# MEASURED ENERGY SAVINGS FROM OUTDOOR RESETS IN MODERN, HYDRONICALLY HEATED APARTMENT BUILDINGS

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## ABSTRACT

Since 1982 the Minneapolis Energy Office and Minnegasco have been testing outdoor reset and cutout controls in modern, hydronically heated apartment buildings. The tests show that in most buildings the reset and cutout together reduce space heating costs by 10 to 20 percent with a payback of less than one year.

An outdoor reset varies the temperature of the water in the heating distribution system in response to outdoor temperature. An outdoor cutout shuts off the circulating pumps and prevents the boiler from firing when the outdoor temperature is warm enough that no heat is needed. Outdoor resets that control the temperature of the boiler water directly were installed in three buildings heated with gas-designed cast iron boilers, along with outdoor cutouts. The devices were evaluated by running the buildings alternately under reset/cutout control and constant temperature control at two week intervals over two heating seasons. Annual savings averaged 6700 Btu/sqft-yr, or 18% of annual space heating costs. At the present price of $0.585 per therm, the savings in dollars ranged from $159 to $1393 per year. The reset and cutout together cost $450 installed, so in all cases but one the estimated payback was less than one year. Limited tests comparing the reset and cutout together with the reset alone were inconclusive.

Temperature data from hallways, apartments and boiler rooms indicate that the outdoor reset improves the seasonal efficiency of the boiler, reduces heat loss from the distribution piping, and limits the tenants' ability to keep their apartments at excessive temperatures.

The savings estimates for cast iron boiler systems are supported by analyses of monthly gas data for five other buildings in which resets were installed. These buildings already had cutouts, and the boiler water temperatures had been reset manually to varying degrees in the heating season before the automatic reset devices were installed, so the savings would be expected to be somewhat less. Savings averaged 6200 Btu/sqft-yr, or 10% of total annual gas use (approximately 13% of annual space heating cost). All five buildings showed paybacks of less than one year for the reset alone.

A different type of outdoor reset that mixes hot boiler water with cooler return water to provide the desired supply temperature was installed in a building heated by a steel fire tube boiler. The building was run alternately in manual reset mode and automatic reset mode over one heating season. Savings were estimated at 4600 Btu/sqft-yr or $1025, for a system with an installed cost of about $3000.

An outdoor reset is probably the most cost-effective major retrofit for hydronically heated apartment buildings with cast iron boilers. Further work is needed to assess the cost-effectiveness for buildings with steel fire tube boilers.

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## INTRODUCTION

One of the major barriers to conservation investment in multifamily buildings is the lack of reliable data on the savings to be realized from specific retrofits. Since 1981 the City of Minneapolis and Minnegasco have been conducting a Multifamily Testing Program to field test specific conservation measures in multifamily buildings. The research forms the technical basis for the City's multifamily conservation program.

Minneapolis has about 2800 multifamily buildings of five or more units. These buildings comprise 51,000 dwelling units, or 32% of the city total. Approximately 1200 of these buildings (21,750 dwelling units) were built after 1945 and are hydronically heated. The vast majority of these are three story walk-ups. These buildings typically use about 50,000 to 80,000 Btu/sqft-yr of gas for space heating, domestic hot water, stoves and dryers.

The physical characteristics of multifamily buildings and the owners' payback criteria make many envelope retrofits impractical. However, there are promising heating system retrofits. Results reported here show that outdoor reset and cutout control is a highly cost-effective retrofit for most hydronically heated apartment builldings in Minneapolis.

## HYDRONIC HEATING SYSTEMS AND CONTROLS

Hydronically heated apartment buildings normally have one or more main heating distribution loops, from which separate baseboard loops run into each apartment (figure 1). A pump circulates hot water through the main distribution piping continuously. Each apartment has a zone valve and thermostat to regulate the flow of hot water into its baseboard loop. In the majority of these buildings in Minneapolis, the boiler is controlled by an aquastat which keeps the water in the system at a constant temperature.

The amount of heat given off by baseboard radiation depends on the temperature of the water circulating through it. Buildings are typically designed so that a water temperature of 180 to 200$^{o}$F is required to balance the apartments' heat loss at the coldest winter temperatures. This water temperature is much higher than is needed for most of the winter.

An outdoor reset varies the temperature of the water in the distribution system inversely with outdoor temperature, so that the minimum temperature necessary to heat the building is provided (figure 2). Different types of boilers require different methods of reset control. On a cast iron boiler, the outdoor reset can control the boiler water temperature directly by controlling the firing of the boiler. Both mechanical and electronic resets are available for this application. Steel fire tube boilers, on the other hand, must be kept at 140$^{o}$F or higher to prevent corrosion and thermal stress that could cause boiler failure. Reset control can be achieved by installing a three way mixing valve that mixes hot boiler water with cooler return water to provide the desired supply temperature. A more sophisticated electronic reset must then be used to adjust the valve position in response to outdoor temperature. (Another option is to install an on/off reset in series with a low limit control to keep the boiler water temperature above 140°F. This is cheaper, but sacrifices much of the resetting capability.)

In addition to the outdoor resets, outdoor cutouts were also installed and tested. Many hydronic heating systems are started manually in the fall and turned off manually in the spring. Between these dates the pump operates continuously and the burners cycle to satisfy the demands of the aquastat or reset. During the spring and fall there are many mild periods when no heat is needed, ranging from mild days with cold nights to mild stretches of several days. It is not practical for the owner or maintenance person to stop and restart the boiler for every mild period, so the common practice is to allow it to run. An outdoor cutout deals with this problem by sensing the outdoor temperature and automatically shutting off the burners and pump whenever heat is not needed. Cutout settings of 55°F were found to be suitable in the test buildings.

## TEST BUILDINGS

The buildings used in the tests are generally typical of newer apartment buildings in Minneapolis, although probably somewhat better maintained than average. They were built between 1967 and 1973 and range in size from 9500 to 38,000 square feet (12 to 45 units). They have central, master metered heating and domestic hot water and tenant metered electricity. Eight of the buildings have atmospheric, gas-designed cast iron boilers, ranging in input from 290,000 to 710,000 Btuh. The ninth has a forced draft steel fire tube boiler with an input of 1,890,000 Btuh. They are of wood frame construction with lightly insulated walls and roofs. All have double glazed windows.

## TEST DESIGN

Outdoor resets and cutouts were installed in three buildings with cast iron boilers (2631, 2100, 3308) in the fall of 1982. The heating systems were run alternately with constant temperature control and reset/cutout control at two week intervals over two heating seasons. For a limited period of mild weather in one building the reset/cutout mode was tested against the reset alone. A three way mixing valve and outdoor reset were installed in a building with a steel fire tube boiler (2017) in the fall of 1983. The heating system was run alternately with and without the reset controller over the 83-84 heating season.

Alternating between modes enabled us to collect data in both modes under comparable conditions of weather, occupancy, maintenance and so on. A two week interval was chosen to make the operating period long relative to the time the system requires to stabilize in going from one mode to another and to allow some time for tenants to adjust their behavior to the new mode after each change, while still allowing both modes to be tested during periods of similar temperatures.

The gas used by the boilers was submetered so that gas used for heat alone could be measured. For the cast iron boilers, which had fixed firing rates, this was accomplished by installing an hour meter to record the burner firing time. The steel fire tube boiler (which also heated the domestic hot water) was already on a separate gas meter. Maximum/minimum thermometers were installed in selected hallways, apartments and boiler rooms to see how the two control modes affected building temperatures and jacket loss from the boilers. Submeters and thermometers were read weekly.

Temperatures of 165°F were sufficient to keep the buildings with cast iron boilers warm in cold weather, so that setting was used for the constant temperature mode throughout the heating season. The resets had fixed one-to-one reset ratios; that is, the boiler water temperature increased one degree for each degree decrease in outdoor temperature. The adjustable starting point was set at 95°F for 70°F outside temperature without causing complaints from the tenants. The cutouts were set at 55°F. In the building with the steel fire tube boiler our agreement with the owner allowed him to adjust the aquastat periodically, so we were in fact testing the automatic reset against a manually reset base condition. The reset itself had an adjustable ratio and starting point, as well as night setback capability. These were adjusted periodically in response to complaints. Thus the supply temperature in each mode did not follow a fixed curve but was somewhat erratic.

Near the end of the first test year one of the owners involved in the testing program became so interested in the reset that he installed it in five other buildings with cast iron boilers. We have analyzed the monthly gas data for these buildings for a full year before and after the resets were installed to supplement our detailed test data. These buildings already had cutouts, and prior to the installation of the resets, the boiler water temperatures had been reset manually to some extent by the building caretakers. These starting conditions, while not uncommon in Minneapolis apartment buildings, were not exactly comparable to the detailed tests, and somewhat lower savings could be expected. These buildings are referred to throuhgout this paper as the "supplemental buildings".

## WHY IT WORKS: EFFECT OF THE RESET/CUTOUT ON SPACE TEMPERATURES AND BOILER EFFICIENCY

The reset and cutout were expected to reduce energy use in several ways:

1. <u>Reducing overheating of apartments.</u> Some tenants keep their apartments at excessive temperatures, and may even open the window for comfort rather than turn the thermostat down. With an outdoor reset, if the distribution system is well balanced the water in the system will be just warm enough to heat each apartment, not hot enough to overheat it or to keep it warm with the windows open. If the distribution system is not well balanced, some apartments will receive just enough heat to keep them warm, while other apartments will have access to enough heat to allow overheating, if the tenant so chooses. Apartments can also be overheated if the zone valve is stuck in an open position. An outdoor reset should greatly reduce the degree of overheating in this situation.
2. <u>Reducing overheating of the hallways.</u> In most hydronically heated apartment buildings the main distribution piping runs in the floor or ceiling of the hallways. With the reset the water that circulates in the distribution loop is cooler, especially in spring and fall. This should reduce overheating of the halls caused by waste heat from the piping.
3. <u>Providing heat only when it is needed.</u> Turning the pump and burners off during mild periods is expected to provide some savings.
4. <u>Increasing the seasonal efficiency of the boiler.</u> Since the water in the boiler is cooler on average, jacket and stack losses should be lower (cast iron boilers only).

Limited budgets, staffing and access to apartments did not allow us to monitor the entire building nor to collect temperature data at close intervals. Therefore, the temperature data we have must be looked at as suggestive rather than definitive. Nevertheless, the data do verify that the above effects are occurring.

Apartment temperatures were collected in three units in building 3308 during part of the 1983-84 heating season, and no difference between reset mode and constant temperature mode was observed. Unfortunately the consumption data for this building during the same period were so scattered that differences in gas use were not statistically significant, so in retrospect this building was a poor choice for testing temperature variations. That the reset can affect space temperatures is demonstrated by experience in the five supplemental buildings. All five buildings had tenant complaints of insufficient heat right after the resets were installed, and the resets had to be adjusted to provide higher boiler water temperatures until complaints were minimized. With the information we have at present it is not clear whether a reset is likely to reduce space temperatures in much of the building or only in those apartments that are already marginally heated due to low flow rates or insufficient fin tube radiation.

Hallway data show a consistent but small drop in temperature of 1 to 4 degrees in going from constant temperature mode to reset mode (figure 3).

No attempt was made to measure boiler jacket losses directly. However, there is a 5 or 6 degree difference in boiler room temperature between the two modes (figure 4), which suggests significant differences in jacket losses. Flue gas temperatures were measured at various boiler water temperatures and a change of about one degree per degree change in boiler water temperature was observed, a very minor effect.

## METHODS OF ANALYSIS OF GAS USE DATA

A conceptual model of gas use as a function of temperature provides insight into the behavior of the two control systems. For this purpose it is helpful to define the boiler load as the amount of heat added to the water per unit time. The load thus includes the heat necessary to balance heat loss from the building, and the heat necessary to maintain the required water temperature in the distribution loop.

First consider constant temperature operation. The load imposed on the boiler to balance heat loss from the building starts at zero at the balance temperature (where heat loss from the building is balanced by solar and internal gains) and increases linearly with decreasing temperature. But the total load on the boiler does not drop to zero at the balance temperature, because the constant temperature controller forces the boiler to maintain the water in the distribution loop at the setpoint temperature, regardless of whether any heat is needed or not. So above the balance temperature there is a small, nearly constant load to maintain the temperature of the distribution water (figure 5).

Next consider reset/cutout operation. The load vs. temperature curve has a somewhat different shape. At very cold outdoor temperatures the load should be the same as with constant temperature operation, since the water temperature is the same. But as outdoor temperatures become milder the reset reduces the distribution loop temperature, thus reducing the distribution losses and possibly reducing apartment and hallway temperatures as well. At an outdoor temperature of 55°F the reset is maintaining the boiler water at about 110°F, compared to 165°F for constant temperature operation. So the load imposed to keep the distribution loop warm is considerably lower. Were the cutout not in place the reset by itself would continue to decrease the load as outdoor temperature increased, until at an outdoor temperature of 83°F the reset would be calling for 83°F water and the load would be zero. But the cutout drops the load to zero at 55°F, abruptly truncating the load curve (figure 5).

Finally, note that jacket and stack losses in both constant temperature mode and reset mode are approximately linear functions of load, so total gas use (load plus jacket and stack losses) will have the same general shape as the load curve, although the slope and position may differ.

Figures 6 through 9 show actual data from the test buildings. The model discussed above describes the data quite well. In constant temperature mode, none of the four buildings for which weekly data were collected actually showed a flattening of gas use vs. degree days at mild temperatures over the periods of observation. This suggests that in constant temperature mode, the balance temperature for these buildings is at or above 65°F. The data were therefore fit to a straight line. The reset plus cutout data showed a steep drop near the cutout temperature in some cases but not in others. These data were therefore fit to three different models to approximate the dotted line in figure 5:

$$G = a + b\ (DD)$$

$$G = a + b\ (DD) + c/DD$$

$$G = a + b\ (DD) + c/DD^2$$

<u>where</u>

G = average daily gas use
DD = average daily degree days (to reference temperature of 65°F), and
a, b, and c are statistically determined coefficients.

For each building the model with the best fit among those in which all terms were statistically significant was chosen.

The normalized annual space heating use was calculated by multiplying the gas use at each degree day value by the normal occurrence of that value, and then summing over all degree day values:

$$NSHU = \sum_{DDmin}^{DDmax} G(DD_i) \times \text{normal occurrence of } DD_i.$$

DDmin is the lowest degree day value for which G(DDi) is greater than or equal to zero. The normal occurrence of DDi is based on a 30 year average (1951 to 1980) for a heating season running from October 16 to April 30. Based on our experience, this is a reasonable approximation of the dates that multifamily owners in Minneapolis turn their heating systems on and off. Some owners run the system one or two weeks more on either end, but very few run it any less. Since the constant temperature and reset plus cutout curves differ most in mild weather, defining the heating season this way gives the most conservative estimate of savings from the reset and cutout.

Gas data from the five supplemental buildings were analyzed using a powerful computer model developed at Princeton University (Dutt, Fels, Goldberg and Stram, 1982). "The model assumes that energy is consumed at a constant rate (baseload $\alpha$) when the temperature is above a certain point (reference temperature $\tau$), and below that point an additional constant amount of fuel (heating slope $\beta$) is consumed for each degree drop in temperature." While most conventional analyses assume a reference temperature of $65^{o}F$, the Princeton model finds the reference temperature that fits the data best.

Once the program finds the best values of $\alpha$, $\beta$, and $\tau$, the normalized annual consumption is calculated as:

$$NAC = [\alpha + \beta H_o(\tau)] \times 365.25$$

where

$H_o(\tau)$ is the average daily heating degree days to reference temperature $\tau$ in a normal year.

This model provided a very good fit to the data from the five supplemental buildings.

## ENERGY SAVINGS

Figures 6 through 9 show space heating energy use as a function of degree days for the intensively monitored buildings with cast iron boilers. For buildings 2631 and 2100 the consumption data for the two years fit the same curves, so data for both years were grouped together for analysis. Building 3308 showed a significant drop in consumption for each mode from year 1 to year 2, so the data for the two years were analyzed separately. (The owner reported inspecting and repairing all the zone valves, some of which had been sticking in the open position, between the two heating seasons. In addition, 4 of 12 units changed occupants, and according to the owner the new occupants are generally more conserving.)

In constant temperature mode there is significant consumption even at zero degree days per day, whereas in reset plus cutout mode use drops to zero at about 7 or 8 degree days per day. For three of the cases the curves converge and eventually cross at lower temperatures, as might be expected since the boiler water temperature in reset mode exceeds that in constant temperature mode for outdoor temperatures below about $0^{o}F$. For the other case the curves are nearly parallel.

The normalized annual space heating use (NSHU) was calculated based on a conservative October 15 to April 30 heating season (7637 FDD, compared with 8159 for the entire year). The average NSHU for constant temperature mode was 36,400 Btu/sqft and for reset plus cutout mode was 29,700 Btu/sqft, giving an average savings of 6,700 Btu/sqft (table 1). [Using an October 1 to May 15 heating season (7711 FDD) increases these numbers to 39,100; 30,700 and 8400 respectively.] The savings for the individual cases were 25.5%, 14.7%, 21.2%, and 9.8% of space heating gas use. At present costs of $0.585 per CCF (hundred cubic feet), this represents annual savings of

$1393, $527, $504, and $159 respectively (figure 10). For three of these cases, the difference in consumption between the two modes is statistically highly significant ($p < .001$). For building 3308 in the second year the difference is not significant due to smaller savings and the large degree of scatter in the data.

Analysis of monthly gas data for the five supplemental buildings supports these findings. The boiler water temperature had been reset manually to varying degrees in the heating season before the automatic reset devices were installed, and all of these buildings had cutouts to begin with, so the savings would be expected to be somewhat lower. Savings for these buildings averaged 6,200 Btu/sqft, or 10% of total normalized annual consumption (NAC) (table 2 and figure 11). The difference between the pre and post consumption was significant at the 5% level or better for three of the five buildings, but not significant for the other two. One building had savings of only 3.7%. This building could not be reset nearly as far as the others without causing tenant complaints. It is possible that a few apartments had insufficient fin tube radiation or that the pump was too small to give adequate water flow under all conditions. It is also possible that a few tenants preferred extremely high temperatures. We hope to investigate the causes of occasional poor savings with reset controls next year.

Data from all eight buildings with cast iron boilers were combined to allow statistical analysis. As has been noted, the initial condition in the five supplemental buildings was somewhat different from the base condition for the buildings in the intensive test group. The goal of the combined analysis was to use all of the information available to us to put a lower limit on the savings that could be expected from the reset and cutout, and an upper limit on the payback. The average savings for the entire group were 6,400 Btu/sqft-yr or 11.8% of total annual gas use. Using a paired t test, the savings are significant at the 1% level or better. Table 3 presents confidence intervals for the mean and for the sample assuming a normal distribution. We would expect 80% of similar buildings in Minneapolis to achieve savings between 2000 and 10,800 Btu/sqft-yr, and 96% to have some savings.

Energy use as a function of degree days for the building with the steel fire tube boiler is shown in figure 12. This building showed savings of 4600 Btu/sqft-yr based on an October 15 to April 30 heating season. The dollar savings are estimated at $1025.

In one building (3308) the reset and cutout were tested against the reset alone to assess the effect of the cutout. Although the data points for the reset and cutout were consistently below the line fit to the data for the reset only, this particular building had so much scatter in the data that the deviations due to the cutout were not statistically significant. The importance of the cutout depends on how careful the owner is in keeping the number of weeks he supplies heat to a minimum, and on how abrupt the change of seasons typically is. In Minneapolis there are roughly 600 hours above $55^{o}F$ between October 1 and May 15, but only 250 hours between October 16 and April 30. We plan to continue recommending the cutout because it is convenient, it is more foolproof than depending on the caretaker to turn the boiler off in the spring, and it probably does give some savings in most buildings. We hope to be able to test it again next year.

## COST, PAYBACK AND INSTALLATION

The resets used on the cast iron boilers were simple mechanical-electrical controls with fixed reset ratios and cost about $250 installed. The cutouts were also mechanical-electrical and cost about $200 installed. Simple electronic resets and cutouts are also available for about the same cost. Buildings 2631 and 2100 each showed paybacks of less than one year for the reset plus cutout. Building 3308 showed a payback of less than one year based on the first year's data, but 2.8 years based on the second year's data. All five of the supplemental buildings showed paybacks of less than a year for the reset alone (table 4).

Assuming that future installations would include both the reset and the cutout (total cost: $450), and that savings could be conservatively estimated using the per square foot data from table 4, over 90% of similar buildings in all size categories can be expected to have a payback of four years or less for the reset and cutout (figure 13).

The electronic reset used on the steel fire tube boiler had an adjustable reset ratio and night setback capability, and was designed to control a mixing valve. With the valve itself and the plumbing required to install it, typical installed costs for this system would be about $3000. The particular test building used showed a payback of about three years, but it is impossible to generalize from it to a typical payback for this system.

The simpler, on-off resets and cutouts for cast iron boilers can be installed by any competent heating contractor. The more elaborate systems for steel fire tube boilers are generally installed by contractors certified by the manufacturer.

## ACKNOWLEDGEMENTS

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Dutt, G.S., M.F. Fels, M.L. Goldberg and D. Stram, 1982. The Scorekeeping Model for Residential Energy Consumption: Procedures and Problems. Prepared for the ACEEE 1982 Summer Study, Santa Cruz, CA, August 21-28, 1982.

Goldberg, M.L., 1982. A Geometrical Approach to Nondifferentiable Regression Models as Related to Methods for Assessing Residential Energy Conservation. PU/CEES Report No. 142, Center for Energy and Environmental Studies, Princeton University, Princeton, NJ.

# Hydronic Heating System

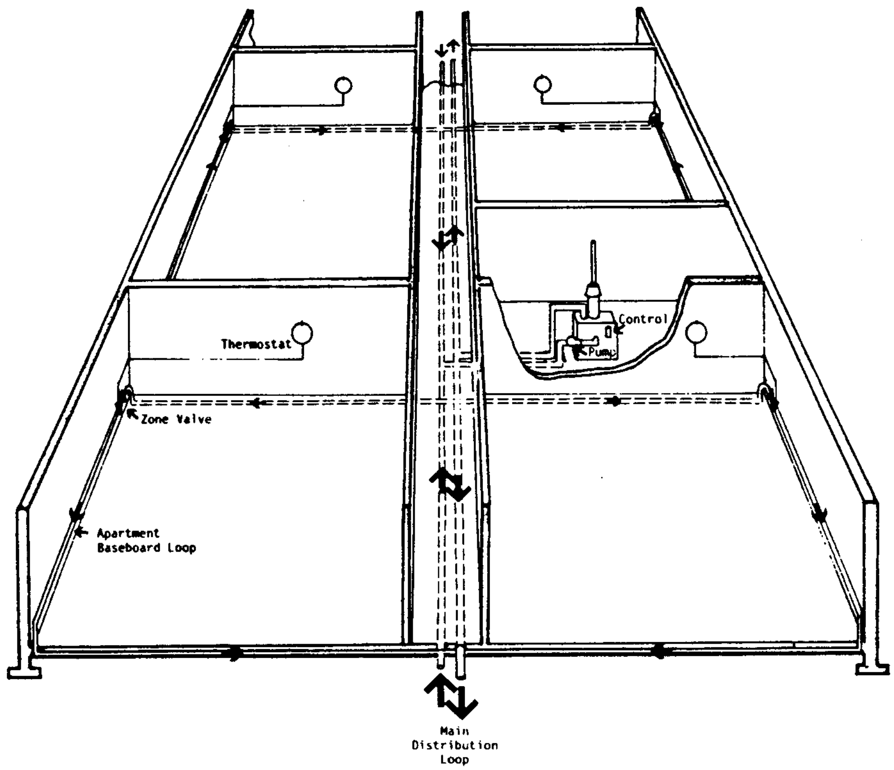



Figure 1

## Control of Water Supply Temperature

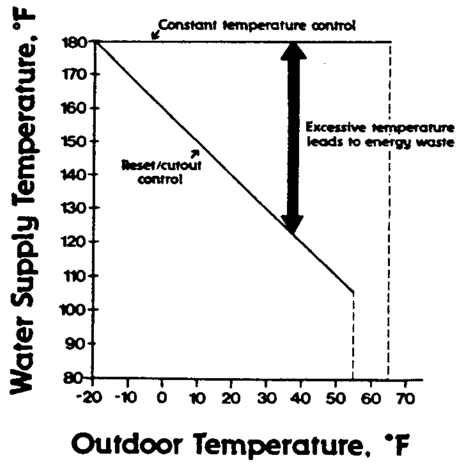



Figure 2

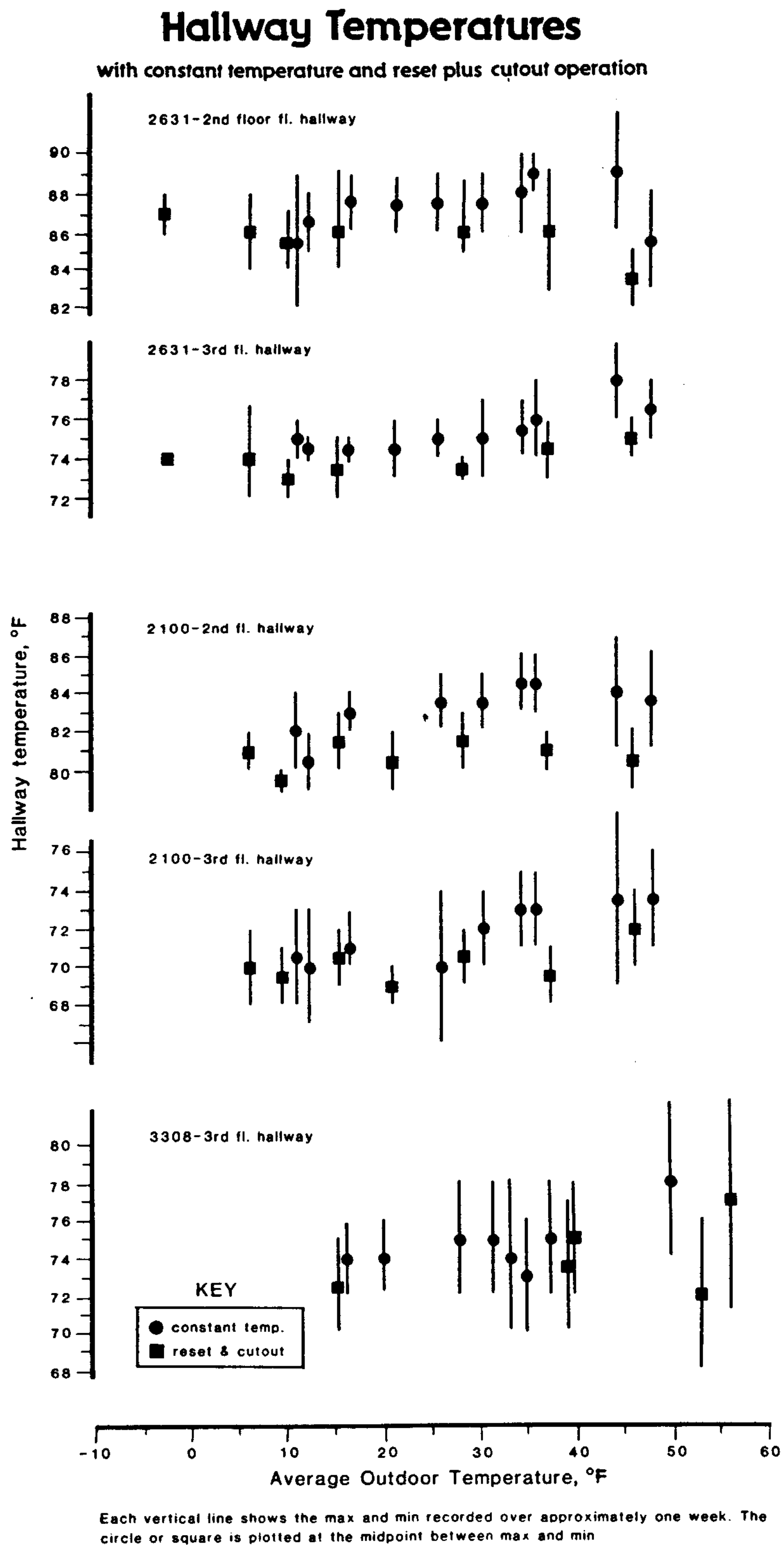
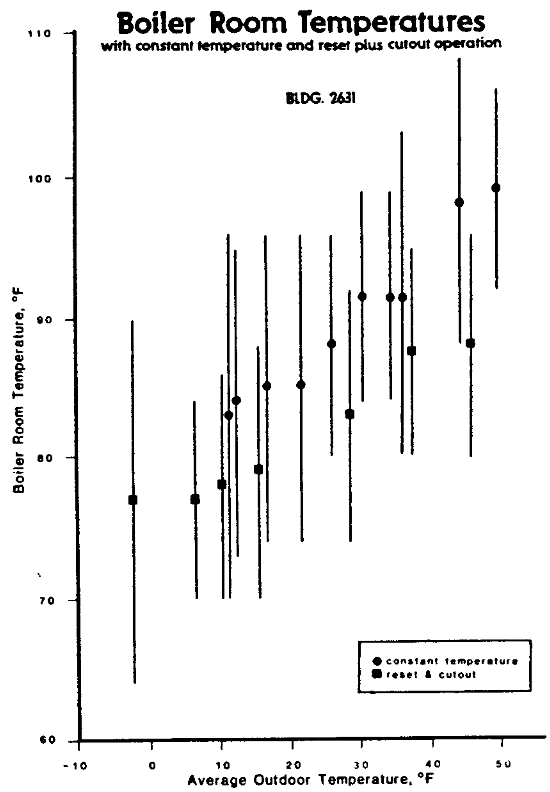
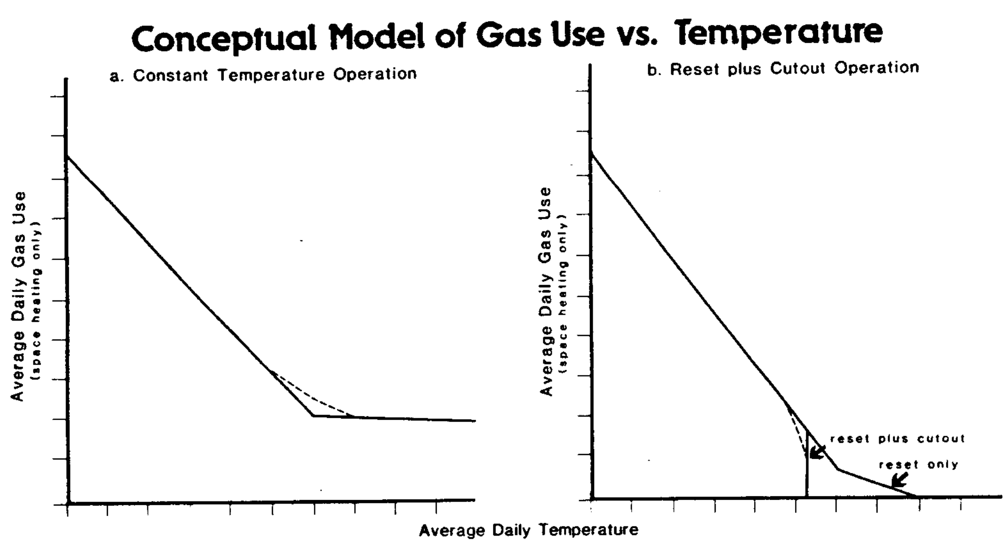

Hallway Temperatures
with constant temperature and reset plus cutout operation
2631-2nd floor fl. hallway
2631-3rd fl. hallway
2100-2nd fl. hallway
2100-3rd fl. hallway
3308-3rd fl. hallway
Hallway temperature, °F
KEY
constant temp.
reset & cutout
Average Outdoor Temperature, °F
Each vertical line shows the max and min recorded over approximately one week. The circle or square is plotted at the midpoint between max and min

Figure 3




Each vertical line shows the max and min recorded over approximately one week. The circle or square is plotted at the midpoint between max and min

Figure 4




The solid line represents daily consumption. The dashed line shows the expected curve when each data point represents a period of several days.

Figure 5

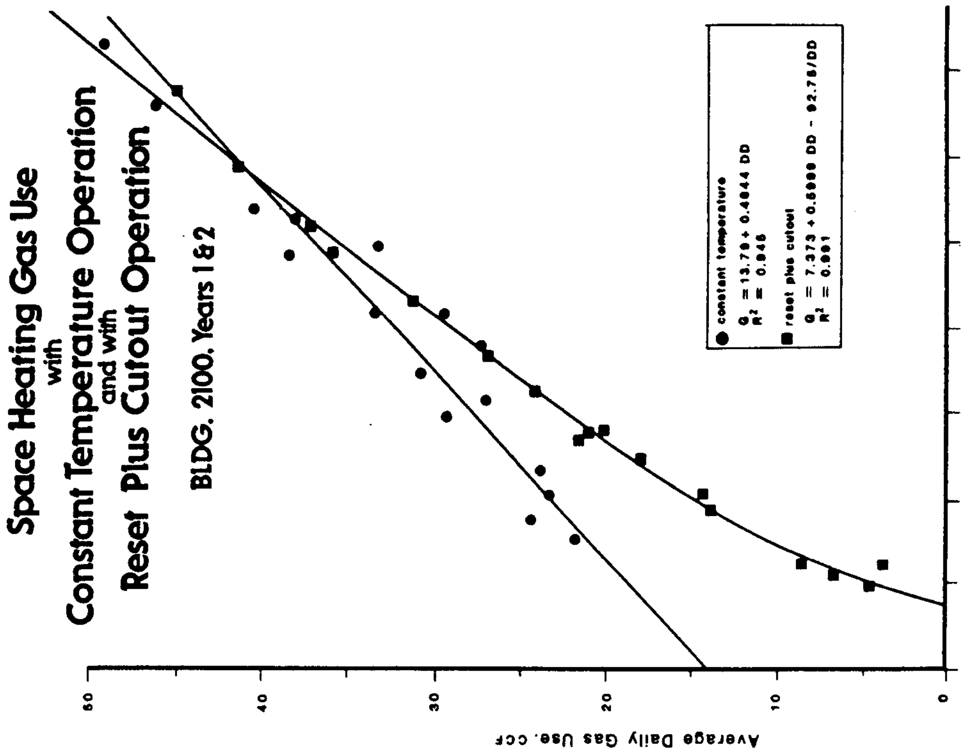



Figure 7

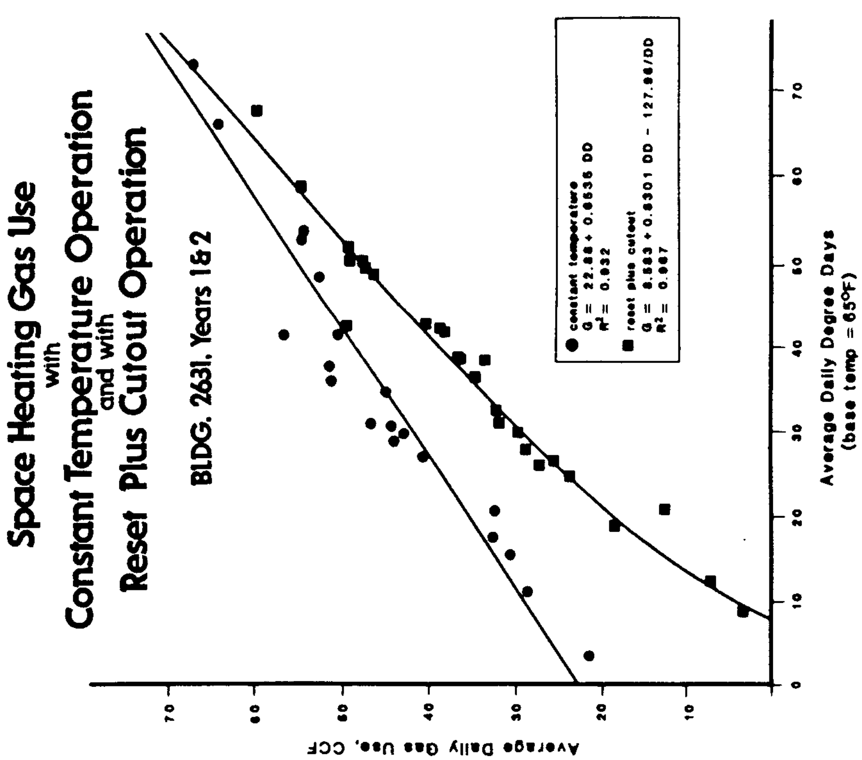



Figure 6

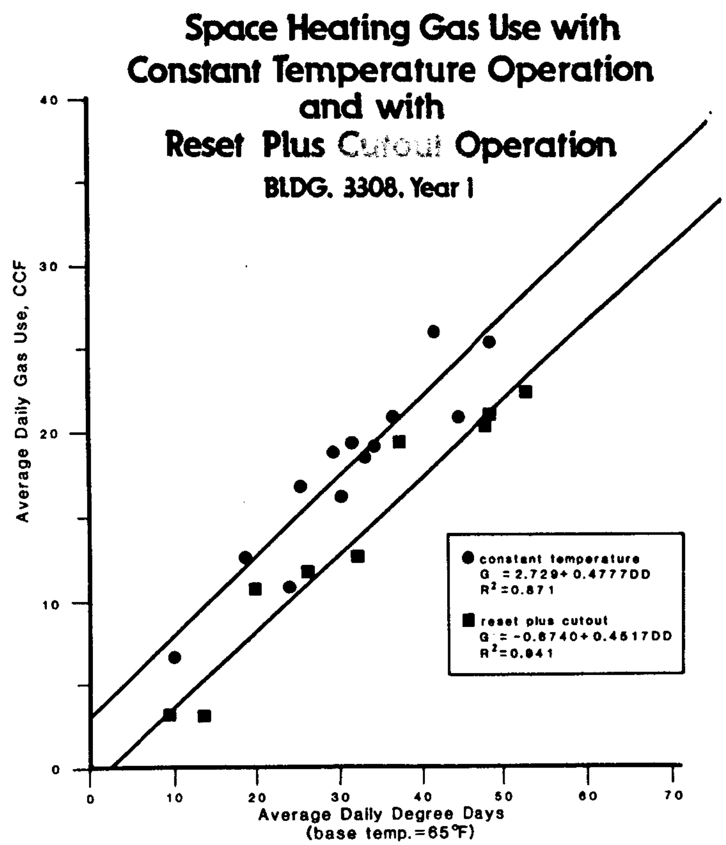



Figure 8

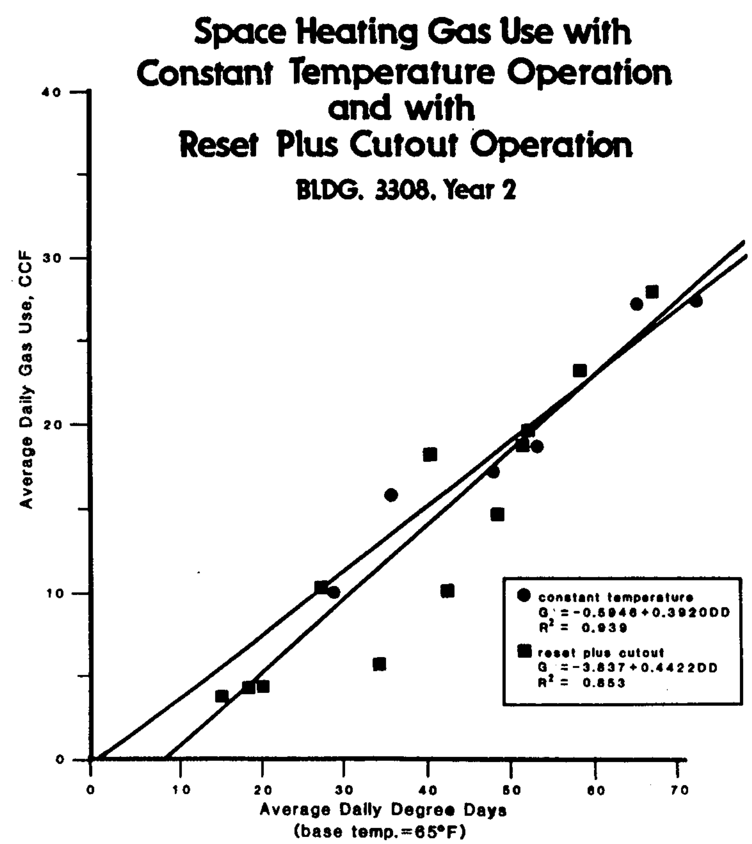



Figure 9

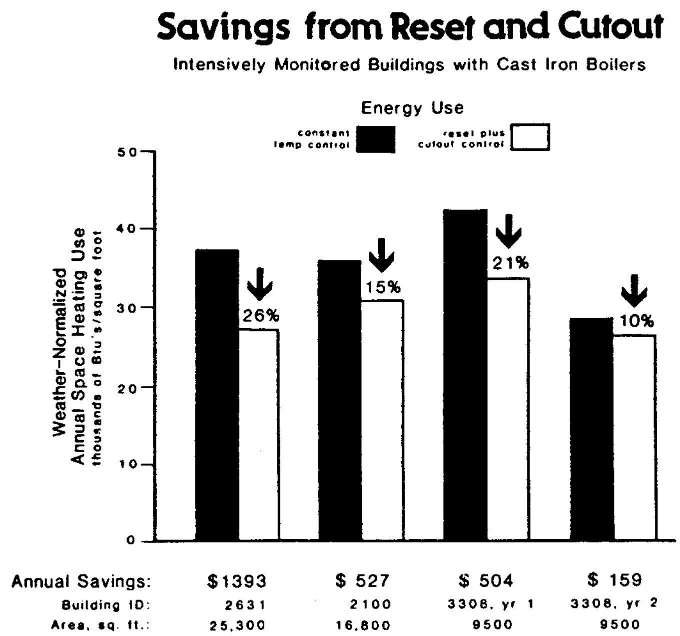



Figure 10

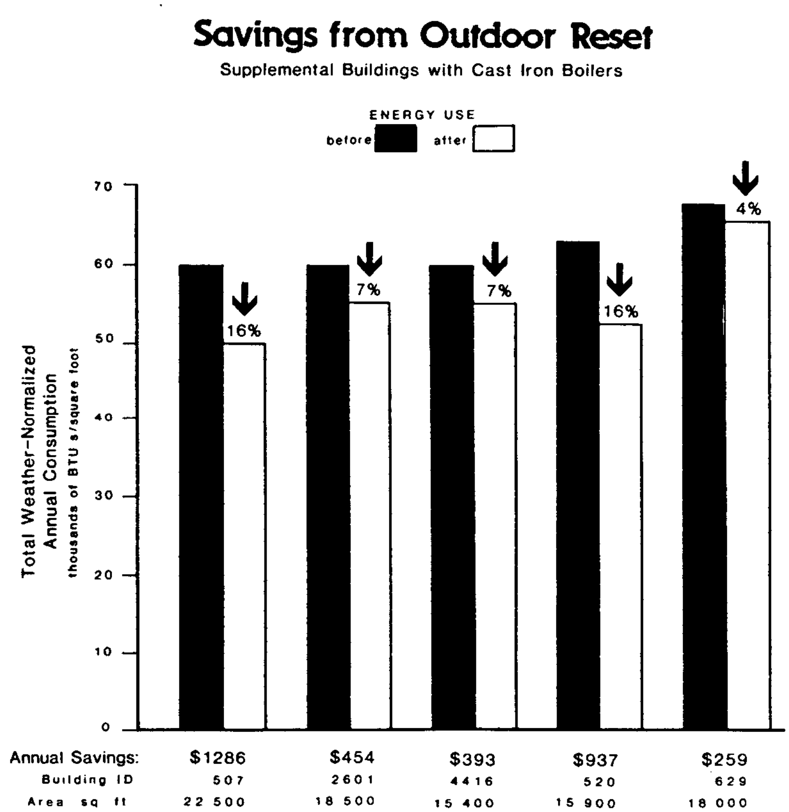



Figure 11

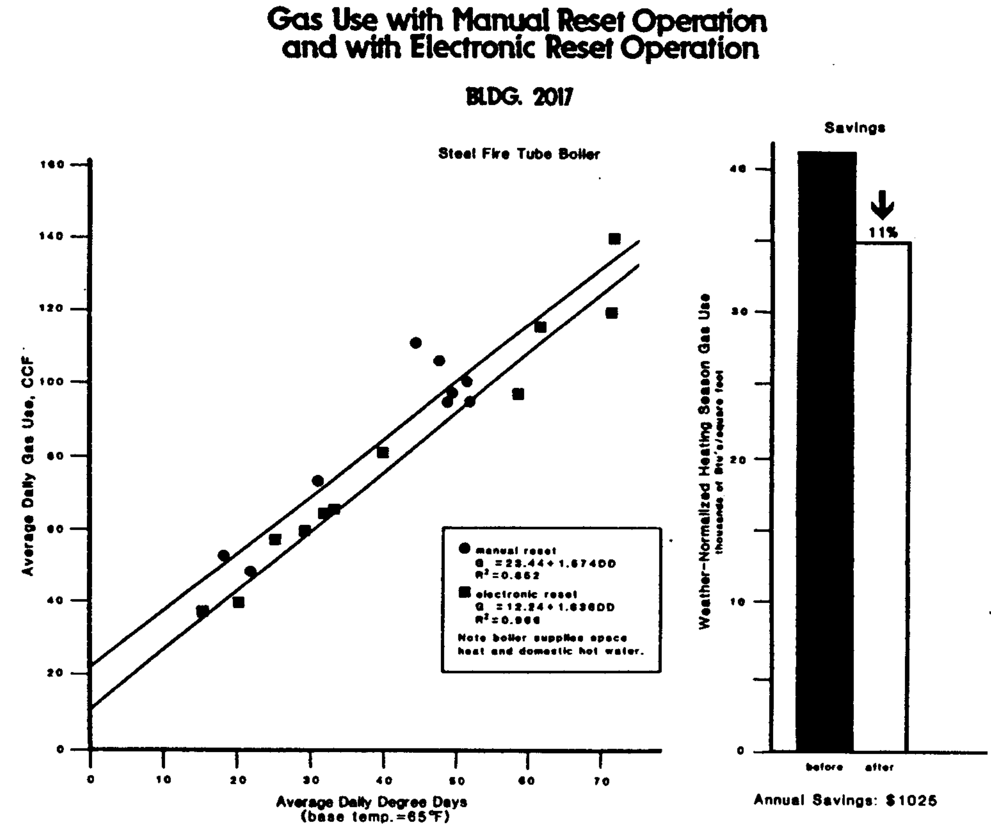



Figure 12

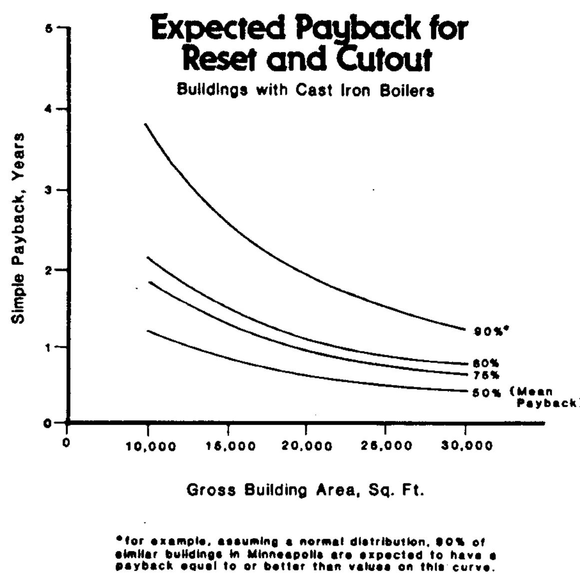



Figure 13

Table 1. Energy use and savings data for the four intensively monitored buildings.

| Bldg I.D. | Test Years | NSHU (CCF)[1] const t mode | NSHU (CCF)[1] reset/cutout mode | NSHU (CCF)[1] difference | NSHU/UNIT AREA ($BTU/ft^2$) const t mode | NSHU/UNIT AREA ($BTU/ft^2$) reset/cutout mode | NSHU/UNIT AREA ($BTU/ft^2$) difference | PERCENT DIFFERENCE % of NSHU | PERCENT DIFFERENCE approx % of NAC[3] |
|---|---|---|---|---|---|---|---|---|---|
| 2631 | 1&2 | 9328 ± 143 | 6946 ± 119 | 2382 ± 184 ($p < .0010$)[2] | 36,900 | 27,500 | 9,420 | 25.5 | 20.1 |
| 2100 | 1&2 | 6141 ± 104 | 5241 ± 80 | 900 ± 140 ($p < .001$) | 36,500 | 31,100 | 5,340 | 14.7 | 11.5 |
| 3308 | 1 | 4057 ± 127 | 3196 ± 134 | 861 ± 186 ($p < .001$) | 42,800 | 33,700 | 9,080 | 21.2 | 16.7 |
| 3308 | 2 | 2772 ± 202 | 2501 ± 172 | 271 ± 344 ($.4 < p < .5$) | 29,200 | 26,400 | 2,860 | 9.8 | 7.7 |
| 2017[4] | 2 | 16,219 ± 649 | 14,467 ± 412 | 1,752 ± 740 ($.02 < p < .05$) | 42,800 | 38,100 | 4,620 | 10.8 | |

Notes: 1. Weather-normalized annual space heating use. See text for calculation method.
2. Probability that the observed difference could occur by chance when no real difference exists.
3. See text for method of calculation % change in NAC from % change in NSHU.
4. Values are for normalized winter gas use for both space heating and domestic hot water by the main boiler.

Table 2. Energy use and savings data for the five supplemental buildings.

| Bldg I.D. | NAC(CCF)[1] const t w/cutout | NAC(CCF)[1] reset w/cutout | NAC(CCF)[1] difference | NAC/UNIT AREA ($BTU/ft^2$) const t w/cutout | NAC/UNIT AREA ($BTU/ft^2$) reset w/cutout | NAC/UNIT AREA ($BTU/ft^2$) difference | Percent Difference In NAC |
|---|---|---|---|---|---|---|---|
| 507 | 13,474 ± 327 | 11,280 ± 326 | 2,198 ± 483 ($p < .001$)[2] | 59,900 | 50,100 | 9,770 | 16.3 |
| 2601 | 11,083 ± 249 | 10,307 ± 258 | 776 ± 360 ($p \sim .05$) | 60,000 | 55,800 | 4,200 | 7.0 |
| 4416 | 9,189 ± 187 | 8,518 ± 438 | 671 ± 477 ($.1 < p < .2$) | 59,600 | 55,200 | 4,350 | 7.3 |
| 520 | 10,093 ± 464 | 8,491 ± 275 | 1,602 ± 564 ($.01 < p < .02$) | 63,300 | 53,300 | 10,050 | 15.9 |
| 629 | 12,089 ± 435 | 11,646 ± 236 | 443 ± 467 ($.2 < p < .4$) | 67,300 | 64,900 | 2,470 | 3.7 |

Notes: 1. Total weather-normalized annual gas use. See text for calculation method.
2. Probability that the observed difference could occur by chance when no real difference exists.

Table 3. Summary statistics: savings for buildings with cast iron boilers.

| Bldg. ID | | Change in Total Annual Consumption CCF | Percent | BTU/Sq.Ft. |
|---|---|---|---|---|
| 2631 | | 2382 | 20.1 | 9420 |
| 2100 | | 900 | 11.5 | 5340 |
| 3308, yr1 | | 861 | 16.7 | 9080 |
| 3308, yr2 | | 271 | 7.7 | 2860 |
| 507 | | 2198 | 16.3 | 9770 |
| 2601 | | 776 | 7.0 | 4200 |
| 4416 | | 671 | 7.3 | 4350 |
| 520 | | 1602 | 15.9 | 10050 |
| 629 | | 443 | 3.7 | 2470 |
| Mean | | 1123 | 11.80 | 6390 |
| Std. Deviation | | 758 | 5.66 | 3150 |
| Std. Error | | 253 | 1.89 | 1050 |
| Signif. Level[1] | | .001<p<.01 | p<.001 | p<.001 |
| Confidence Intervals For the Mean[2] | 1 S.E. | [870,1376] | [9.9,13.7] | [5340,7440] |
| | 80% | [770,1476] | [9.2,14.4] | [4930,7850] |
| | 90% | [653,1593] | [8.3,15.3] | [4440,8340] |
| | 95% | [540,1703] | [7.5,16.1] | [3970,8810] |
| Confidence Intervals For Sample[3] | 1 S.E. | [365,1881] | [6.1,17.5] | [ 3240,9540] |
| | 80% | [ 64,2182] | [3.9,19.7] | [2000,10789] |
| | 90% | [-288,2534] | [1.3,22.3] | [ 540,12240] |
| | 95% | [-629,2872] | [-1.2,24.8] | [-860,13640] |
| One Tailed Conf. Ints. For Sample[4] | 75% | 588 | 7.8 | 4170 |
| | 80% | 449 | 6.8 | 3590 |
| | 90% | 64 | 3.9 | 2000 |
| | 95% | -288 | 1.3 | 54 |

1. Probability that these savings data could occur by chance when no real savings exist.
2. For example, there is a 95% probability that the true mean savings are between 3970 and 8810 BTU/ft$^2$.
3. For example, 80% of similar buildings in Minneapolis could be expected to have savings between 2000 and 10,780 BTU/ft$^2$.
4. For example, 90% of similar buildings in Minneapolis could be expected to have savings greater than or equal to 2000 BTU/ft$^2$.

Table 4. Simple payback estimates for the test buildings.

| Bldg. I.D. | Estimated First Year Savings, CCF | Estimated First Year Savings, $ | Cost, $ | Estimated Simple Payback, Years |
|---|---|---|---|---|
| 2631 | 2382 | 1393 | 450 | 0.3 |
| 2100 | 900 | 527 | 450 | 0.9 |
| 3308 yr1 | 861 | 504 | 450 | 0.9 |
| 3308 yr2 | 271 | 159 | 450 | 2.8 |
| 2017 | 1752 | 1025 | 3000 | 2.9 |
| 507 | 2198 | 1286 | 250 | 0.2 |
| 2601 | 776 | 454 | 250 | 0.6 |
| 4416 | 671 | 393 | 250 | 0.6 |
| 520 | 1602 | 937 | 250 | 0.3 |
| 629 | 443 | 259 | 250 | 1.0 |