Electronic Line Voltage Thermostats: A Worthwhile Retrofit for Baseboard Heat?

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Electronic line voltage thermostats (ELVTs) were retrofitted to control baseboard heat in apartments. Low ELVT hysteresis was expected to save energy, by providing comfort at lower setpoints. Tests were run December ’94 to May ’95 in Portland, OR in 27 all-electric apartments. ELVTs and bimetallic thermostats alternately controlled heating. Hourly premise electric use, zonal baseboard electric use and temperatures, and outside temperature were recorded. Temperatures recorded at times baseboards turned on and off captured thermostat hysteresis and setpoints.

ELVT hysteresis was uniformly low, averaging 0.61 °F. Old thermostat hysteresis ranged from below a degree to 6 + °F, averaging 2.48 °F; averages varied substantially between apartment complexes. ELVTs were associated with lower setpoints (by 0.88 °F) but higher full-time average inside temperatures (by 0.29 °F). Similar frequencies of thermostat adjustment implied setbacks were less deep with ELVTs than with bimetallics.

Tenants weren’t told that ELVTs would save energy, but most tenants preferred ELVTs and wanted to keep them after testing. Bimetallic thermostats were often used as on/off switches. ELVTs were more often used as temperature regulating devices, reducing depth of setback.

Average premise demand (energy use) fell slightly with ELVTs. Demand fell for occupants accustomed to little setback. Occupants used to larger setbacks showed increased average demand with ELVTs. Most occupants used setback; shallower setback with ELVTs precluded significant energy savings. Absent setback, ELVTs would have saved about 222 kWh/unit-year.

Non-diversified premise peak demand fell significantly with ELVTs, by 6 percent. Peak demand reduction patterns depend on setback habits. With little setback, ELVTs reduce demand independent of time of day; with moderate setbacks, demand reductions are at morning warm-up.

ELVTs offer energy and peak demand savings as replacements for bimetallic thermostats if bimetallics have high hysteresis. Energy savings result if occupants habitually use little setback. Peak demand savings are possible for a range of setback habits.

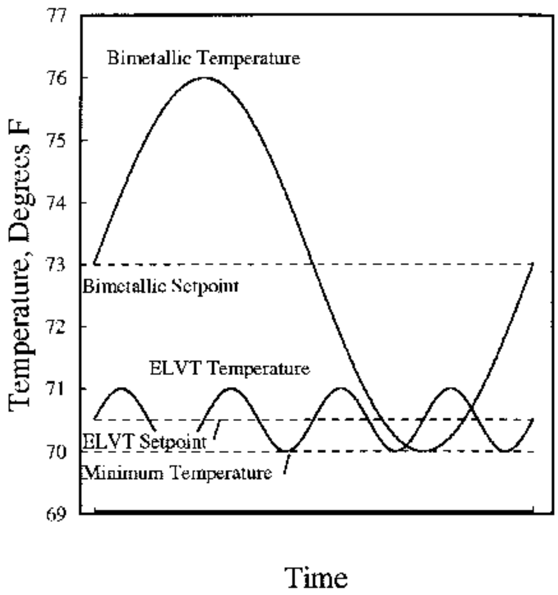
INTRODUCTION

Recently introduced electronic line voltage thermostats (ELVTs) have been touted as energy savers. The hypothesis is that more accurate control will enable lower setpoints, while maintaining equal comfort, compared to older bimetallic line voltage thermostats. ELVTs are more accurate in two ways: (1) ELVT temperature swings above and below the setpoint are smaller than for bimetallic thermostats, and (2) they suffer less ‘‘droop.’’ Droop is a fall in average temperature at the same setting, as heating approaches full-time operation.

Figure 1 shows how two thermostats can maintain the same minimum temperature with different setpoints. Higher ‘‘hysteresis’’ (difference between turn-on and turn-off temperatures) of the bimetallic thermostat requires a higher ‘‘setpoint’’ (average temperature maintained during operation) to get the same minimum temperature. This simplified diagram shows the bimetallic thermostat’s hysteresis as six degrees, and the ELVT’s as one degree; their setpoints differ by 2.5 degrees. Note that for a steady heating load, thermostat setpoint and average room temperature are the same. The savings hypothesis assumes occupants set thermostats to keep temperatures at or above their minimum acceptable comfort temperature. If this assumption is correct, ELVTs will lower average temperatures by half the difference in the two thermostats’ hysteresis.

If thermostats are set for comfort in the fall, resulting temperatures may decline due to droop as weather gets colder. With a single setting, selected for comfort and used day and

Figure 1. *Hysteresis, Setpoints, and Minimum Temperature*



night, upward setpoint adjustments to compensate for droop could result in upward ''ratcheting'' of thermostat settings during the heating season.

Previous investigations implied ELVTs would provide energy savings, compared to bimetallic line voltage thermostats. Quebec Hydro (Handfield, Le Bel & Minea 1994) reported energy savings in a test-reference comparison in homes. EPRI (Gorthala, Stolz & Hagen 1994) observed that ELVTs controlled temperature better, and drooped less, in a vacant house compared to a bimetallic thermostat.

ELVTs were offered to the City of Portland Energy Office (PEO) for its rental weatherization program. PEO wanted to verify if ELVTs provided enough energy savings, in the rental weatherization context, to warrant use in PEO's retrofit programs.

Research Questions

Previous EPRI and Quebec Hydro work addressed scenarios where occupants used constant temperature settings. Thermostat adjustments were expected mainly to compensate for droop during cold weather. In these scenarios, accurate control provided by ELVTs made reduced average temperatures and energy savings almost a foregone conclusion. The only unanswered question was, are thermostats really set to maintain minimum acceptable temperature?

For PEO, the issue was whether occupants use thermostats in this fashion. Resulting research questions were: (1) What are energy savings due to ELVTs?; (2) What are typical thermostat use behaviors?; (3) How does thermostat use influence savings?; and (4) How do ELVTs affect electrical demand?

Experiment design

Experiment design was finalized at the kick-off meeting in November 1994. Testing was viewed largely as a human factors investigation. Testing many apartments was deemed more important than apartment diversity, or a random sample. We sought complexes of convenient-to-monitor apartments, to maximize sample size with available budget.

Experimental format. We believed it was important to compare thermostats as used by the same occupants. We chose a modified before-and-after format. Half the apartments were equipped with ELVTs in November, and half kept the original thermostats. On February 1, thermostats were swapped; ELVTs replaced remaining bimetallics, and ELVTs installed earlier were replaced by the originals.

Setback use. Setback use was not ruled out. Early plans to exclude this effect were revised. The prospect of easy data analysis without setback was sacrificed, in the interest of realism.

Sample selection. PEO recruited clusters of individually metered all-electric apartments with baseboard heat. Existing thermostats were wall-mounted bimetallic line voltage types without auxiliary anticipators. The buildings were one and two story, frame construction, of 1960 to 1978 vintage, representing much of Portland's rental housing stock. PEO chose units that were already weatherized. Apartments with baseboard heat on mixed-use circuits, and heated waterbeds, were ruled out. Apartments complexes with a history of low tenant turn-over were sought; otherwise there were no demographic constraints.

Participant interactions. Participants were told that the purpose of testing was to assess operating characteristics and acceptance of ELVTs. Mention of energy savings was carefully avoided. Participants were paid $10/month to allow testing and for answering questions in three phone surveys. One in three tenants also received $5/month for allowing a data logger to share their phone line. Phone surveys, by Portland State University, investigated acceptance of ELVTs, and frequency of adjustment of both thermostat types.

Monitored data

Hourly data were recorded. ‘‘Data-Trap’’ loggers, made by Lambert Engineering, each capable of 24 analog and 60 ‘‘computed channels,’’ and 200 days data storage, were chosen for their setpoint measurement capabilities. Ten loggers, each serving either two or three apartments, were used. Data were first retrieved daily, then weekly or bi-weekly after site verification. Loggers shared participants’ phone lines, calling out to an 800 number.

Raw data. We recorded total premise electrical use and by-zone baseboard electrical use and temperature for each apartment. Outside temperature was recorded for each complex. True power was measured using current transformers and a reference voltage; typical power accuracy was +/− 1%. Temperatures were sensed with Analog Devices AD592CN sensors, with a time constant of approximately one minute in still air, and +/− 0.5 °F typical accuracy at 75 °F. Inside temperature sensors were located immediately below thermostats controlling each zone, experiencing the same air temperature as the thermostat. A typical apartment had three zones of baseboard heat—living/dining/kitchen, master bedroom and second bedroom. A few units had either one or three bedrooms.

Computed channels. Temperatures at which thermostats turned each zone’s heat on and off were captured using the loggers’ ‘‘conditional averaging’’ capability. For each zone, the logger was set to compute a status, defined as ‘‘on’’ for instantaneous baseboard power between 150 W and 20,000 W. When status transitioned from ‘‘off’’ to ‘‘on,’’ the zone’s temperature was recorded as the turn-on temperature. Similarly, transitions from ‘‘on’’ to ‘‘off’’ triggered recording of turn-off temperature. Channels were sampled about 240 times per hour.

If a baseboard cycled several times during an hour, recorded turn-on temperature was the average of several turn-on temperatures; likewise for turn-off temperatures. If baseboards didn’t change state during an hour, a missing data code was recorded. If a manual thermostat adjustment caused an immediate change in state, actual temperature at the time of change (rather than the new setting) was recorded.

These data yield both setpoint (average of turn-on and turn-off temperatures) and hysteresis (difference of turn-off and turn-on temperatures) for each zone’s thermostat. They also allow counts of each zone’s manual thermostat adjustments, by review of plotted data.

Data validation. Data validation included automated range checks, partial sumchecks, and completeness checks. In addition, all data was plotted for human review.

ANALYSIS METHODS

Data analysis consisted of two main steps. Pre-screening was done to avoid analysis of anomalous data. Data comparisons were then made to determine temperature and energy use changes due to thermostat type.

If inside temperatures varied solely due to thermostat type, measuring ELVT effects would have been simple. But many uncontrolled factors affected inside temperatures, including individual temperature preferences, night setback use, variations in ‘‘float’’ caused by solar and internal gains, tenant absences, transients while tenants adjusted to new thermostats, ‘‘micro-changes’’ in tenancy, outside temperature fluctuations, and tenant turn-over. We could have ignored these, relying on experimental format to normalize for all of them. But our sample size and data collection period (just two months of cold weather for each half of the test), was vulnerable to random noise; we wanted to avoid as many random influences as we could.

Data pre-screening

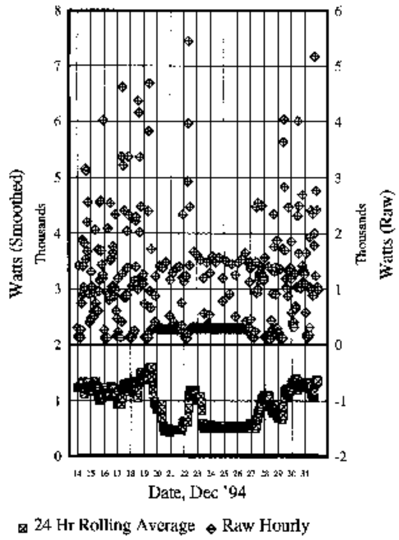
Pre-screening to mitigate uncontrolled influences is described below. When data segments were affected by avoidable conditions, we excluded them from analysis. Data were omitted in blocks of 24 hours when this was done, to avoid bias between day and night temperatures.

Tenant absences. Absences longer than a day were detected by reviewing minimums in smoothed non-heating energy use. Non-heating energy use (premise total minus baseboards) was smoothed using 24 hour rolling average, see figure 2. When a possible absence was signalled by a minimum, raw hourly data were checked for confirmation. If raw non-heating data were flat except for water heater recoveries, an absence was confirmed; the affected block of data was omitted from setpoint, energy use and average temperature computations.

Tenancy changes. Apartment managers helped by reporting tenant move-outs. We excluded apartments from analysis if there was not sufficient data for both thermostat types, used by the same tenant. Test unit 18 was evaluated for hysteresis only, due to a move-out.

Tenancy micro-changes. Significant changes can occur without a tenant moving out. Different occupants (new roommate, etc.) can be signalled by changes in non-heating energy use. We examined plotted weekly averages of non-heating energy use. Large step changes triggered closer review for signs of changed occupancy. We omitted test unit 21 from analysis (except for hysteresis), due to a changed occupancy about the time of the thermostat swap. The tenancy formally

Figure 2. Non-Heating Energy Use for Unit 4



changed later, but some of the family evidently departed early; there was a substantial change in both non-heating energy use and heating patterns.

Transient responses to thermostat swaps. Ideally, replacement thermostats should be set the same as those replaced. However, when thermostats were swapped, setpoint transients occurred. This was unavoidable; the old thermostats didn't have scales marked in degrees, or weren't well calibrated. Some tenants took time to find preferred settings. We reviewed graphs of zonal temperatures after thermostat swaps for transients. When early use didn't match later use, early post-swap data was omitted from analysis. This occurred several times.

Other uncontrolled variables

The remaining uncontrolled variables were difficult to compensate. For example, interaction between a consistent night setback and variable outside temperatures produces wide variation in average inside temperatures. We were acutely conscious of this, since pre- and post-swap weather differed in severity. Average outside temperatures for the test months were: December, 41.1 °F; January, 43.2 °F; February, 46.6 °F; March, 48.1 °F; April, 50.1 °F; and early May averaged 55.6 °F. Some test units used little heating after March.

Setback use and outside temperature variations. With setback, long term average inside temperature and setpoint depend on outside temperature. Plots of weekly average setpoint versus weekly average outside temperature showed this was often true. Unfortunately, the functional relationships were not statistically robust enough for non-judgmental measurement and systematic correction. We had to rely on experimental format to average out these effects.

Variations in temperature float. During mild weather, inside temperature sometimes ''floats'' (rises significantly above heating turn-off temperature without heating operation), due to internal or solar gains. Increased average inside temperature due to float does not imply increased heating energy use. We'd like data free from float, but in Portland, Oregon, that's unlikely; temperatures are seldom consistently cold for long periods. Late spring showed substantial float effects. We decided to discard data after 4/22/95, and blocks of data prior to that averaging 55 °F or warmer outside. This reduced but did not eliminate float effects.

Data comparisons

Thermostats affect temperatures, so first we reviewed temperature change as an indicator of energy savings due to ELVTs. The question was, which temperature? Without setback, changes in setpoint during heating operation would be the preferred metric. Setpoint is immune to confounding effects of float. However, we had allowed setback use in the interest of realism. With setback, setpoint becomes a function of outside temperature. With setback and cold weather (i.e., no float), changes in full-time average inside temperature would be the preferred metric. With setback and float interwoven in our data, there was no clear choice. We examined changes in both setpoint and full-time inside average temperatures as metrics.

Zonal heating energy use is uneven. A zone's setpoint is more significant if dominates space heating energy use. In our whole-apartment setpoint temperatures, we weighted each zone's setpoint temperature according to that zone's contribution to total heating energy use.

We used the following parameters, intended to represent regular, undisturbed occupancy and thermostat use:

- Zonal average ''heat on'' temperatures for each zone
- Zonal average ''heat off'' temperatures for each zone
- Zonal average heating setpoint (average of first two items) for each zone
- Zonal average hysteresis (difference of first two items) for each zone
- Zonal full-time average temperatures for each zone

- Zonal and total heating energy use
- Zonal heating energy use fractions (zonal heat/total heat)
- Heating-energy-weighted apartment average hysteresis
- Heating-energy-weighted apartment average setpoint temperatures
- Whole-apartment unweighted full-time average temperatures
- Whole-apartment unweighted 24 hour temperature profile (averages of each hour)
- Whole-apartment diurnal temperature swing (24 hour profile max minus min)
- Whole-apartment average hourly demand
- Whole-apartment peak hourly demand

We also determined an experimental heat loss coefficient for each apartment. Regressions of premise total energy use versus temperature difference for heating conditions were made, using weekly average power and weekly average inside and outside temperatures.

RESULTS

The context for our results is as follows: Heating energy use during December 1994 through April 1995 was about a third of the total energy. Average apartment heat loss coefficient was 50 Watts/°F. Two thirds of the heating energy was used in the kitchen/dining/living room zone. One quarter of the 56 bedrooms were essentially unheated. Full-time average living room zone temperatures were 70.07 °F, with bedrooms averaging 68.74, 67.94, and 67.6 (largest to smallest). Setpoint temperatures were also higher in living room zones than in bedrooms. Average room temperatures were lower during milder weather (February . . . April 1995) than during colder weather (December 1994 . . . January 1995). Most occupants used setback at least some of the time.

We examined temperature effects of ELVTs first. Energy and demand effects were analyzed after temperature effects were understood.

Temperature changes with ELVTs

Temperature effects are summarized in Table 1. Hysteresis and setpoint are heating-energy-weighted averages for each apartment. Average inside temperatures and diurnal temperature swings are unweighted averages. Results are grouped by which thermostat type was used first, to show weather effects. The top group used ELVTs during milder weather; the bottom group used ELVTs during colder weather. Group averages are shown because weather effects were significant. In the following text, parenthetical values are standard error values.

Hysteresis. Hysteresis with old thermostats averaged 2.48 °F (+/−0.337); ELVTs averaged 0.61 °F (+/−0.085). Hysteresis of ELVTs was relatively uniform, but the bimetallics ranged from less than a degree to over 6 °F. Bimetallic thermostat hysteresis tended to be relatively uniform within an apartment complex, with large differences from one complex to another. The relatively low hysteresis of original thermostats in complex 2, with 19 apartments, dominated many aspects of our study's outcome. Bimetallic thermostats without temperature scales (e.g., markings such as ''colder—warmer,'' ''comfort zone'') usually had greater hysteresis.

Setpoints. As expected, setpoints were lower with ELVTs. The 0.88 °F (+/−0.34) decrease was only slightly less than half the decrease in hysteresis, 1.87 °F (+/−0.32). ELVTs showed lower average setpoints 68% of the time. There may have been a small minority who set thermostats to avoid overheat from overshoot, for whom ELVTs enabled higher setpoints without discomfort.

Full-time average temperatures. Full-time average temperatures were higher with ELVTs, by 0.29 °F (+/−0.35). No significant decrease was a surprise in light of the lower setpoints.

Temperature setback use. Most occupants used setback. We used average diurnal temperature swing as a measure of setback. Diurnal swing averaged 2.16 °F (+/− 0.25) with bimetallic thermostats, and fell to 1.87 °F (+/− 0.26) with ELVTs. There was a substantial range of setback behaviors; see Figure 3. Extreme examples of setback are typified by use of thermostats as manual on/off switches rather than as automatic temperature regulators.

Reconciling changes in setpoint and full-time inside temperature

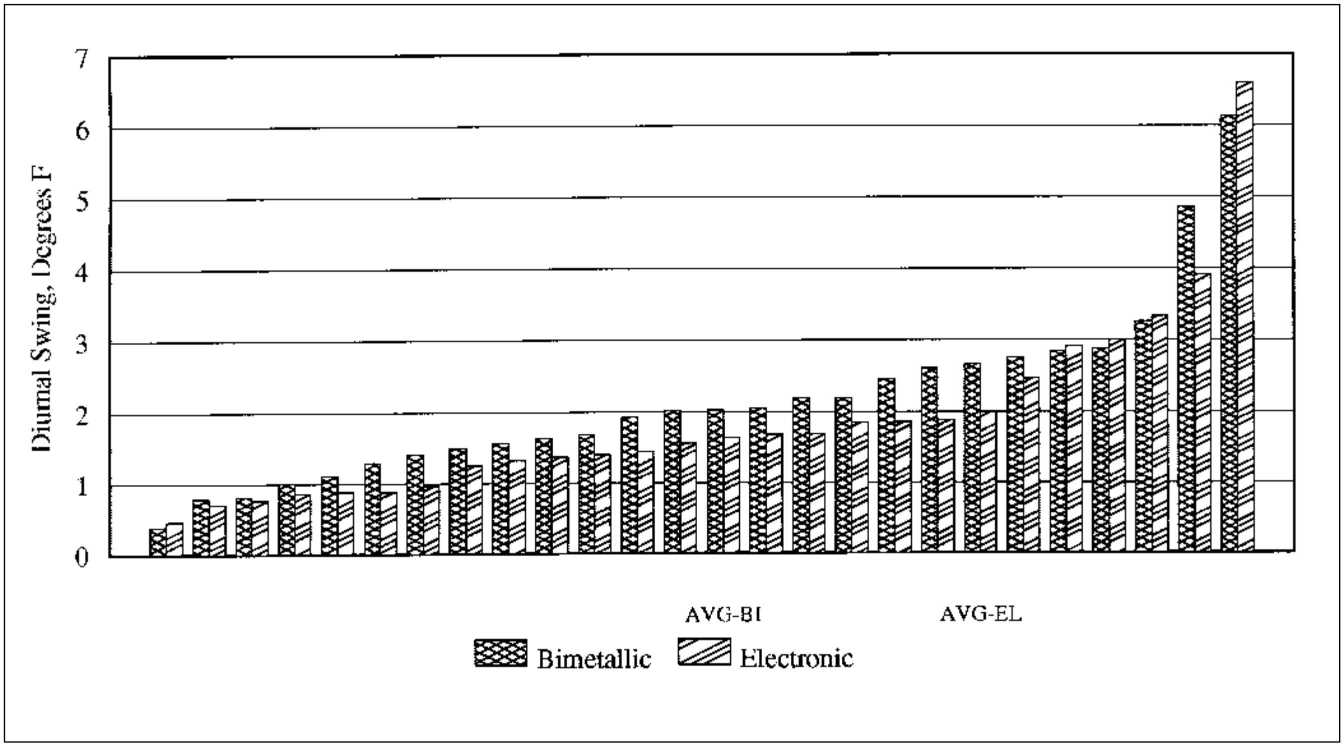
Increased full-time average temperatures with ELVTs was inconsistent with decreased setpoint, unless something else had changed. But several things might explain the seeming contradiction. Our setpoint temperatures and full-time average temperatures are weighted differently, affecting the validity of some comparisons. Without setback and float, setpoint and full-time average temperature will be nearly identical, as in figure 1. But when setback is used, setpoint temperature doesn't tell the full story; *changes* in setback use are not detected by setpoint measurement. One could

Table 1. *Temperature Comparisons—Bimetallic vs Electronic Thermostats*

	Bimetallic Thermostat					Electronic Thermostat				Electronic Thermostats				
Unit No.	Hyster-esis	Avg Setp't	Avg Inside Temp.	Temp Swing Deg F	Stat Type	Hyster-esis	Avg Setp't	Avg Inside Temp.	Temp Swing Deg F	Hyster-esis	Avg Setp't	Avg Inside Temp.	Temp Swing Deg F	Date Vacated
Bimetallic thermostats used first:														
2	5.71	75.19	73.27	1.57	H	0.57	74.97	74.87	1.25	5.14	0.22	−1.60	0.32	
3	3.69	72.42	71.57	2.87	H	0.67	72.41	71.97	3.92	3.02	0.01	−0.40	−1.05	
6	2.51	69.47	68.99	2.75	H	0.39	68.89	68.04	3.34	2.12	0.58	0.95	−0.59	
9	2.27	69.12	67.18	2.67	H	0.31	68.08	67.15	3.01	1.96	1.04	0.03	−0.34	
12	2.14	75.74	74.27	1.11	H	0.59	73.90	73.97	0.46	1.55	1.84	0.30	0.64	
13	1.80	73.52	70.76	2.19	H	0.96	72.05	70.28	1.69	0.84	1.47	0.48	0.49	3/5/95
15	0.53	70.76	70.18	0.82	H	0.32	67.79	69.32	1.85	0.21	2.97	0.86	−1.03	
16	0.89	68.97	68.88	1.29	H	0.25	69.73	69.91	1.86	0.64	−0.76	−1.03	−0.56	
18 *	0.61				C	0.54				0.07				1/18/95
20	1.16	69.35	68.86	1.50	C	0.54	70.57	70.75	1.56	0.62	−1.22	−1.89	−0.07	
22	1.31	70.34	72.73	1.92	C	0.23	68.27	70.25	1.88	1.08	2.07	2.48	0.03	
23	3.14	73.01	72.79	0.39	H	0.26	69.27	69.79	0.87	2.88	3.74	3.00	−0.48	
25	3.58	67.79	66.33	2.45	H	0.66	67.59	67.82	2.92	2.92	0.20	−1.49	−0.47	4/20/95
26	6.16	73.27	69.34	4.85	H	0.42	69.57	68.83	1.40	5.74	3.70	0.51	3.46	
Group Avg	2.54	71.46	70.40	2.03		0.48	70.24	70.23	2.00	2.06	1.22	0.17	0.03	
Electronic thermostats used first:														
1	4.08	70.90	68.63	2.18	C	1.03	71.50	71.15	1.32	3.05	−0.60	−2.52	0.86	3/2/95
4	1.05	73.24	72.24	2.84	C	0.64	73.33	73.22	1.64	0.41	−0.09	−0.98	1.21	
5	3.37	69.81	68.46	0.79	H	0.36	66.04	66.77	0.71	3.01	3.77	1.69	0.08	
7	0.99	74.78	72.74	1.64	C	0.41	70.92	71.18	0.87	0.58	3.86	1.56	0.77	
8	2.43	69.46	66.47	2.61	C	0.55	69.27	67.93	1.69	1.88	0.19	−1.46	0.92	
10	0.26	68.05	66.47	2.05	C	0.14	69.32	67.87	0.77	0.12	−1.27	−1.40	1.28	
11	0.61	70.95	69.88	2.01	C	0.60	70.94	69.74	1.37	0.02	0.01	0.14	0.65	
14	1.90	71.64	70.14	1.68	H	0.89	72.90	72.20	1.44	1.01	−1.26	−2.06	0.24	
17	2.32	68.99	65.02	3.26	H	1.77	68.42	63.80	2.46	0.55	0.57	1.22	0.80	
19	0.03	73.92	71.47	1.42	C	0.11	75.41	75.09	0.96	−0.08	−1.49	−3.62	0.45	
21 *	3.32				H	0.30				3.02				3/2/95
24	5.87	66.22	61.45	1.01	H	0.80	66.43	65.07	0.86	5.07	−0.21	−3.62	0.15	
27	5.26	76.55	73.54	6.13	H	2.11	73.96	72.03	6.59	3.15	2.59	1.51	−0.46	
Group Avg	2.42	71.21	68.88	2.30		0.75	70.70	69.67	1.72	1.68	0.51	−0.79	0.58	
Other Averages:														
Overall	2.48	71.34	69.67	2.16		0.61	70.46	69.96	1.87	1.87	0.88	−0.29	0.29	
Complex 1	4.80	71.37	68.69	2.96		0.85	69.36	68.71	2.53	3.95	2.00	−0.02	0.44	
Complex 2	1.45	71.07	69.69	1.91		0.53	70.34	69.85	1.62	0.92	0.72	−0.16	0.29	
Complex 3	4.49	72.84	71.16	2.21		0.76	72.96	72.66	2.16	3.74	−0.12	−1.51	0.05	
Cadet	1.25	71.22	69.94	2.02	C	0.48	71.06	70.80	1.34	0.78	0.16	−0.85	0.68	
Honeywell	3.20	71.40	69.51	2.24	H	0.68	70.13	69.49	2.16	2.52	1.28	0.02	0.07	

* = Evaluated for hysteresis only, due to tenancy changes
Thermostat types: C = Cadet; H = Honeywell

Figure 3. *Diurnal Temperature Swing Histograms*



also argue that changes in temperature float, like changes in setback, could be undetected using setpoint alone. We addressed this issue first.

Temperature float. We didn't directly measure float; its effects are combined with night setback effects in our diurnal swing data. We compared setpoint and full-time average temperature as a discriminant. When both float and setback are present, this comparison shows which dominates. If full-time average temperature is below setpoint, setback dominates; if above, float dominates. Our data show setback dominates. Nonetheless, 24 hour temperature profiles showed some float; we worried that float might be an obfuscating factor.

First-cut analysis used data through mid-May 1995 for most apartments. If float effects were seriously influencing the diurnal swing data, deleting the warmest weather should reduce the diurnal swing magnitude substantially.

We deleted the warmest weather (over 55 °F). Deletion of the warmest blocks of data did reduce the diurnal swings slightly (by .04 °F for bimetallics and by 0.18 °F for ELVTs), but the seeming contradiction remained. Revealingly, the difference in diurnal swing between bimetallics and ELVTs *increased*, from 0.16 °F to 0.29 °F. This shows that lower diurnal swing with ELVTs isn't an artifact of temperature float.

Temperature distributions. Our setpoint data are heating-energy-weighted but our full-time average temperatures weight all zones equally. We checked zonal temperature distributions to see if weighting explains the difference between setpoint and full-time average temperatures.

Most heating energy was used in the living/kitchen/dining zone, regardless of weather or thermostat type. With ELVTs, the zonal energy use distribution remained roughly constant with weather. But for bimetallic thermostats, the percentage of energy use in the bedrooms decreased during milder weather.

Temperature-wise, the living/kitchen/dining zone always was warmer than the bedrooms. But zonal temperature distributions shifted with weather or thermostat type. Bimetallic thermostats showed lower zonal temperatures with milder weather. With ELVTs, all zonal temperatures *increased* as weather got milder; see figure 4.

These observations show two things. First, weighting differences influenced the comparison of setpoint and average temperature. Bedrooms, using the least energy, were warmer with ELVTs during mild temperatures. From a heating energy standpoint, the decreased setpoint with ELVTs is probably more meaningful than the increased average temperature. Second, these same observations show a thermostat-type-dependent change in use of setback.

Figure 4. Zone Temperatures by Thermostat & Weather

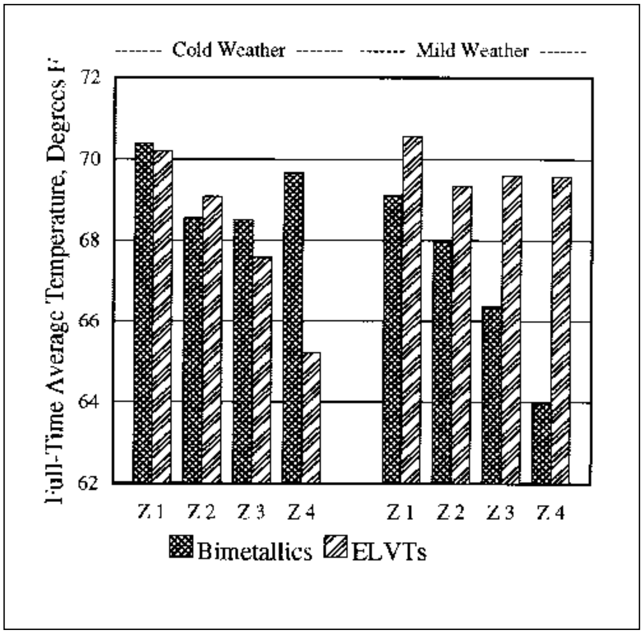
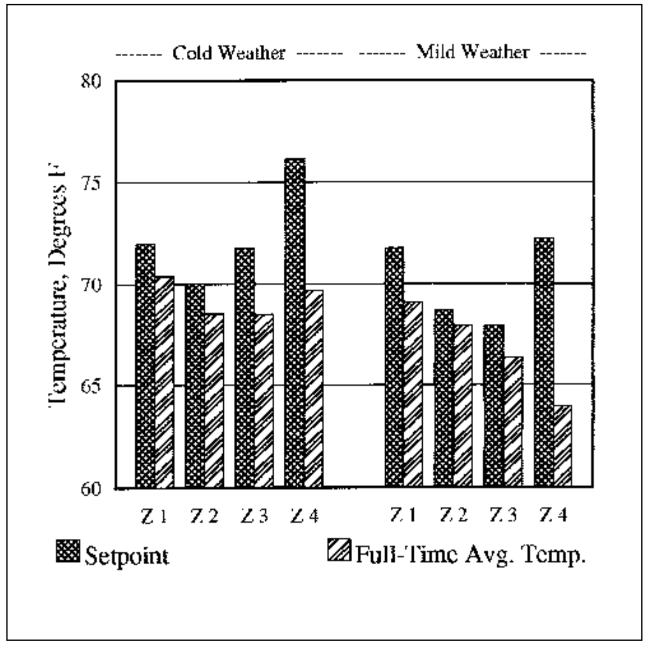


Figure 5a. Zone Setpoints & Temps—Bimetallics

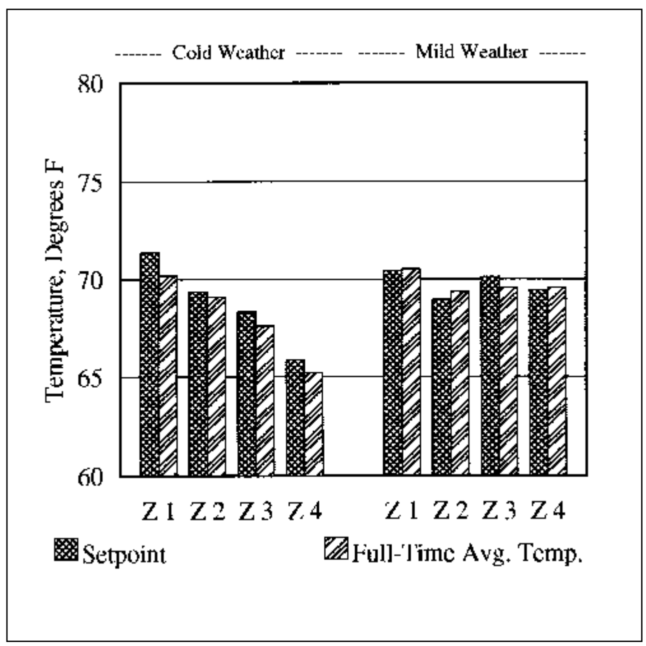


Setback changes. Since setpoint data is blind to changes in setback, the inconsistency could be partly due to a change in setback use. With warmest weather discarded, diurnal swing for ELVTs was 0.29 °F (13%) less than for bimetallics. Our conceptual model, that ELVTs reduce overshoot past setpoint, implies that setbacks should start from a lower temperature. That should produce *lowered* full-time average temperatures. Instead, we saw an increase. Occupants must have reduced their use of setback in some way with ELVTs.

While checking temperature weighting effects, we found that heat was sometimes turned off in the bedrooms during mild weather with bimetallic thermostats, but left on during mild weather with ELVTs. This contributes to lower diurnal swing for ELVTs than for bimetallics. But finding one thermostat-type-dependent behavioral difference made us wonder if there were others. We plotted zonal setpoint and temperature for both thermostat types for comparison of setbacks; see figures 5a and 5b. Average temperatures are closer to setpoint temperatures for ELVTs than for bimetallics in all cases.

This shows that less setback was used with ELVTs than with bimetallics, for all zones regardless of weather. ELVTs showed a marked reduction of setback during mild weather. For another check on setback use, we counted thermostat adjustments for both thermostat types. Plots of setpoint temperature were visually reviewed, for two two-week periods with similar outside temperatures. These counts (see Table 2) showed similar frequency of adjustment for both thermostat types during colder weather. The frequency of adjustment data suggest that thermostats were turned down about as often, but not as much, with ELVTs.

Figure 5b. Zone Setpoints and Temps—ELVTs



Energy use changes with ELVTs

We examined whole-apartment hourly demand data for changes in both average and peak values, to assess ELVT energy and demand savings. Demand data for complete data

Table 2. *Thermostat Setpoint Changes Counted in Two-Week Intervals*

Zone>>	LIV/KIT/DIN		BEDROOM 1		BEDROOM 2		BEDROOM 3		Total All Zones
Time Period>>	Dec–Ja	Feb–Ap	Dec–Ja	Feb–Ap	Dec–Ja	Feb–Ap	Dec–Ja	Feb–Ap	
AVERAGE NUMBER OF CHANGES:									
All T' stats	16.0	15.8	8.0	6.6	7.2	5.7	0.5	3.0	62.8
Bimetallics	13.9	16.1	4.3	8.3	10.4	4.2	0.0	0.0	57.2
ELVTs	18.2	15.6	11.8	4.6	4.6	7.6	1.0	6.0	69.4

sets and a single tenant are summarized in table 3. The peak demand data are non-diversified. That is, they show the peak value for the thermostat type regardless of what hour it occurred (timing of peaks is discussed later). Again, data are grouped by which thermostat type was used first.

The effects of unequal weather severity are obvious. Predictably, the ‘‘bimetallic thermostats used first’’ group showed reductions in average and peak demand, with ELVTs used during milder weather. The ‘‘ELVTs used first’’ group shows an increase of average demand for ELVTs, but no increase in peak demand. Weather was almost as influential as thermostat type in determining demand change patterns.

Peak demand. Peak demand showed a statistically significant reduction with ELVTs. Even with weather-driven scatter, the 447 Watt (6%) reduction in peak demand has a greater than 95% probability of being a non-random effect; with a one-tailed test, t value is 1.87.

When peak demand is treated as a function of both thermostat type and order of test (i.e., weather), using analysis of variance techniques, we get the following confidence interval: At the 90% confidence level, the true mean reduction in peak demand is between 53 Watts (0.7%) and 841 Watts (11.2%).

Control theory suggests ELVTs should smooth demand. ELVTs achieve their more accurate control by reducing overshoot. ELVTs must modulate more frequently to do so, reducing the likelihood of individual baseboards operating steadily for an hour or more. This applies more to a ‘‘set-it-and-forget-it’’ (S&F) scenario. It applies less for a setback scenario.

We must ask, is the observed reduction simply a reduction in the ‘‘spikiness’’ of demand patterns with ELVTs, which when averaged over many homes produces a zero reduction in their aggregated peak demand? Or does it represent a real reduction in peak demand at the substation or system level? To reduce demand at the system level requires one of two things. If the individual house peaks occur at random times with respect to each other, there must also be a reduction in *average* demand for system demand to be reduced. Alternately, reduced peaks must be non-randomly timed (in phase) with respect to each other, and must overlap the time of system peak, for a system peak reduction to occur.

Which condition is satisfied depends on setback habits. For S&F users, heating demand and its reduction will be relatively flat with time; a reduction in average demand (discussed later) is needed to conclusively show a system peak reduction. For setback users, peaks in heating demand are most likely during recovery from setback, and are non-random, occurring mostly in the morning hours. For these users, the question is has the peak been reduced and does it overlap system peak? Whether morning warm-up coincides with system peak is a question for each utility. But we can look at how peak demand was affected by setback.

We ranked our apartment sample by the amount of setback (represented by diurnal swing) used with bimetallic thermostats, as an indicator of their usual setback habits. The low setback half, with diurnal swing of 1.36 °F (not exactly S&F, but as close as we can come with a meaningful part of our sample) showed peak demand reduced by 340 Watts. The high setback half, with diurnal swing of 3.1 °F, showed a peak demand reduced by 564 Watts. Setback users had a larger than average reduction in peak demand with ELVTs. The reduction in setback we observed with ELVTs translated into lowered demand at morning warmup.

Average demand. Table 3 shows a reduction in average demand that is not significant. Lack of significant average demand (energy) savings may be due to reduced setback used with ELVTs. To test the validity of the preceding statement, we posed this question: If no setback is used with

Table 3. Premise Demand Comparisons—Bimetallic vs. ELVT

	BIMETALLIC T'STATs		ELVTs			REDUCTIONS DUE TO ELVTs	
Unit No.	Avg Demand Watts	Peak Demand Watts	Stat Type	Avg Demand Watts	Peak Demand Watts	Avg Demand Watts	Peak Demand Watts
BIMETALLIC THERMOSTATS USED FIRST:							
2	1685	8629	H	1438	7879	247	750
3	1465	7961	H	1152	7663	313	298
9	1355	8104	H	1186	6015	169	2089
12	2242	9582	H	1484	7377	758	2205
13	829	7334	H	773	6443	56	891
16	1111	7198	H	886	5818	225	1380
20	2210	12324	C	1949	12655	261	−331
22	1318	6689	C	1378	8258	−60	−1569
23	1783	6432	H	1299	6325	484	107
25	1471	8500	H	1233	7101	238	1399
26	1419	8451	H	843	5616	576	2835
GROUP AVERAGE:							
	1535	8291		1238	7377	297	914
ELVTS USED FIRST:							
1	2525	9358	C	2750	9635	−225	277
4	1645	7044	C	1939	6613	−294	431
5	873	7026	H	917	5451	−44	1575
7	1426	7065	C	1350	6080	76	985
8	1319	6698	C	1670	8256	−351	−1558
10	655	5241	C	896	5961	−241	−720
11	595	3531	C	643	3248	−48	283
14	1662	7638	H	2209	8878	−547	−1240
17	575	5641	H	556	5703	19	−62
19	1149	6572	C	1468	7000	−319	−428
24	401	4574	H	732	4215	−331	359
27	1574	10900	H	2052	10018	−478	882
GROUP AVERAGE:							
	1200	6774		1432	6755	−232	19
OVERALL AVERAGE:							
	1360	7500		1339	7053	21	447
Standard Error:						70	238

NOTE: C = Cadet Thermostat; H = Honeywell Thermostat

a bimetallic thermostat, how can there be less setback with an ELVT? Applying this question to our sample, reductions of average demand should be greater for those apartments that used the least setback with old thermostats. We tested for this by ranking the sample by setback use and comparing low and high setback halves, as for peak demand. The lower setback half showed reduced average demand of 59 Watts; the half with highest setback showed an *increased* demand of 20 Watts. These results aren't statistically significant for our sample size. But they are consistent with the idea that occupants using little setback with bimetallic thermostats couldn't reduce setback as much with ELVTs as occupants who used large setbacks with bimetallics. This suggests energy savings depend on setback habits.

CONCLUSIONS

ELVT hysteresis averaged 0.61 °F in the field. The replaced bimetallics had highly variable hysteresis from less than a degree to over 6 °F. The expectation of users selecting lower heating setpoints was borne out in most instances; setpoints averaged 0.88 °F lower with ELVTs. Due to reduced use of setback with ELVTs, full-time average inside temperatures increased by 0.29 °F, despite the lowered setpoints. Droop was not significant in our study.

Energy savings from lowered setpoints were not proven; there may have been savings, but they were not statistically significant. Study participants paid for their own heating; most were accustomed to using setback. They reduced their setback use with ELVTs, probably offsetting most of the energy savings from lowered setpoints. If occupants had not used setback with old or new thermostats, savings of roughly 222 kWh/apartment year ($14.41/yr at $0.065/kWh) would have occurred.

The reduced setback was not deliberate ‘‘takeback,’’ since test occupants were not given expectations of energy savings. Bimetallic thermostats were often used as on/off switches, more often than ELVTs, for night setback and to turn off bedroom heating in the spring. Although the frequency of adjustment was similar, ELVTs were more often used as temperature regulating devices instead of as manual on/off switches.

ELVTs showed statistically significant reductions in non-diversified peak demand. Reductions occurred for both sample halves, the low setback group and the high setback group. Demand reductions were slightly higher for the high setback group. Demand reductions are believed to arise from different mechanisms, depending on prior user setback habits. For those using relatively little setback, demand savings probably resulted partly from lowered average heating energy use. For users of more setback, heating was more likely to operate continuously for long periods with bimetallic thermostats, during recovery from setback. ELVTs, used with less setback, probably required less continuous operation to recover.

For energy savings, ELVTs can be used as replacements for bimetallic line voltage thermostats of known high hysteresis, where users are unlikely to practice setback. Some existing bimetallic thermostats we tested had low hysteresis; across-the-board replacement may be unwarranted. ELVT retrofits may be particularly appropriate in situations where setback use is unusual. Ceiling and floor radiant heat have long time constants that discourage setback use. Nursing homes and other 24 hour facilities may not use setback.

Tenants in rentals who do not pay for heating may still use setback, from habit or for cooler sleeping temperatures. Situations where energy cost savings are less likely to drive thermostat use, such as single family homes and master-metered rentals, may need further study.

For reduction of system demand, occupant setback habits are important for utilities unless they peak at morning warm-up times. System demand reductions will occur for retrofits when setback isn’t used with old thermostats. For setback users, much of the demand reductions will result from reduced duration of recovery from setback; individual utilities will need to gauge their situations accordingly. If setback is used with old thermostats, the demand reductions may be accompanied by little or no energy savings. For demand reductions, it is still important to selectively replace existing thermostats with high hysteresis.

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