The Challenge of Vapor-Diaphragm Thermostat Retrofits in Existing Multifamily Buildings

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ABSTRACT

Various space-heat thermostats have been proposed over the years by utilities and manufacturers as a potential source of space heat energy savings – including electronic line voltage, vapor diaphragm, and programmable models. The question remains, do thermostat retrofits generate actual energy savings – and if so, under what conditions?

This paper describes two phases of metering research conducted during the 2004-2005 and 2005-2006 heating seasons. The study was designed to confirm or dispel the following hypotheses: (1) reducing the thermostat temperature setting results in savings of about 7% of space heat for a 1ºF reduction in temperature; (2) equivalent comfort can be achieved at lower temperatures where hysteresis is reduced; and, (3) changing bimetal thermostats to vapor diaphragm thermostats, without thermostat pre-sets, labeling, or tenant education, automatically results in energy savings. The study focused on multifamily units having extensive external surface exposures and larger than average floor areas.

The first key finding was that, among selected units, annual energy consumption decreased by 513 kWh for each 1ºF decrease in the space temperature: nearly 14% of the annual space heat. The second finding was that equivalent comfort was in fact delivered by the reduced hysteresis and lower space temperatures. Findings on the third hypothesis were inconclusive, because tenants were not able to discern space temperature differences of 1-2ºF, and were not, without further education or product labeling, able reliably to set thermostats to the lower levels required for energy savings. The paper concludes with a discussion and recommendations for product research and program design.

Introduction

This study arose out of uncertainty about the energy impacts of residential space heat thermostat retrofits in multifamily housing units. Seattle City Light proposed residential thermostat replacements as an eligible measure in negotiations with the Bonneville Power Administration for a Conservation Augmentation contract in 2001. At that time Bonneville was not willing to allow this as an eligible measure for multifamily buildings. Since then, the Northwest Power and Conservation Council's Regional Technical Forum reviewed available data on energy savings from thermostat replacements and established deemed energy savings for a similar measure (electronic line voltage thermostats) under Bonneville's Conservation and Renewables Discount program, but only for single family homes. Existing research did not convincingly demonstrate energy savings for thermostat replacements in multifamily buildings. There was no current research on vapor diaphragm thermostat replacements in multifamily buildings.

Based on the Regional Technical Forum endorsement of the measure in single-family homes, City Light approached Bonneville to ask if multifamily thermostat replacements would be accepted as an eligible measure under the existing Conservation Augmentation contract. Bonneville agreed to accept multifamily thermostat replacements if City Light could convincingly quantify the energy savings from this measure. This metering study is intended to help answer the question of what energy savings result from multifamily thermostat replacements.

This paper describes two phases of metering research conducted during the 2004-2005 and 2005-2006 heating seasons. The analysis focuses on a combined analysis of both phases and identifies differences between the two as appropriate. The paper concludes with a discussion and recommendations for product research and program design.

Objectives and Hypotheses

The purpose of this study was to investigate the performance of vapor-diaphragm thermostat retrofits in multifamily residential units. The study focused on multifamily units having extensive external surface exposures and larger than average floor areas, with the expectation that these had the greatest likelihood of demonstrating any possible impacts. The first phase of this study (winter 2004-2005) had three objectives. In the second phase (winter 2005-2006), objectives were added to confirm or dispel three hypotheses.

1. **Energy Savings Objective.** Evaluate energy savings from vapor diaphragm thermostats installed in multifamily residential units with electric baseboard space heat, located in the Seattle City Light service area.
2. **Associated Characteristics Objective.** Determine significant building and tenant characteristics that are major determinants of energy savings associated with installing vapor diaphragm thermostats to replace bimetal thermostats.
3. **Proof of Concept Objective.** Critique the "proof of concept" from the metering methodology, and offer recommendations regarding a Phase 2 round of additional metering study.
4. **Thermostat Setback Hypothesis.** Reducing the thermostat temperature setting results in savings of the expected magnitude, which is approximately seven percent (7%) of annual space heat for a one-degree (1ºF) reduction in temperature, based on reported savings for single-family housing.
5. **Comfort Hypothesis.** Equivalent comfort can be achieved at lower temperature settings when hysteresis is reduced.
6. **Thermostat Retrofit Hypothesis.** Changing bimetal thermostats to vapor diaphragm thermostats, without thermostat pre-sets, labeling, or tenant education, automatically results in energy savings.

Theory: How Vapor Diaphragm Thermostats Save Energy

Vapor diaphragm thermostats maintain the temperature in the space closer to the set temperature on the dial (smaller hysteresis) than do bimetal thermostats. The hysteresis, also known as dead-band, refers to the temperature difference range between a thermostat coming on and shutting off (or conversely the range between shutting off and coming on). Typically the hysteresis of a vapor diaphragm thermostat is about 2°F as opposed to a bimetal thermostat at 5°F or above. Occupants can achieve the same or better comfort levels than before while setting the thermostat to a lower average temperature. This action saves space-heating energy. By lowering the thermostat set-point, the same level of comfort can be achieved.

Most of Seattle's multifamily housing units have electric resistance space heat, which was the lowest-first-cost choice for builders. Baseboard and radiant heaters allow for zonal heating with independent thermostats, which can save energy when unoccupied rooms have lower temperature settings or are operated fewer hours. It is believed that occupants often set thermostats higher than the desired average temperature in order to avoid extended cool periods during times between heater on-cycles, causing the room at times to overheat. It is difficult for traditional bimetallic thermostats to maintain near-constant temperatures in these systems.

Newer design vapor diaphragm and line voltage thermostats offer more precise temperature control than conventional bimetal thermostats. The more accurate calibration and more frequent duty cycles yield increased comfort for occupants. The basis for replacing space-heat thermostats is achieving a tighter 'dead-band' and avoiding excessive temperature 'droop'.

Dead-band (also known as hysteresis) is the difference between the temperatures at which the heater switches off or on. Bimetallic thermostats typically cycle on and off every 90 minutes, have a dead-band of about 5°F, and a droop of about 5°F. Droop occurs when heat builds up from the current passing through wires inside the thermostat. A sensor not insulated from this build-up turns off the heater too soon. Occupants can become uncomfortable from excessive droop, because ambient temperatures do not rise to the expected level. They can also become uncomfortable from a wide dead-band, which leaves the heater off too long between duty cycles and allows the space to cool excessively before re-warming.

Vapor diaphragm and electronic line voltage thermostats have a narrower dead-band, around 2°F, and a commensurately smaller droop of about 2°F. These thermostats come on and off more frequently, responding to smaller changes in room temperature, often operating in 10-15-minute cycles. Thermodynamically, these thermostats by themselves do not save more energy over the bimetallic type. However, occupants can achieve the same or better comfort levels than before while setting the thermostat to a lower average temperature. By lowering the thermostat set-point, space heating is saved and the same level of comfort is achieved. Room temperatures do not need to swing as high as before, while the low point of the cycle remains the same. If the thermostat were set down by only 1ºF on average, energy savings could be about 7% of space heating; and if by 2ºF , savings could be about 14% (EPRI 1994; E Source 1997; Johnson et al. 2000).

Methodology

The study team investigated energy impacts of replacement thermostats by conducting metering research over two winter seasons, supplemented by tenant interviews. Basic characteristics were collected for 22 candidate multifamily buildings: 12 in Phase 1 and 10 in Phase2. Characteristics included year built, floor area, number of living units, energy efficiency upgrade history and bimonthly electric billing histories for each unit. The billing histories were screened to identify units with significant heating energy consumption, resulting in the identification for the study of 418 candidate apartments: 84 in Phase 1 and 334 in Phase 2. A characteristics binning strategy for Phase 1 was defined and included two divisions for each of the four categories of weatherization, floor area, exterior surface exposure and occupant behavior of heater operating hours. The binning strategy included 16 characteristics bin combinations. The binning strategy was modified for Phase 2 to include two divisions for each of two categories on floor area and exterior surface exposure for only one weatherization category. The Phase 2 strategy included four characteristic bin combinations.

Baseline Data Collection and Final Sample Selection

Interviews were performed with each of the twenty-two resident managers to verify previously identified characteristics and supplement additional characteristics to further categorize the candidate units into the characteristics bins. Residents were also interviewed for recruitment into the study and to obtain further characteristics. The units recruited were also screened by testing the thermostat to verify significant hysteresis in operation of the existing bimetal thermostat. Eighteen units were ultimately recruited for the Phase 1 study. Table 1 summarizes the distribution across the characteristics bins. The investigators decided to delete heating hours from the binning strategy for Phase 2. This factor is tenant behavior dependent and not available for population extrapolation. Twenty units were recruited for the Phase 2 study and are summarized in Table 2 across the characteristic bins.

Table 1. Final Sample Selection, Phase 1

Bin	Weatherization	Floor Area	External Exposure	Heating Hours
1			Extensive	High 2
2		Large	5	Low 3
3			Minimal	High 1
4	Weatherized	6	1	Low 0
5			Extensive	High 2
6		Small	5	Low 3
7			Minimal	High 0
8	11	5	0	Low 0
9			Extensive	High 1
10		Large	2	Low 1
11			Minimal	High 0
12	Not Weatherized	2	0	Low 0
13			Extensive	High 0
14		Small	3	Low 3
15			Minimal	High 2
16	7	5	2	Low 0
Cases	18	18	18	18

Table 2. Final Sample Selection, Phase 2

Bin	Weatherization	Floor Area	External Exposure
A		Large	Extensive 14
B	Weatherized	15	Minimal 1
C		Small	Extensive 5
D	20	5	Minimal 0
Cases	20	20	20

Test Equipment and Procedure

A device was developed for hysteresis testing of wall-mounted thermostats. It consisted of a transparent plastic container with dimensions of about 12 inches by 6 inches by 4-1/2 inches. Two sealable ventilation holes were cut in it. A small fan was installed to circulate air around the thermostat. An air temperature sensor was included to measure the air temperature around the thermostat during testing. And, a switched light bulb was mounted inside as a heat source. The following steps were used in testing the hysteresis of the thermostats:

1. The thermostat was turned up, if off, until it clicked on.
2. The test equipment was held in place against the wall covering the thermostat and remained there until the test was completed.
3. The fan was turned on and remained on until the test was completed.
4. The air vents in the device were closed and the light was switched on. This heated the air circulating around the thermostat in the small enclosed space.
5. When the thermostat clicked off from the heated air in the device, the air temperature was noted.
6. The light bulb was switched off and the air vents opened. This allowed the air in the device to cool down to room temperature.
7. When the thermostat clicked on, again the air temperature in the device was noted.
8. The cycle was repeated several times until the readings provided consistent on and off temperatures.
9. The difference between the off and on temperatures was considered a strong indicator of the thermostat hysteresis.

Interpreting Hysteresis Test Results

The hysteresis testing device did not provide an exact measurement of the actual thermostat hysteresis; however, it did provide a relative indication of thermostat performance. The test repeatedly showed an off-on temperature difference of about 6°F for the new vapor diaphragm thermostats that were rated at a hysteresis of 2°F. Therefore, only test results on bimetal thermostats with temperature difference values greater than 15°F in the study were accepted. Most bimetal thermostats tested with this device resulted in temperature differences in excess of 20°F. In all, thermostats were tested in 26 units (57 total thermostats), of which 22 were determined to have large hysteresis for all thermostats. Of the 57 total thermostats tested, four were determined to have small hysteresis. This resulted in 93% of bimetal thermostats tested to have significantly large hysteresis.

Detailed On-Site Measurement Using Data Loggers

Ampere loggers were installed on up to two heat circuits in each the sampled units (up to three circuits in Phase 2). Temperature loggers were installed at each bimetal thermostat that was to be replaced with a vapor diaphragm thermostat. One temperature logger was installed to obtain outdoor air temperature at each building. The metering equipment remained in place for four weeks, then the thermostats were replaced and an additional four weeks of data were collected. All data channels were downloaded and analyzed. Anomalous data were identified and specific questions were generated to ask the tenants for possible explanation of anomalies. Some tenants were unreachable. The tenants interviewed indicated consistent use of both thermostats and were unaware of pre-post temperature differences observed in the data.

Phase 1 data collection. Two units were dropped from the sample: one due to significant logger data loss and one due to vacating the unit shortly after the thermostat was retrofitted. Two other units experienced thermostat mechanical failures, which resulted in half the electric heat logger data (one of two channels) being invalid for the failed thermostats. These units were eventually dropped because the failed thermostats affected the operation of the remaining thermostats in the units. General observations of the data included: two living rooms and five bedrooms had insignificant heater use in both the pre- and post-periods; post-period outdoor temperature was about 5ºF warmer than pre-period outdoor temperature; 17 thermostats had a lower post-period average temperature when the heat was on; and, 11 thermostats had a higher post-period average temperature when the heat was on. During intervals when the thermostat was "on", the space was 0.4ºF cooler in the post- than in the pre-period. When it was "off", the space was 0.3ºF warmer in the post- than in the pre-period. The average observed space temperature was 70 ºF.

Phase 2 data collection. One unit was dropped from the sample because it had very low heat consumption. It was erroneously identified as a high space heat consumption unit due to anomalies in the billing data. General observations included: six bedrooms had insignificant heater use in both the pre- and post-periods; post-period outdoor temperature was about 2 ºF degrees cooler than the pre-period outdoor temperature; 26 thermostats had a lower post-period average temperature when the heat was on: and, 20 thermostats had a lower post-period average temperature when the heat was on. During intervals when the thermostat was "on", the space was 0.2ºF warmer in the post- than in the pre-period. When it was "off", the space was 0.8ºF warmer in the post- than in the pre-period. The average observed space temperature was 69 ºF.

Findings

The energy savings analysis included the three primary tasks of performing a regression analysis, adjusting the data for pre-post outdoor temperature differences and extrapolating the energy savings to an annual basis. The metered data were used to correlate hourly kW heat to outside air temperature for both the pre- and post-periods. The correlations were then applied to Typical Meteorological Data (TMY) hour temperature data to extrapolate pre- and post-consumption to the entire heating season. Anomalous data, which included units where space heat increased at the same time space temperatures decreased (and the reverse condition), were eliminated from the sample.

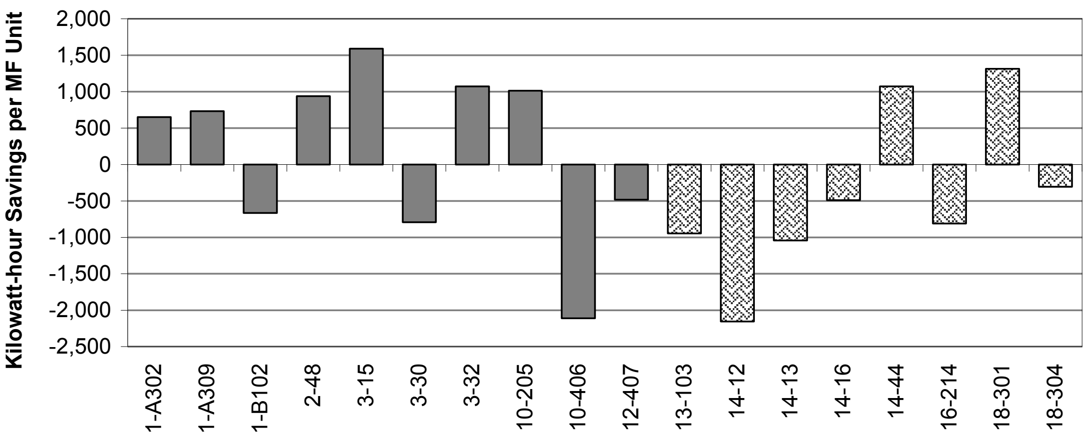
The data were further analyzed for inconsistencies between adjusted annual savings and space temperature differences between the pre-and post-periods. Four Phase 1 units were found to have either increased heat consumption with decreased space temperatures or decreased heat consumption with increased space temperatures. These four units were removed from the sample. This left 18 units from the combined research phases for analysis of energy savings.

The average energy savings were 195 kWh with a standard deviation of 1,152. Values that were more than + or – two standard deviations from the mean were considered outliers. All savings values fell within two standard deviations; therefore no outliers were eliminated.

Annual energy savings for the whole apartments ranged from -2,154 to 1,591 kWh per year with an average value annual energy increase of 78 kWh per year (see Figure 1). The average annual energy increase relates to an average space temperature increase of 0.1°F during periods that the heat was on and an average increase of 0.5°F when the heat was off. The standard deviation of savings was 1,155 kWh per year. All savings values fell within two standard deviations; therefore no outliers were eliminated.

The average space temperature difference, Delta T "off", is somewhat ambiguous because it is a measure of only the difference in space temperature while the heaters are off. This can be an indication of difference in the amount of temperature setback between pre-and post-periods based on how far the tenant turned the thermostat back when they left or went to bed. It can also be a function of how far the temperature drifted down when they turned it back based on how cold or warm the outside air temperature was. Therefore, it has limited value in determining actual differences in the amount of tenant setback

Figure 1. Adjusted Annual Energy Savings, Combined Phases



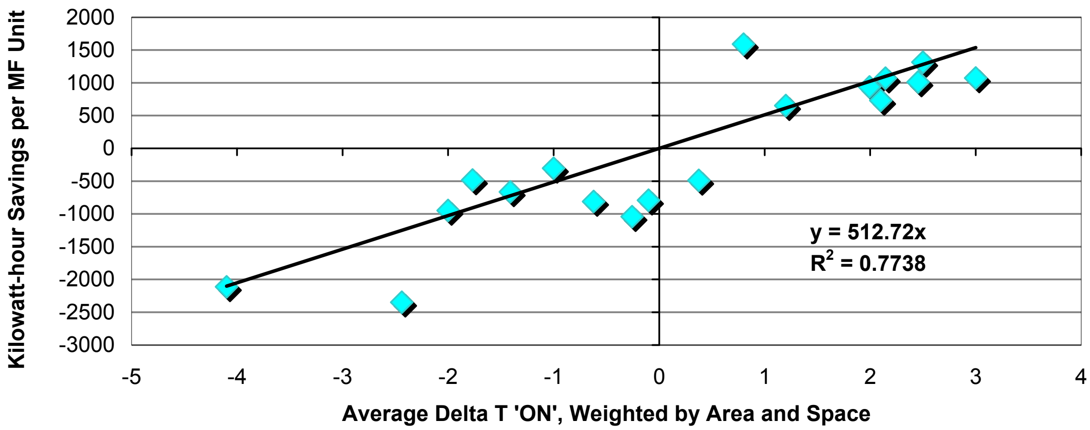
Space Heat Savings and Space Temperature Analysis

An important aspect of the data collected in the study is that the relationship between energy consumption and space temperature can be determined. This section provides that analysis and adjustments to best represent the data on a multifamily dwelling unit level.

As the space temperature was increased or decreased, the space heat consumption correspondingly increased or decreased. Using the Delta T "on" and the annual kWh savings, this relationship was plotted in a figure (not shown) similar to Figure 2. The Delta T values were simple averages of all temperatures within the unit associated with space heat savings. The original correlation line through the data had a good statistical fit with an R-squared of 0.748. The slope of the line showed that for every 1°F change in average room temperature, the annual space heat changed by 514 kWh.

Using the average space temperature change to represent the total unit savings introduces bias in the relationship because each space temperature represents a different sized unit and other factors such as different room temperatures based on occupant temperature preferences. To reduce the bias, the average temperature change values were weighted by approximate floor area of each space to normalize the unit size. The values were also weighted to the magnitude of the energy savings of each space to further normalize to other factors that effect energy savings such as the variations in preferred space temperature.

Figure 2. Space Heat Energy Changes as a Function of Space Temperature Change, Weighted by Area and Space



Even though the values are somewhat different due to the weighted averages, the results shown in Figure 2 are almost the same as (less than 1% different from) the correlation previously described. The figure summarizes the data to illustrate the relationship between change in space temperature and impact on energy consumption. The slope of the correlation line indicates the sensitivity of the relationship. The correlation line through the data has a good statistical fit with an R-squared of 0.774. The slope of the line shows that for every 1°F change in average room temperature, the annual space heat changes by 513 kWh.

Conclusions

It is difficult to draw firm conclusions concerning energy savings resulting from installing vapor diaphragm thermostats in weatherized multifamily units, based on the Phase 1 and Phase 2 results. However, the following conclusions are offered.

Energy Savings Objective

Phase 1 of the study proved the concept of energy savings from replacing bimetal thermostats with vapor diaphragm thermostats.

Overall energy savings per multifamily housing unit fell within the range of 166 to 342 kWh per year as a result of replacing bimetal thermostats with vapor diaphragm thermostats. This represents 6-12% of the November-April space heat. Given the expectation of 7% savings from every 1°F drop in average thermostat temperature settings, this would imply a 1-2°F drop in those settings. The average temperature reading taken near those thermostats only changed by 0.5 degrees. However, this does not necessary equate to the same change in thermostat settings because the average observed values include significant heat-off hours for those cases where more than one thermostat was associated with the heating circuit.

It should be noted that, in Phase 2, overall post-period annual energy consumption increased by 420 kWh over the pre-period. This value is based on an average overall increase in space temperature of 0.5°F during the post-period compared to the pre-period. This may be due to the colder post-period average outdoor temperature, which may have prompted tenants to keep their units slightly warmer.

The following observations were also made from combined Phase 1 and Phase 2 analysis. Across both phases of the study, annual energy consumption increased by 78 kWh after installation of the vapor diaphragm thermostat. This was accompanied by a 0.1°F increase of the average space temperature during the post-period compared to the pre-period. The Phase 2 units tended to have significantly greater space heat consumption based on the billing analysis. This may have also been a factor relating to the demographics of the sample. Although we did not collect demographic data from tenants, investigators observed that the Phase 2 participants tended to be a higher income group. This is also reflected by the significant number of Phase 2 units that were condominiums, presumably owner-occupied.

Associated Characteristics Objective

Phase 1 energy savings were greater in units that had not been weatherized, in units with larger floor areas, in units with more extensive exterior exposure, in units where the occupants do not set back the thermostats at night or when they leave the unit, and in living room spaces within units.

Energy savings were significantly greater in units that had not been weatherized. Savings in these units are on the order of about 650 kWh per year. Energy savings in weatherized units were more uncertain and fell in the range of about -100 (increased energy use) to +150 kWh per year. However, it appears likely that the savings value is closer to the 150 kWh per year value.

Units with larger floor areas use more space heat so the vapor diaphragm thermostat provided greater energy savings. They also require more thermostats because the units are larger, due to more bedrooms.

Units with more exterior surface area resulted in greater energy savings from the thermostat retrofit. Units with small exterior surfaces do not have significant heat consumption. No sample units in the small-surface categories were found in the recruiting process.

Vapor diaphragm thermostats installed in living room spaces saved more energy than thermostats installed in bedroom spaces.

Units where the occupants do not set back the thermostats at night or when they leave the unit resulted in greater energy savings from thermostat retrofit. This follows from the higher baseline energy use, due to not setting back temperatures.

This last point is useful information in support of tenant education. It should be emphasized that occupants reduced the thermostat setting as much as was comfortable, and that setting back the thermostat when they are away or at night would save even more energy.

Proof of Concept Objective

Phase 1 of the study proved the methodology for determining savings. The hysteresis testing methodology developed for the study was successfully implemented. The tests resulted in determining that 93% (54 of 57) bimetal thermostats tested had significantly larger hysteresis than the vapor diaphragm thermostats.

Minor changes in the methodology from Phase 1 were implemented in Phase 2 to reduce data loss and contain study costs. These steps significantly reduced data collection problems; no thermostat failures occurred in Phase 2. However, investigators found that it is more difficult to correlate and extrapolate annual heat consumption based on data collected during very cold periods.

In the course of Phase 1, investigators noted that some replacement thermostats malfunctioned, and that there is a possibility of thermostat failure from manufacturing defects. Complete more rigorous thermostat testing was done at time of installation to ensure equipment was functioning properly. There was a 5% failure rate of the new vapor diaphragm thermostats, at the time of installation.

In Phase 2, investigators deferred hysteresis testing until the metering equipment installation site visit. This eliminated one site visit that only resulted in a seven percent rejection of units. Initial recruitment in similar studies should include 10% extra units to compensate for attrition due to hysteresis testing. Downloading of data loggers at thermostat replacement helped identify failed loggers in the pre-period, and provided an opportunity to correct and extend the pre-period for a few additional weeks so that the site would not be lost. It was helpful to call each tenant within one week of thermostat replacement to verify the equipment was functioning properly.

Investigators considered vacancy and tenant turnover in units adjacent to the sampled units, in the attempt to explain variations in heat consumption of the sampled units; no relationship was in fact found.

In another study of this type, investigators would make use of longer periods covering "shoulder months", with greater variability of exterior temperatures. It is more difficult to correlate and extrapolate annual heat consumption based on data collected during very cold periods.

Thermostat Savings Hypothesis: Confirmed

Reducing the thermostat temperature setting did result in savings. However, the savings observed were of greater magnitude than expected. The expected magnitude was approximately 7% of annual space heat for a 1ºF reduction in temperature. Actual savings were 14% per degree reduction, in affected units.

Multifamily units across the study showed a heat to space-temperature relationship of 513 kWh per 1ºF change in temperature. A 1ºF drop accomplished by thermostat retrofits across all units in a building would result in average savings would be some fraction of 513 kWh. (Keep in mind that units selected for this study had higher than average pre-period consumption.) The sample size of the non-weatherized category was too small to accurately determine the variation between weatherized and non-weatherized categories. The energy savings for the study sample are greater than the literature suggests, but was also expected to be greater due to the stratification of the sample selecting high space heat consumers.

Comfort Hypothesis: Confirmed

Equivalent comfort was achieved at lower temperature settings when hysteresis was reduced.

Based on post-period interviews, the study found that most tenants cannot distinguish a one- or two-degree difference in space temperature. There were many tenants who maintained a slightly higher space temperature in the post-period, and were unaware that there was a difference, just as there were many who were unaware of a lower post-period temperature. Tenants were satisfied with the new thermostat and elected to keep it at study end.

Thermostat Retrofit Hypothesis: *Not* Confirmed (Results Inconclusive)

Changing bimetal thermostats to vapor diaphragm thermostats, without re-sets, labeling, or tenant education, did *not* automatically result in energy savings in all sampled units.

There was a large variation in results across the sampled units. This was due to confirmation of hypothesis 5. Since the tenants could not tell if the temperature were higher or lower during the post-period, some slightly increased the temperature and some slightly decreased the temperature. Findings on the final hypothesis were inconclusive, because tenants were not able to discern space temperature differences of 1-2ºF, and were not, without further education or product labeling, able reliably to set thermostats to the lower levels required for energy savings.

This was also compounded since many tenants did not have thermometers or degree markings on their old thermostats, and the thermostats that did have degree markings may have been out of calibration. This emphasizes the need for an educational component to accompany new thermostats.

Program implementers should be aware that there is the possibility of thermostat failure from manufacturing defects. Tenant education about thermostat operation would likely provide savings beyond values observed in this study, where setbacks did occur. The study did not provide any instruction to the tenant about thermostat operation. Any instruction may be only effective for the duration of tenancy; however the knowledge would carry over to wherever the tenant moved to next.

Discussion

It is difficult to draw firm conclusions regarding the magnitude of energy savings that can be achieved in multifamily units that are retrofitted from bimetal to vapor diaphragm thermostats. The study purposely instructed the tenants to use the new thermostats as they would the old ones. There was no mention about energy savings to the tenants, so that they would not be consciously or unconsciously biasing energy consumption (they were simply asked to try out a new type of thermostat in which the utility was interested). As a result, there was a large variation in unit energy savings. In general, when the occupants reduced the thermostat set-point temperature, energy consumption decreased and when they set the new thermostat higher, energy consumption increased.

This is a similar result to that found in a study that was conducted on Pacific Northwest single-family homes using electronic thermostats to replace bimetal thermostats (Lambert 1996). Lambert similarly instructed tenants that the study was to assess operation and acceptance of the new thermostats. As a result, some apartments experienced an increase in average temperature and some experienced a decrease. This finding was also similar to that found among single-family and multifamily units served by Northeast Utilities, receiving electronic thermostat retrofits (Johnson et al. 2000). In that study, dead-band was also significantly reduced, and yet some residents increased the set point and others decrease the set point, leading to savings at some sites and increased energy use at others.

Our study did show, as in the two preceding field studies, that if the new thermostats were set at a lower average temperature, energy savings would be the result. Among the 18 units in the combined Phase 1 and Phase 2 analysis, the average annual electric consumption for space heat was about 3,780 kWh, as estimated from the utility bills. The estimated energy savings of 513 kWh per degree temperature drop, then, represents nearly 14% of annual space heat of the multifamily units. This is twice as much as concluded in the EPRI study (1994). However, the EPRI results were based on single-family homes that were not screened to be significantly high space heat users. Across the entire population of multifamily units in Seattle, the savings would be much closer to the EPRI result because many multifamily units with few external exposures have significantly small space heat consumption.

Lambert concluded that, for the average observed decrease in space temperature of 0.88°F, annual energy savings would be about 222 kWh per year. Lambert, also, did not screen the sampled units for high heat consumption as we did, so a lower savings value would be expected in his study. Johnson (2000) concluded that annual savings were about 642 kWh per site: 1,228 kWh in single-family homes and 333 kWh for multifamily units, all unscreened for prior high heat consumption.

Johnson (2000), for Northeast Utilities, notes that "the ability to identify sites with potential savings would maximize program impacts." It appears from current study observations that the best candidates for vapor-diaphragm thermostats in existing multifamily buildings would be dwelling units with three or more external exposures (walls, ceiling, floor), a factor which happens to be highly correlated with those units meeting the significant-space heat criteria, having 2,400 kWh or more of space heat per year. In this study, about 25% of building units were screened into this category. Energy savings were also greater for studied units in buildings that had not been weatherized. Other factors correlated with higher savings were larger floor area (hence heated space), living-room installation, and use by occupants who do not manually set-back the thermostat at night or when leaving the unit. Observed savings in units having these factors occurred in spite of the lack of product labeling or tenant education. Thermostat retrofits should be avoided in smaller units with few external exposures and insignificant space heating, and in weatherized buildings, as cost-effective energy savings are unlikely to result.

Closing Remarks

Various space-heat thermostats have been proposed over the years by utilities and manufacturers as a potential source of space heat energy savings – including electronic line voltage, vapor diaphragm, and programmable models. The question remains, do thermostat retrofits generate actual energy savings – and if so, under what conditions?

This study focused on multifamily units having extensive external surface exposures and larger than average floor areas. The study found annualized savings of 513 kWh per unit for each 1ºF decrease in the space temperature: nearly 14% of the annual space heat. Across all units in a building, the average savings would be some fraction of this level. The study found that equivalent comfort was in fact delivered by the reduced hysteresis and lower space temperatures. However tenants were not able to discern space temperature differences of 1-2ºF, and were not, without further education or product labeling, able reliably to set thermostats to the lower levels required for energy savings. Hence the following recommendations are offered.

Focus impact analysis on set-point. Instead of focusing on absolute savings for the sampled units in this study, the area of focus should be on determining the impact of thermostat set-point on space heat. This change in focus is judged appropriate primarily due to the comments from the post-period data collection tenant interviews, which indicated respondents were not able to determine that they were maintaining the spaces at different average temperatures. This inability follows logically from the increased comfort provided by a thermostat with decreased hysteresis.

Focus process analysis on product labeling and tenant education. Those interested in thermostats as a program measure should work with thermostat manufacturers to test alternative methods for permanent product labeling. It would be beneficial to have the new thermostats labeled such that the "ideal" energy-savings temperature set-point, say 68°F, were at the top center of the thermostat dial with an arrow or mark indicating the ideal setting during unit occupancy. Market research should be conducted to determine the product design most effective at influencing short-term and long-term behavior. Market research should also focus on methods of tenant education that are effective at conveying information about how vapor diaphragm thermostats produce increased comfort, about how that increased comfort can lead to uncertainty about the best thermostat setting, about ideal daytime and nighttime set-points, and about the environmental and bill savings benefits.

Require product labeling and tenant education in thermostat program. Energy savings will not be achieved from a thermostat replacement program unless the thermostat installation is accompanied by a significant emphasis on product labeling and tenant education.

Product labeling with an arrow or mark indicating the ideal or recommended temperatures set-point (say 68°F) would indicate to people that this is the normal or best setting. It also provides the installer with an initial set-point. However, if an installer finds an old thermostat in the low or off position, the new thermostat should be set to the minimum position. Occupants may not know what temperature their old thermostat has been set at because it may only have "low" to "high" or "comfort zone" labels, or may be significantly out of calibration.

Tenants must understand that most people will not notice a small decrease in space temperature, and that the resulting energy savings can be significant from a lowered set-point. Without ongoing education, program savings will likely decline or not occur as tenancies turn over. It may be advisable to place an educational sticker on or near the thermostat, or mail an annual educational flyer to program participants.

As for program design, thermostat replacement is more appropriate in retrofit applications rather than in new construction. Where building codes have tightened, many multifamily units may now use minimal space heating, and thermostats may become less effective as a conservation measure. Retrofits in older buildings with zonal heat should receive the program emphasis, and then only key units within those buildings, as identified in this study.

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