SHORT-TERM MONITORING METHODS USED IN DOCUMENTING THE PERFORMANCE OF INDIVIDUAL EFFICIENCY IMPROVING MEASURES FOR SPACE HEATING SYSTEMS IN MULTIFAMILY BUILDING

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ABSTRACT

There are significant opportunities for making cost-effective energy saving improvements to the existing space heating systems in older multifamily buidings in Chicago. Four measures that are particularly promising for single-pipe steam buildings are: thermostatic boiler controls; balancing by proper vent treatments; derating the gas and air input to the boiler; vent dampers. These measures are being studied as part of a Gas Research Institute sponsored study of space heating improvements in multifamily buildings. This paper presents the preliminary results of a review of some of the short-term monitoring methods used in this project. It also presents preliminary performance results from the first half-season evaluation of the four ECMs.

The current field data collection procedures used in the Chicago's multifamily building energy conservation program are evaluated to determine their usefulness in predicting building-specific energy savings for the balancing and thermostatic boiler control ECMs. The results indicate that a weekly reading of max-min thermometers in each apartments has a level of precision comparable to hourly and weekly averages of continuous data from each apartment.

Evaluation of weekly Normalized Annual Consumption (NAC) for each of the test and control building indicates that it is feasible to use short-term monitoring periods to significantly discern savings of greater than 20%.

The performance of these various Energy Conservation Measures (ECMs) is documented by measuring changes in boiler gas consumption and by performing least-square fit against outdoor air temperature. Measured savings for the four test ECMs range from 8 to 45%. The level of confidence in the documented savings is satisfactory except for the vent damper.

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INTRODUCTION

Since January 1985 the Center for Neighborhood Technology (CNT) has been engaged in evaluating the performance of four Energy Conserving Measures (ECMs) for heating systems in existing multifamily buildings. The research is being done under contract with the Gas Research Institute (GRI). The goal is to develop valid data and procedures to facilitate the selection and implementation of these promising measures.

These ECMs are all modifications to the existing space heating system. They seem to be relatively low cost measures which have an aggregate savings potential of 20 to 30% (Katrakis, 1982). Furthermore they appear to be appropriate for almost all of the heating systems in the 5-unit to 50-unit three-story walk-up multi-family buildings. However, they are recommended less frequently, and installed much less frequently than more well-known, but considerably less cost-effective measures such as storm windows, attic insulation, insulating jackets, etc.

Recent comprehensive surveys by the U.S. Office of Technology Assessment, Lawrence Berkeley Laboratory and the Multifamily Residence Technology Transfer Working Group of the U.S. DOE reveal a lack of available, verifiable information on the effectiveness of conservation measures for multifamily housing. We believe that it is necessary to provide quality information about relatively unknown yet highly cost-effective ECMs to the energy conservation professional as well as the building owner. This will increase the likelihood that these ECMs will be applied and therefore significantly improve the magnitude of total savings, indoor temperature control, and the return on investment from energy conserving efforts in multifamily buildings.

Information on specific ECM performance is especially important for energy conservation programs where ECM implementation is contingent on the owner's decision to borrow money at interest. In these cases the owner makes the ultimate decision about what measures will be installed. If audit recommendations are not backed up by adequate documentation of ECM performance then these programs could degenerate into storm window and boiler replacement services.

The purpose of this paper is to describe the ongoing efforts at CNT to document the performance of these potentially very cost-effective ECMs for the space heating system. Special emphasis is placed on reviewing the effectiveness of short-term performance monitoring methods which can be part of an ongoing ECM evaluation and documentation program and the building energy audits.

TEST BUILDINGS AND ECMs

Over 90% of the buildings entering the City of Chicago's Community Energy Savers Fund (CESF) have single-pipe steam, space heating systems with the original cast-iron radiators and the original coal-fired steel fire-tube boilers that have since been converted to gas. The buildings are three-story walk-up structures of masonry construction with flat roofs and were built over 60 years ago. There are over 20,000 of these buildings in Chicago alone with over 280,000 living units--approximately 30% of the total living units in the city. These buildings are predominately in the low to moderate income areas of Chicago and appear to be the major source of the 6000 abandoned housing units per year.

The single-pipe steam boiler control prior to retrofit is typically a return line aquastat and a time clock. A pressure control also is connected in series primarily as a safety device. However it often operates during morning warm-up periods. The steam distribution is greatly influenced by the main line and radiator vents which control the rate at which air escapes from many different points in the distribution. The rate of air discharge from a given radiator or steam supply line determines the amount of steam available at that point and therefore the average temperature in the surrounding space. The single-pipe heat distribution system is described elsewhere in more detail (Katrakis and Becker, 1985), (Peterson, 1985).

Eleven buildings were identified, instrumented, and monitored during the last heating season. These buildings are all three-story walk-ups of masonry construction, and with single-pipe steam heating systems since this by far the predominant type of multifamily building system in Chicago. The selected buildings afforded the best combination of access for data collection, no major maintenance or repair problems, and no existing plans for energy conserving improvements during the course of the research project.

The four test ECMs are: thermostatic boiler controls; balancing by air vent treatments; vent dampers; derating. Thermostatic boiler controls consist of replacing the commonplace time clock and return line aquastat with some type of indoor air temperature thermostat system. Two systems currently used by CNT include a single thermostat located in the consistently coolest apartment, and a four-to-six-point temperature averaging themostat. Balancing by vent treatment refers to installing appropriately sized main line and radiator vents to provide even temperatures throughout the building. The balancing procedure is described in more detail elsewhere (CNT, 1985), (Katrakis et. al., 1986), and (Peterson, 1985) for descriptions of this ECM. Vent dampers are electro-mechanical devices interlocked with the heating plant ignition system to automatically close a damper in the vent pipe from the boiler to the chimney when the boiler stops operating. Derating consists of reducing the gas input and corresponding air input to the boiler in order to match the actual building heating load. Derating is not currently recommended because there is not adequate documentation of its effectiveness and there is concern about possible negative effects to building comfort, and to chimney and heat exchanger lifetime. The work being done with derating is also pertinant to sizing replacement boilers--another significant ECM in the current energy CESF program.

RESEARCH PROGRAM

The work is focussed on achieving four objectives:

a. evaluate the performance of the test measures in terms of annual savings and life cycle costs.
b. develop necessary product specifications and installation procedures for each of the test measures.
c. develop the necessary algorithms to predict the site-specific performance of the test measures
d. evaluate the feasibility of implementing the test measures in terms of impact on comfort; sensitivity to management, operation, and maintenance practice; code issues.

The work done to date (GRI, 1986) at the eleven buildings includes installing a Data Aquisition System in each of the buildings to continuously monitor boiler gas usage and indoor air temperature distributions. Each apartment temperature is sampled every 30 seconds, averaged over 10 minutes and recorded. The DAS system at each building includes one or two 16-channel analog to digital converters, integrated circuit temperature transducers, a 126 kilobyte single disk drive desk-top microcomputer, and the associated communication, calibration, and analysis software. Equipment has also been installed by the Institute of Gas Technology to conduct short-term measurements of seasonal boiler efficiency. Lawrence Berkeley Laboratory has also installed DAS units to continuously monitor boiler paramters necesary to measure boiler seasonal efficiency. During the past heating season measurements of gas consumption and indoor air temperatures were also taken manually, for redundancy purposes and also to be able to evaluate the usefulness of the manual data collection procedures being used by the energy conservation service technicians.

The experimental design for the first heating season consisted of using four of the buildings as controls--documenting their energy consumption charateristics. Operation and maintenance improvements were implemented on the other seven buildings in order to bring the heating systems up to some comparable level of reliability and performance. The four test measures were applied to each of the four buildings during the latter half of this heating season. One building received both vent damper and main line vent treatments in order to determine if the performance of both measures can be monitored simultaneously. A second building received both main line and radiator vent treatments. The third building heating plant was derated. The fourth building received a replacement thermostatic boiler control.

Where feasible the test measures were flip-flopped. This includes the vent damper, two different main line vent interventions, and derating.

GAS USAGE ANALYSIS

Algorithms

The Normalized Annual Consumption, (NAC), for a building, G_S, is related to the average seasonal outdoor temperature, T_S, as:

$$G_S = (a + b\,TO_S)\,d_S,\quad 9.158 \qquad (1)$$

where a and b are regression coefficients from daily gas consumption data, and

d_s is the number of heating days in the season.
The constants, a and b, are calculated from the least-squares fit of daily gas consumption, G_d, on the average daily outdoor temperture, T_d.

The goodness-of-fit of the linear regression is measured by its correlation coefficient r^2. In addition to r^2, the standard error in G_s is also calculated since r^2 alone may not be the best indicator of goodness of fit, especially in cases where the goodness-of-fit varies significantly over the range of outside air temperatures due to heteroskadacity.

Gas usage analysis is also carried out for the temperature differential, i.e., for the difference in the indoor and outdoor temperatures. This done by replacing TO_s and TO_d by $(TIBA_s-TO_s)$ and $(TIBA_d-TO_d)$ respectively where $TIBA_s$ is the average seasonal indoor temperature and $TIBA_d$ is the average daily indoor temperature.

Gas Usage - Seasonal and Weekly Least Squares Fit

The above algorithms were used to calculate G_s for nine of the buildings in this study. The rsults, for the regression of G_d against TO_d, as well as G_d against $(TIBA_d-TO_d)$ are shown in Table 1. In both regressions, the daily outdoor temperature, TO_d, used is based on degree day data collected at the O'Hare International Airport, Chicago. The number of heating degree days in a day, DD, are related to the average daily temperature, TO_d, as:

$$TO_d = 65 - DD \tag{2}$$

The standard error for G_s from the G_d vs. $(TIBA_d-TO_d)$ regression is not consistently better than that from the G_d vs TO_d regression for all the buildings. Therefore there is no clear advantage to using indoor air temperature as part of the least squares fit analysis of daily consumption data. The same results occur when outdoor air temperatures measured at each building are used in the regression. This is significant inasmuch as continuous monitoring of indoor temperatures is costly and time consuming.

In order to compare the effect of monitoring duration on the predicted G_s values, the results of regression of weekly data are presented in Table 1 for five buildings. The predicted G_s values from seasonal data are also listed for comparison. The G_s values based on weekly data were calculated for several different weeks for each building, and the average of these values as well as their standard error are listed.

The standard deviation of the average of the weekly regressions varies from 5 to 12% of the mean value. Therefore we can discern approximately a 20% savings if we compare the week before to the week after a retrofit.

INDOOR TEMPERATURE ANALYSIS

The effectiveness of short-term monitoring methods in predicting indoor temperature parameters is examined in this section. The indoor temperature parameters considered are building average temperature (TIBA), range (TIR), skew (TIS), and building minimum temperature (TIMIN). These parameters are defined as follows:

$$\mathrm{TIBA} = \mathrm{TIB}_i/N_a, \tag{3}$$

$$\mathrm{TIMIN} = \mathrm{Minimum}\ (\ I_i)\ ,\ i=1,2...N_a, \tag{4}$$

$$\mathrm{TIMAX} = \mathrm{Maximum}\ (\ I_i)\ ,\ i=1,2...N_a, \tag{5}$$

$$\mathrm{TIR} = \mathrm{TIMAX} - \mathrm{TIMIN}, \tag{6}$$

and

$$\mathrm{TIS} = (\mathrm{TIBA} - \mathrm{TIMIN})/\mathrm{TIR}. \tag{7}$$

TIB_i is the temperature of the i-th apartment, and N_a is the number of apartments in the building. In computing these parameters, all the time-averaged temperatures used have been averaged over the same time-period. Thus, while computing hourly averages, the temperatures have been averaged over an hour; over a week for weekly averages, and so on.

The "spot" measurements considered here are one-time measurement of the temperature in each apartment with a hand-held digital thermometer. The hourly and weekly values were obtained from averaging DAS data. In addition, min-max thermometers were also installed in each apartment, and the settings recorded each week. The midpoints were assumed to be the weekly averaged indoor temperature, TIBA. The parameters were then calculated using eqs. (3)-(7).

The effectiveness of short-term tests is measured here by the deviation of the parameter values based on short-term measurements with the "correct" seasonal average parameter values. The "correct" parameter values are assumed to be the DAS measurements averaged over a half-season. Two different comparison methods are presented below.

Comparison of Three Different Measurement Systems

The temperature parameters, TIBA, TIR, and TIS, obtained from spot temperature measurements, min-max thermometer data, and hourly and weekly averaged DAS data are tabulated in Table 2 for six buildings. The spot measurements were made several times (the number of runs are listed in parenthesis below the building name), and the temperature parameters were calculated for each run. The TIBA, TIR, and TIS values obtained from the data corresponding to the various runs were spread over a range, and the maximum and minimum values of each of these parameters are listed. The spot measurements were made in the hallway of each apartment as well as in the rooms. The apartments were divided into these two regions since thermostatic sensors are normally located in hallways, whereas the comfort conditions are most important in the rooms, and shutting the room doors can isolate these two regions from each other.

The weekly max-min measurements correspond to the weeks in which the spot measurements were made. They were used to calculate TIBA and TIR parameters listed in Table 2. The DAS measurements were also averaged for the hour and the week during which the spot measurements were made. The range of values of TIBA and TIR computed for each of these time periods are tabulated in Table 2. Finally, for comparison, the values of these parameters for each of the six buildings calculated for averaged half-season of DAS data are also listed.

The standard deviation of the minimum and maximum deviation from the half season DAS average for TIBA is 4°F, whereas the corresponding value for the max-min thermometer is about 2°F. The max-min thermometer precision is about the same as for the hourly and weekly averages using the DAS data. Note that there is a similar result in the TIR parameters--max-min thermometer measurements have a standarad deviation of about 4°F which is considerabley better than the spot measurements and about the same level of error as for the DAS measurements.

The comparatively large difference in precision between the spot measurement averages and hourly averages, and the smaller difference between hourly and weekly averages suggests than an hour is the smallest time-period in which a reasonable estimate of the building average can be obtained. For most research purposes however, where the change in building temperature is being documented so as to relate it to various building envelope or heating system improvements, the temperature record for at least a week is required.

Bin Analysis

We have examined the DAS data collected at the buildings in this study in order to observe the effect of the outdoor temperature on the indoor temperature parameters. In order to accomplish this, the following procedure was followed. Each 10-minute DAS temperature record was assigned to one of 14 bins depending on the value of the outdoor temperature at the time that data was recorded. Every bin corresponded to a 5°F difference in the outdoor air temperature measured at the building, ranging from 57 to -13°F. Once all the DAS data in the time period being analyzed (normally a week, or more) was assigned to bins, the temperature parameters for each bin were calculated. This analysis effectively shows the building average decreases and the range increases as the outdoor temperature decreases. Similar trends have been observed in six other buildings. In one building (Sherman), however, the building temperature range also decreased with decrease in outdoor temperature. We have also calculated the average parameters for the building (over all the bins) using two averaging techniques. The first is to calculate the occurence-weighted average (the weight for the parameter in any bin is the number of DAS data recordings that occured while the outdoor temperature corresponded to that bin), and the second, the normalized bin-hour weighted average (the parameters in a bin are weighted by the number of hours in a heating season that the temperature corresponding to the bin occurs).

We have tried to evaluate the usefulness of bin analysis as a technique for short-term monitoring by comparing the values of indoor temperature parameters from weekly data with those from half-season data. Three weekly analyses for each building were carried out, and the minimum and maximum values of each parameter are listed in Table 3. Also listed, are the half-season values for each parameter. The parameter values for one temperature bin, 32-37°F, which corresponds to the average Chicago heating season temperature, as well as the normalized bin-hour weighted averages of the parameter values are given in Table 3. The half-season values have been calculated from 7 to 10 weeks of DAS data.

The ranges of the building average are quite tight (within +/-2.5°F), both for the 32-37°F bin as well as for the normalized season averages. The maximum deviations of the individual building averages based on weekly data for the half-season average are -1.3 and +1.7°F, though most are within +/-1.5°F. The spread of the range of TIR values based on weekly data is quite tight too, lying within 3°F. A precision of +/- 2°F can be assigned to the individual weekly averaged building ranges. For the skew, a precision of +/-0.1 is assigned.

DOCUMENTED SAVINGS

The following results are based on measured performance of one ECM per building. Table 4 includes the measured savings for each ECM.

Thermostatic Boiler Control

At the one building where the boiler control was changed from a time clock with return line aquastat to an indoor air thermostat with and outdoor high limit thermostat. A comparison of the projected annual consumption using one week of available pre and post retrofit daily data from periods with similar outdoor air temperature yields a significant savings of 45%. The standard error associated with each measurement indicate a 100% likelihood that the pre and post retrofit projections are different.

It is now necessary to document the savings over the entire range of outdoor air temperatures.

Main Line Vent Treatments

At one six-unit building two alternate sets of main line vents were alternately installed, 3 to 7 days each, over a two month period. One set consists of conventional moderate sized vents specifically used for venting single-pipe steam main lines. The other set consists of custom-modified steam traps, normally used on two-pipe steam systems, with venting capacities that are 400% of the largest commercially available main line vents. Their capacity is approximately 800% of the set of moderately-sized vents.

Definite changes were documented in the building indoor temperature. The larger vents caused a repeatable improvement in all but one of the indoor temperature parameters (Katrakis et. al. 1986): the range was reduced; building minimum indoor temperature was increased; the skewness of the temperatures was reduced. However the average indoor temperature increased when outdoor air temperatures were above $30^{o}F$ and decreased when outdoor air temperatures were below $30^{o}F$.

The large capacity vents result in a 15% reduction in energy usage compared to the original vents. This difference in consumption is known with a 98% level of significance.

If our current assumption is accurate, that there is a 4% change in annual energy consumption for every $1^{o}F$ change in average indoor temperature then we can project an approximate 4% decrease in energy consumption due to putting in the larger sized main line vents. Note that if the thermostat setpoint is reduced to take advantage of the improved temperature balance the resulting additional savings will be approximately 8%.

Derating Gas and Air Input

A preliminary analysis has been done using the available data from a building where the boiler is being flip-flopped between the initial firing rate of 2.65 million BTUH to a derated level of 1.45 million BTUH. The change in normalized annual consumption between the derated and the initially rated periods is 17% when not correcting for the different average outdoor temperatures between the two modes. When projections are made based over the entire range of outdoor temperatures the annual projected savings is 9%.

Since the average outdoor air temperature during the two modes was considerably higher than the average over the entire heating season it is necessary to obtain gas usage data from each mode during colder weather in order to get an accurate measurement of energy savings over an entire heating season.

There were also positive changes in indoor temperature conditions; the average building temperature increased by 1°F, the average minimum temperature increased by about 3°F. Therefore, the higher temperatures can be maintained in order to improve comfort or to provide a margin for additional reductions in the thermostat set-point. If the thermostat setpoint is reduced by 3°F to return the building to the original minimum temperature, the average building temperature may also decrease by about 3°F which would result in an additional 12 to 15% savings. These positive changes in the indoor air temperature parameters were not expected and are probably due to the unusual boiler controls at this building. An indoor thermostat in one of the colder apartments is used to initiate the boiler firing cycle but the boiler pressure control is used to stop the boiler. We think that the positive improvements are due to the lower operating pressure during the firing cycle. This allows the boiler to operate for a much longer period of time per cycle and therefore steam can reach the building extremities.

It is necessary to continue these tests through periods in colder weather to evaluate the corresponding changes in energy consumption and indoor temperature conditions. Also it is necessary to test derating on atmospheric boilers and in buildings with the more conventional boiler controls.

Vent Damper

A vent damper was flip-flopped several times at one building with a cast-iron sectional atmospheric boiler. The difference in NAC between the two modes was 3%, however the level of significance is less than 90%. the average outside air temperature during periods without damper operation was 38°F, while during periods without damper operation the outside air temperature was 45°F.

Correcting the NAC of the period with the operating damper to reflect performance at outside temperatures of 38°F results in a projected savings of 19% for the vent damper. This correction was done using the best available part-load efficiency data for this type of boiler (Weil-McLain, 1981).

Other researchers have documented savings in the range of 10% in the same type of heating plant when it is used in a hot water system. It seems reasonable to expect a higher savings in a steam system since the average temperature of its heat transfer fluid is significantly higher--215°F versus 180°F--during operation and therefore it may have higher off-cycle losses.

Measurements are currently being taken of the actual heating plant seasonal efficiency with and without vent damper operation. this will provide an additional point of comparison. Further flip-flop tests of the damper are necessary in order to monitor savings throughout the likely range of outdoor air temperatures and to improve the level of significance of the measurements.

Our review of the literature and of the plant efficiency measurements at the buildings indicate that vent damper savings projections could be significantly affected by the following factors: a. the size of the pilot flame gas bypass opening in the damper blade; b. whether or not there is a vent damper for the domestic hot water heaters which share the same chimney with the boiler; c. whether the boiler cycles off the pressure control. Current vent damper control circuitry does not permit the vent damper to close if the boiler shuts down on pressure.

CONCLUSIONS

We found that correlating the gas consumption against indoor minus outdoor temperature does not yield substantially improved values of standard error than when correlated against outdoor temperature alone. Therefore it is not worth the additional cost to gather indoor air temperatures for the sake of improving statistical significance.

There is a 10% standard error in the predicted seasonal consumption for the week-long monitoring period as opposed to a season, or half-season long monitoring period of daily averaged gas usage and outdoor air temperature. This implies that while weekly monitoring may be sufficient to see the effect of a complete package of Energy Conservation Measures on the seasonal gas consumption, it certainly is not long enough a period to discern the effect of a single ECM, unless its annual savings is over 20%.

Comparison of the different methods of measuring indoor temperature show that spot measurements alone are insufficient to estimate the seasonal average indoor building temperature or range. Min-max thermometers, however, are considerably more precise and surprisingly quite near to the precision of a half season average of DAS data. The minimum time-period in which any significant conclusions about the building indoor temperature parameters can be made seems to be an hour. However, for most research problems, a week is the shortest monitoring time-period.

The bin analysis method using DAS data estimates the parameters, both in a particular bin as well as for a normalized season, with a higher level of precision than does arithmetic averaging for the time period.

We recommend that min-max thermometers be added to the tool kit used in the energy audit field work and as part of the tool kit for installers of the boiler control and balancing ECM. A low cost research option may be to use max-min thermometers in each apartment to identify the apartment in a building that is closest to the building average, and then to continuously monifor the indoor air temperature in this apartment for one week. Bin analysis of the monitored data will provide good estimates of the building average, range and skew.

Each of the four test measures has been applied in one building. The results based on a half season show a high level of savings for all the measures, although the results of the vent damper tests are uncertain. As shown in Table 4 the simple paybacks for each of the measures are less than one year. The main line vent tests only show the change in performance between two alternate replacement vent configurations. Further testing is essential in order to: obtain an acceptable level of significance in the projected changes in NAC for each test measure; to generalize the performance results over an entire heating season and throughout the likely range of outdoor air temperatures; to evaluate the performance of these measures in different buildings and heating systems. This would then permit developing performance predicting models and implementation procedures that could be applied to single-pipe steam heated buildings

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Table 1 Predicted normalized annual consumption--seasonal daily and weekly data.

	FULL SEASON					HALF-SEASON					
	AVERAGE OF DAYS					AVERAGE OF DAYS			AVERAGE OF WEEKLY		
	OUTDOOR TEMP.			IN-OUT TEMP		OUTDOOR TEMP.			OUTDOOR TEMP		
	# OF DAYS	NAC (MMBTU)	% SE	NAC (MMBTU)	% SE	# OF DAYS	NAC (MMBTU)	% SE	# OF WEEKS	NAC (MMBTU)	% SE
Argyle	137	2493	4	2482	5	41	2509	13	7	2600	5
Marquette	134	1045	4	1038	5	48	1297	5	7	1431	6
Rascher	117	713	6	711	5	39	801	12	6	774	12
Sherman	181	1669	3	1656	4	64	1437	12	9	1890	5
Winnamac	128	702	4	698	4	38	692	17	7	895	8

Table 2 Comparison of Spot, Min-Max and DAS Measurements

		AVERAGE, IBA						RANGE, TIR					
		SPOT		MIN/MAX	DAS AVERAGES			SPOT		MIN/MAX	DAS AVERAGES		
		APT	HALL		HOURLY	WEEKLY	1/2 SEA	APT	HALL		HOURLY	WEEKLY	1/2 SEA
Argyle	MIN	69.7	69.6	71.2	70.0	70.4	73.1	4.6	3.2	6.0	9.8	11.9	11.4
	DEV	-3.4	-3.5	-1.9	-3.1	-2.7		-6.8	-8.2	-5.4	-1.6	0.5	
(7)	MAX	76.5	75.8	74.8	76.3	73.6		19.3	18.6	11.0	19.8	14.9	
	DEV	3.4	2.7	1.7	3.2	0.5		7.9	7.2	-0.4	8.4	3.5	
Bosworth	MIN	68.2	68.3	68.6	68.1	68.2	70.5	6.2	5.8	6.5	7.1	6.4	7.4
	DEV	-2.3	-2.2	-1.9	-2.4	-2.3		-1.2	-1.6	-0.9	-0.3	-1.0	
(6)	MAX	72.6	71.8	72.1	71.9	72.1		11.5	8.0	10.0	9.3	8.6	
	DEV	2.1	1.3	1.6	1.4	1.6		4.1	0.6	2.6	1.9	1.2	
Marquette	MIN	79.7	78.1	78.8	79.1	80.6	81.6	2.9	3.0	3.5	7.4	8.8	8.1
	DEV	-1.9	-3.5	-2.0	-2.5	-1.0		-5.2	-5.1	-4.6	-0.7	0.7	
(5)	MAX	85.2	84.4	82.1	83.0	82.2		17.5	13.3	6.5	11.0	11.1	
	MIN	3.6	2.8	0.5	1.4	0.6		9.4	5.2	-1.6	2.9	3.0	
Rascher	MIN	69.4	69.8	66.0	69.5	69.2	70.5	7.0	6.9	6.5	7.4	12.6	5.7
	DEV	-1.1	-0.7	-4.5	-1.0	-1.3		1.3	1.2	0.8	1.7	6.9	
(6)	MAX	78.4	78.1	72.1	73.8	73.5		20.3	20.6	11.5	15.6	14.2	
	DEV	7.9	7.6	1.6	3.3	3.0		14.6	14.9	5.8	9.9	8.5	
Sherman	MIN	72.5	72.7	72.6	70.7	71.7	73.7	5.2	8.8	5.5	6.4	10.8	11.5
	DEV	-1.2	-1.0	-1.1	-3.0	-2.0		-6.3	-2.7	-6.0	-5.1	-0.7	
(7)	MAX	75.5	76.0	74.4	75.4	74.8		11.8	15.9	12.0	13.9	12.6	
	DEV	1.8	2.3	0.7	1.7	1.1		0.3	4.4	0.5	2.4	1.1	
Winnemac	MIN	66.4	67.2	71.5	68.2	71.4	72.70	7.8	5.1	4.3	6.5	6.1	6.90
	DEV	-6.3	-5.5	-1.2	-4.5	-1.3		0.9	-1.0	-2.6	-0.4	-0.8	
(4)	MAX	75.7	75.3	72.6	76.3	73.7		12.9	10.1	6.5	8.4	8.1	
	DEV	3.0	2.6	-0.1	3,6	1,0		6.0	3.2	-0.4	1.5	1.2	
AVERAGE DEV MIN		-2.70	-2.73	-2.23	-2.75	-1.77		-2.88	-3.03	-3.12	-1.07	0.93	
AVERAGE DEV MAX		3.63	3.22	1.00	2.43	1.30		7.05	5.92	1.08	4.50	3.08	

Table 3 Bin Analysis

BUILDING	DURATION (weeks)		32-37 DEGREE BIN				NORMALIZED HALF-SEASON AVERAGES					EXPECTED VALUES			
			BUILDING TEMP. PARAMETERS				BUILDING TEMP. PARAMETERS				OUTDOOR TEMP.	BUILDING TEMP. PARAMETERS			
			AVERAGE	RANGE	MINIMUM	SKEW	AVERAGE	RANGE	MINIMUM	SKEW		AVERAGE	RANGE	MINIMUM	SKEW
Albany	1*	MIN	69.3	10.2	65.9	0.30	69.2	9.9	65.9	0.32					
		MAX	69.5	10.9	66.1	0.32	69.7	11.2	66.0	0.34					
	7		71.0	9.1	67.6	0.39	70.5	7.3	67.5	0.41	31.7	70.0	8.0	66.7	0.37
Argyle	1	MIN	71.9	10.9	65.3	0.55	72.8	10.9	66.3	0.58					
		MAX	74.3	13.2	67.2	0.61	74.1	13.4	66.4	0.60					
	7		73.2	10.8	67.5	0.52	73.2	10.7	67.6	0.53	33.6	72.9	13.0	66.7	0.48
Bosworth	1	MIN	71.3	7.2	68.2	0.43	71.2	7.7	67.7	0.4					
		MAX	71.9	7.6	68.8	0.44	72.1	9.2	68.5	0.47					
	7		71.3	6.3	68.2	0.49	71.2	7.1	67.6	0.51	34.2	70.5	7.8	66.6	0.48
Marquette	1	MIN	83.9	6.5	80.2	0.56	82.3	9.1	78.0	0.49					
		MAX	85.1	7.7	80.9	0.57	82.4	8.5	78.8	0.51					
	7		84.0	7.6	80.0	0.53	82.0	7.2	78.6	0.47	33.7	81.5	10.1	76.8	0.47
Rascher	1	MIN	71.1	4.4	67.6	0.48	70.6	5.5	67.1	0.46					
		MAX	71.5	6.9	68.9	0.58	71.2	7.8	68.2	0.56					
	7		70.9	4.4	68.8	0.47	71.0	4.6	68.8	0.48	33.8	69.9	9.6	64.5	0.53
Sherman	1	MIN	73.5	11.8	66.2	0.47	73.7	12.6	66.9	0.49					
		MAX	74.2	14.7	68.2	0.51	74.3	13.7	68.2	0.52					
	7		73.4	11.8	67.8	0.52	73.9	12.1	67.7	0.51	33.8	73.8	12.1	67.1	0.55
Winchester	1	MIN	70.4	6.8	66.9	0.5	71.3	7.0	67.1	0.5					
		MAX	72.5	8.4	68.3	0.53	72.6	10.1	68.3	0.53					
	7		70.8	9.5	66.0	0.51	71.2	10.0	65.3	o.48	33.8	70.1	10.7	64.5	0.44

Table 4 Measufre ECM Performance

	Measured Cost- Effectiveness								Change in Indoor Temperature Parameters							
	Change In NAC MMBTU	%	Conf. Level %	Outdoor Temp. (oF) PRE	Outdoor Temp. (oF) POST	Annual Savings ($)	Installed Cost ($)	Simple Payback (YRS)	Average Building (oF) EV	Average Building (oF) BIN	Minimum (oF) EV	Minimum (oF) BIN	Range (oF) EV	Range (oF) BIN	Skew (oF) EV	Skew (oF) BIN
Indoor Thermostat (Oakdale)	1,700	46	99	30	48	5,000	1,700	0.34	-4.6	-6.8	-1.6	-6.4	-5.1	+.8	-.05	-.06
Main Line Vent (Albany)	74	15	99	36	42	220	100	.45		0		.75		-3.0		+.10
Vent Damper	17	3	<90	38	45											
(Albany)	110	19	-	38	38	660	600	1	-	-	-	-	-	-		
Derating	450	18	98	40	51											
(Winchester)	200	8	-	34	34	1,200	600	1.5	+1		+2.8		-2.2		-.04	