were required to provide (actually in excess of what NYC regulations require) and, now that they had the capability to monitor and control, all that they would provide.

We will never know if our strategy might have avoided most complaints. But we did confirm our prediction that the hard-line approach would result in a variety of behavioral responses, of which the no-heat complaint was only one. From the combined temperature and power profiles in individual apartments we were also able to see ice applied to sensors, the use of electric space heaters, and the use of gas ovens as supplementary heating sources. Eventually several boxes were pried open when it was discovered that the panels would fail in the "heating on" mode. And in one case the lead maintenance mechanic wired bypasses around the controlling relays.

All of these behaviors might have been reduced if tenants had the possibility of overriding the system for short periods of time. Receiving a tenant complaint usually resulted in having an operator increasing the temperature setpoint permanently in a zone. This compromise was the answer to a complaint, but always leads to potential savings deficiency. End-user interface should be explored and designed to match building performance with residents' needs.

The new system complicated the logic in responding to a no-heat complaint. Previously maintenance staff had simply to check the breaker and the baseboard thermostat and if these were properly operative, replace the baseboard element. Now staff had to know if the apartment temperature actually required heat in relation to the setpoint; a temperature measurement was now necessary as well as looking at the control status on the system screen in the management office. We provided instructions, a written procedure with AEA phone support, and staff training but this set of behavioral modifications has also proved slow and somewhat difficult.

Monitoring apartment temperatures on a daily basis and dealing with end-users expectations have built our experience in understanding the mechanism of an electric building as a whole. Analysis of historical data and trends provides solid information on building response and tenants' behaviors. The system has learned to predict accurately the electric demand based on outdoor and ambient temperature conditions. Furthermore, tenants have also understood that the heat in their apartment is not unlimited. Window openings do not occur at 75°F as often as at 85°F therefore capping the maximum temperature was definitely the driving force behind usage savings.

The initial audit recommended window replacements and insulation of air conditioner sleeves. These measures were not implemented because of budget restriction. We believe that their implementation as well as any measure that could improve building envelope tightness would have reduced the need to increase temperature setpoints in a significant number of apartments. Leaky windows interfere with the convective flow of apartment air, which is the only carrier for electric baseboard heating. An additional improvement might have been the replacement of all outdated baseboards with the communication and control modules built-in.

CONCLUSION

The retrofit of an Energy Management and Control System (EMCS) can be cost-justified and effective in improving the performance of a residential apartment complex heated by baseboard resistance elements. Barriers to the effectiveness and maintainability of common control functions can be overcome by having all sensors and controls integrated into a two-way communications system so that apartment temperatures can be monitored, alarmed, and reset as necessary from a central location rather than requiring apartment access. Costs and disruption are considerably less than alternative approaches of converting such facilities from electric space heat to either centralized or decentralized fossil fuel fired systems. A wireless technology based on mesh-network communications is shown to be workable in this building context and can be expected to decline in cost. However, the response of residents to change in environmental conditions should not be under-estimated and if not properly prepared for together by the project team and the building management client can cause system rejection and project failure. The method of introducing the system and altering the temperature control regime is considered as a significant variable in project acceptance and success. Remote setpoint capability provides the opportunity for very gradual change in apartment temperatures, allowing occupant acclimatization to new conditions and, as a result, better acceptance. Project dynamics did not allow testing of this hypothesis. A future test would be worthwhile. With the sudden, one-step change in apartment temperature provided in this case, management needed a great deal of perseverance and support to cope with the volume of complaints and other forms of resident resistance. A system-commissioning period with a commitment to problem identification, complaint resolution, and building staff training is a critical success factor for this kind of project.

ACKNOWLEDGEMENTS

The authors would like to recognize various parties for their vital support of the project - David Hepinstall, Executive Director of AEA, the NYC DHCR Weatherization Assistance Program and the NYSERDA AMP team.