THE MULTI-FAMILY PILOT PROJECT: SINGLE PIPE STEAM BALANCING HOT WATER OUTDOOR RESET

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ABSTRACT

In the fall of 1984 the Energy Office initiated the Multi-family Pilot Project (MFPP) to test a deliver mechanism and to refine the technology for conservation retrofits in single pipe steam (SPS) and multizone hot water (MZHW) apartment buildings.

The major cause of energy waste in SPS buildings is uneven heating. The temperature is usually set to satisfy the coolest apartment which overheats other apartments and wastes energy. This paper summarizes balancing strategies including: controlling the boiler cycle, installing main line and radiator air vents, conducting a tenant survey to identify remaining problems, and using thermostatic air vents and other techniques to fine-tune the system.

Installations were completed on 25 buildings. Energy savings averaged 9.3%, the average cost was about $1400, and the median simple payback was 1.4 years. Field and laboratory tests were conducted on main line and radiator air vents which showed significant differences in venting rates and the importance of these differences in achieving even heating.

The most cost effective retrofit for MZHW apartment buildings is the outdoor reset of boiler water temperature. The MFPP tested a delivery mechanism for the retrofit. Installations were completed on 18 buildings. Energy savings averaged 9.1%, the average cost was $615, and the median simple payback was 1.9 years. A computer simulation was done to determine how large of a performance degredation is incurred when the reset ratio used varies from the ideal. As much as 50% of the potential savings can be lost with the use of the wrong reset ratio.

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Since 1981 the Minneapolis Energy Office has been testing retrofit strategies for energy conservation in multi-family buildings. By 1984 enough information had been gained that a pilot installation program, the Multi-family Pilot Project (MFPP), was developed. Two generic types of apartment buildings were addressed, multizone hot water (MZHW) and single pipe steam (SPS).

Uneven heating can be a major sorce of energy waste in single pipe steam buildings. Before the MFPP, the office had tested steam balancing strategies in only two buildings[1]. Significant effort was directed at improving technical knowledge about how to balance steam buildings as well as testing marketing and installation methods. Installations were completed in 25 buildings. A powerful set of techniques to achieve even heating was further developed. In most cases these are sufficient to achieve a resonably good balance and the tenant comfort of many buildings has been greatly improved. Each SPS system is unique and each building must be treated individually. Therefore, it has not been possible to predict in advance exactly which techniques will work. Instead, the building is balanced in steps by trial and error and the balancing is therefore labor intensive.

The conservation measures that are relevant to multi-zone hot water buildings are the outdoor reset, outdoor cutout, and low flow showerheads. These measures had been previously tested and found to function well and to achieve good savings[2]. The main emphasis in the MFPP was to test the mechanism of a large scale installation project. Outdoor resets and cutouts were installed in 18 buildings. Test marketing of LFSH was conducted, however, this is not covered in this report. These measures have proven in general to be easy to install and to function well. The main technical issues left to investigate are the correct reset ratio and the outdoor sensor location requirements. This paper discusses the effect of the outdoor reset ratio on the realized energy savings.

SINGLE PIPE STEAM HEATING SYSTEMS

How the SPS Heating System Works

A major and almost universal cause of energy waste in single pipe steam (SPS) heated buildings is uneven heating. The SPS system is inherently the most difficult to balance and control. Opening windows even in the coldest weather to cool down overheated apartments was part of the original design and normal operation. The thermostat is generally adjusted to satisfy the coolest apartment, with the result that other apartments are overheated by as much as 10 to 15°F.

A typical SPS heated building has only one thermostat. When the thermostat calls for heat the boiler comes on, heats the water, and generates steam. The distribution system is initially full of air. Steam moves through the piping under very low pressure (generally less than one pound per square inch gauge, psig), heating the metal and pushing the air out through air vents on the mains and the radiator. As steam reaches each vent, the heat of the steam causes the vent to close, so that no steam escapes into the room. Within the the steam condenses, releasing heat and making room for more steam to enter. The condensed water trickles back to the boiler through the same piping that supplied the steam. When the thermostat is satisfied either by an actual increase in space temperature or by the heat anticapator, it turns the boiler off. As each radiator cools the air vent opens, allowing air to re-enter the system.

In the simplest terms, the major cause of uneven heating is that the boiler provides more heat to some radiators than to others. This happens for several reasons: large differences in steam arrival times, excessively short boiler cycles, radiator sizing, and building and system design[1].

The Art Of Steam Balancing

Steam balancing is an art as well as a science. Current knowledge is sufficient to achieve a good balance in most buildings. Space temperature control in a well balanced building is limited to about 4°F for temperature differences between apartments and swings of temperatures within an apartment. This degree of control can produce significant energy savings and increase tenant comfort. A procedure to achieve this is given in the four step process below. Balancing allows the lowest comfortable temperature throughout the building therefore saving energy and money. References 3 and 4 are guides to steam balancing for apartment owners and give more complete details.

Step One: Building Survey. During the building survey the boiler and steam distribution system are thoroughly assessed in conjunction with an overall audit of the building. A diagram of the distribution system in the basement and sketches of the radiator location and size in the apartments is drawn, and the specification for the first phase of installation are made at this time.

Step Two: First Phase of Installation. Almost all SPS buildings should have additional main line air venting, larger air vents on the more distant radiators and the installation of thermostatic radiator valves (TRV's) in the apartments over the boiler room. Proper boiler cycle control must be established. These steps should be done during the first phase of installation as well as correcting any maintenance problems that are found. In this way the basic easy to fix problems are corrected before the temperature assessment.

Step Three: Temperature Balance Assessment. The purpose of the temperature balance assessment is to determine as close as possible, without unreasonable expense, how the heating system functions in the building, what the temperatures are, and how the tenants perceive the comfort level. A combination of a tenant survey with selective monitoring with strip chart recorders appears to offer the best balance between expense and information.

The tenant survey is an inexpensive method of obtaining both the tenants subjective impression of their apartment's space temperature and detailed information about how the system operates. To increase the accuracy and usefulness of the survey inexpensive mercury thermometers should be passed out to all of the tenants before or along with the survey forms. The tenant survey should be handed out with literature describing how their radiators should work. Many malfunctioning radiators can be located and repaired this way. The survey will identify those apartments that need further work. A good response rate is necessary for best results. Passing the surveys out a week to ten days before the rent is due and having them turned in with the rent is a good technique.

Step Four: Fine-Tuning. Since each building is unique, and even seemingly identical ones built next to each other differ, there is no systematic approach for all buildings. The steam balancer must gather whatever information s/he can and design solutions for that building. The sections on basic technologies and fine tuning detail the balancing techniques that are available for this use.

Reduce Thermostat Setting. All during steam balancing the control of the thermostat is very important. The thermostat should be set to the lowest comfortable setting possible until some tenant complaints are generated. If most of the building is too cool, the building may be in good balance. If only one to two apartments are cold, work should be done to warm them up, such that the thermostat setting can continue to be reduced.

Basic Technologies for SPS Balancing

Cycle Control. Proper control of the length and timing of the boiler cycle is of paramount importance in steam balancing. The optimum cycle length is typically for the boiler to remain on until all radiators are completely full and then to turn off promptly. This minimizes the heat output difference between different radiators while still keeping the temperaturre surges within apartments low[1]. Several methods are available which can possibly produce proper boiler cycles. In the beginning of the MFPP a cycle holding relay was used to hold the burner on until a sensitive pressuretrol determined that the distribution system was filled with steam. Later this was changed to the thermostat method because it is easier for contractors to understand, cheaper to install, and eliminates problems in those cases where the boiler output is too low to pressurize the system[3]. The thermostat method involves a thermostat with an adjustable differential without a heat anticipator, usually a remote sensing type. The sensing element is located near the last group of radiators to receive steam. The differential determines the amount of temperature increase the sensor must experience before it shuts off the boiler. The greater the differential, the longer the boiler cycle will be. By proper adjustment of the differential, sensor location, and air venting rates the proper cycle can be achieved.

Control of the thermostat is important when trying to reduce energy costs in multifamily buildings. In Minnesota even a 2^{O}F increase can increase costs 6%. Tenant operation of the thermostat may not provide the feedback and control necessary for good balancing and savings. The remote sensing thermostat operates as a regular thermostat with the added advantage that the thermostat itself can be located beyond tenant access, usually in the boiler room. Only the remote sensor, a small temperature sensing device, is located within an apartment. This discourages tenant tampering. These thermostats are sensitive to feedback and must be isolated from all other electronic controls.

Air Venting. Proper air venting can be used to control the relative speed of steam delivery to various radiators in a building. When used in conjunction with a proper boiler cycle, it is a powerful balancing technique. Two types of air venting are used; main line air vents (MLAV) on the main distribution pipes and variable air vents on the individual radiators.

The purpose of the **main line air vent** is to rapidly vent the relatively large quantity of air in the main lines. Although there is very little back pressure during the fill part of a boiler cycle, these vents lower it even further and preferentially enhance the flow of steam down the main distribution pipes at the expense of flow up into the radiators near the boiler. Thus the far radiators receive steam more quickly than before, and the close radiators receive steam more slowly.

The arrival time of steam to various radiators can be further regulated by the use of **variable sized radiator air vents**. In conjunction with MLAVs they can significanlty reduce the time lag for steam fill between near and far radiators. The function of the radiator air vent is to provide a means for air to be driven out of the radiator as steam enters. At a given pressure the fill time of a radiator varies proportional to its heat capacity and inversely proportional to the venting capacity of the radiator air vent. It is possible to control the speed at which a radiator will fill with steam by installing a radiator air vent with a certain venting capacity. Used in this manner, radiator air vents are helpful in evening out the heat distribution in a building.

In order to obtain a better understanding of these effects, a series of lab experiments were conducted to measure the flow rates of commercially available main line and radiator air vents. The flow rates of open pipe orifices of different sizes were also measured to compare the commercial vents with orifices of a known diameter[5]. One of the goals of the flow rate experiment was to obtain a quantitative comparison of various air vents. This comparison can be used as a guide for deciding which vents should be used to even out the heat in a given building.

The results of the laboratory tests can best be summarized graphically. Figures 1 and 2 are summaries of the flow rates of the main line air vents and radiator air vents that were tested respectively. This comparison is based on a gauge pressure of 1" water. The results at 1" water were chosen as most representative of actual operating conditions. The relative positions of the

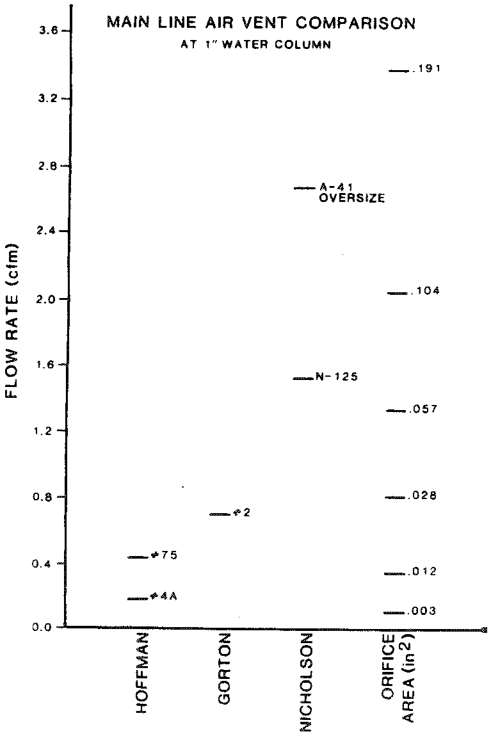

Figure 1

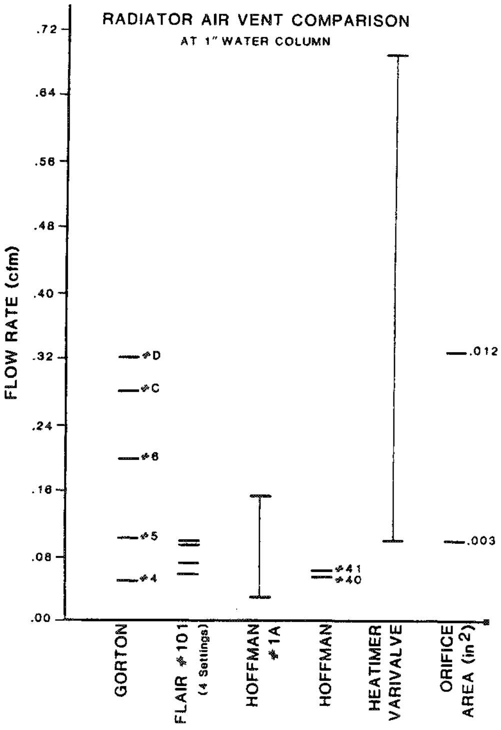

Figure 2

vents on the graph do not change significantly up to a pressure of 28" water (1 psig).

Field experiments were also conducted in an apartment building to determine the point at which the law of diminishing returns makes a further increase in air vent capacity uneconomical[5]. For MLAV no significant difference of steam arrival time at the end of the main lines was noticeable when orifice area was .191 square inches or larger. At .104 square inches orifice area, the steam took approximately 15 seconds longer (a 10% time increase) to reach the end of the short branch, and about 45 seconds longer (a 16% time increase) to reach the end of the long branch. This seems to indicate an orifice area of .104 to .191 square inches is needed to efficiently vent the main line. Radiator air venting showed no increase in venting rate when the orifice was greater than .011 square inches.

Steam System Pressure and Operation. During the 1984-85 heating season balancing was done using a cycle holding relay (CHR) which required a pressuretrol to measure the pressure at which the heating distribution system was completely full and shut the burner off. The original pressure at which a particular system was full varied quite a bit. The range was 0.5 to 5.5 psig. The building which started at 5.5 psig fill pressure prior to the added venting was reduced to 0.9 psig afterwards. In all cases, buildings could be made to pressurize at less than one pound by the addition of air venting. While the pressure at which the building pressurized could be quite variable, the time to fill the system was fairly constant. The main determinant of fill time is the ratio of the boiler output to the heat capacity the distribution system mass which did not change. The increased pressure vented the same amount of air through smaller holes at higher pressure in the same amount of time.

In five of the buildings, the heating system failed to ever completely fill with steam and pressurize. The boiler was sufficiently big to heat the building on design days, but the distribution systems output capacity was greater than that of the boiler. The distribution system would fill with steam until its output to the building just matched that of the boiler and steady state was reached. For these buildings the system filled and operated at atmospheric pressure. The CHR based control system cannot work under these conditions. The thermostat based system outlined above was therefore used.

Fine-Tuning of Hot and Cold Apartments

Correcting Cold Apartments. To increase the temperature in an apartment either the heat input must be increased or the heat loss decreased. Several techniques are available to do each.

If no steam ever reaches one or more radiators and the boiler cycle is being properly controlled, then the radiator itself may not be operating properly. The hand valve should be checked to determine if it is operating properly and is open. The stem may be broken with the valve in the off position. The air vent operation should also be checked. This can be done by removing it and testing to see if it passes air; if not, it should be replaced.

In some cases, good balance cannot be achieved with the existing radiators. This is especially true of apartments that are too cold because radiators have been removed. Therefore it may be necessary to add to or rearrange a building's radiators, though this is major work and may be expensive. To reduce costs unused radiators from the hallway can sometimes be used or there may be old radiators stored in the basement.

Risers to radiators in apartments above may sometimes be insulated. If the apartment is too cold this insulation can be removed and the risers will act as an additional radiator.

Sometimes the thermostat is set high because of a few cold and drafty apartments. While weatherizing an entire apartment building is usually not cost effective, decreasing the heat loss from the colder apartments by reducing air infiltration or increased insulation can help to achieve more even heating. The reduced thermostat setting can then make the weatherization cost effective.

Correcting Hot Apartments. To decrease the temperature in an apartment, the heat input must be decreased. Several techniques are available to do this.

Normally there will always still be some temperature variation between apartments. The differences are due to such time-dependent variables such as solar gain, internal gains, infiltration, and wind conditions, also some apartments may have too much radiation. To compensate for this, the building can be divided into a number of different zones, each with some degree of separate thermostatic control. Thermostatic radiator vents (TRVs) are devices for accomplishing this. These are usually installed on the largest radiators in the warmer apartments or in rooms, such as a bedroom, where a cooler temperature than the average is desired. TRVs work by responding to temperature changes near the radiator. They are filled with a fluid which expands and closes the air vent if the temperature goes above the setpoint. When the boiler turns on, no air can be released and thus no steam can enter. Most TRVs can be set to provide a fixed room temperature or to allow the room temperature to be varied by the occupant, with a preset maximum chosen by the owner.

In order to decrease the average heat gain, a radiator can be turned off or exchanged for a smaller one. However, single pipe steam radiators cannot be throttled down using the hand valve which should be kept either full on or full off.

If risers to radiators on floors above are uninsulated a thin layer of 1/4 - 1/2" insulation is sufficient to stop the majority of the heat flow.

Small apartments with only one radiator are sometimes too hot if the radator is turned on or too cold if it is off. A TRV will usually solve this.

Energy Savings

The energy savings for 12 of the 25 SPS buildings were measured using PRISM analysis[6]. The mean savings was 9.3% with a range of a 14.4% increase to a 25.2% decrease in consumption, see figure 3. The average direct cost to the apartment building owner was about $1,400 and the median simple payback period was 1.4 years[7].

Two buildings had anomalous savings values. Balancing achieves energy savings by lowering the average building temperature. The building where energy use increased was fairly well balanced before installation. The installation solved several underheating problems which increased resident comfort, but which also more than offset the gains from reducing overheating and resulted in a net energy use increase. The building with 25.2% savings set the thermostat very low after installation and much of the building experienced underheating.

In the beginning of the MFPP the extent to which buildings had to be treated individually was not realized and a large number of technical difficulties arose. More buildings had installations than could be fully serviced given available staff. As a result the thermostat settings were not monitored carefully, but were left up to the caretakers to control. This probably resulted in reduced savings in some buildings. Emphasis is now placed on the active participation of the owner and caretaker to keep the thermostat setting to a minimum and to individually troubleshoot cold apartments.

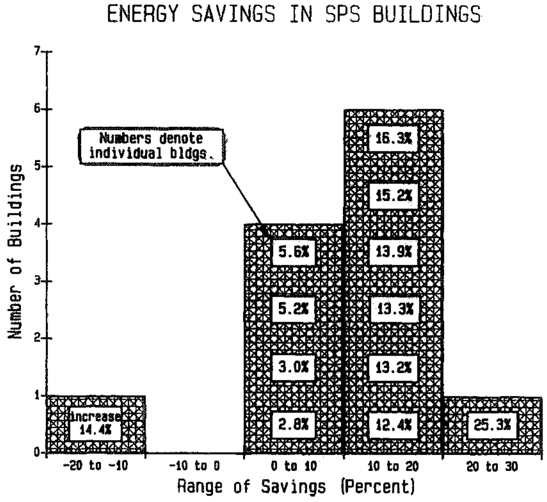

Figure 3

Table I **SPS sample disposition**

25	Original cases
-10	Poor or insufficient pre-date
- 2	System pressure too low
- 1	Analysis pending
12	Remaining cases with reliable Pre & Post results

Case Study of Steam Balancing

During the first year of the MFPP one system was more difficult to balance than any other: the Aldrich buildings. The heating system actually heats two buildings side by side. Even though the buildings were part of the MFPP and received many visits, the heating remained uneven during 84-85.

The caretaker kept the thermostat at 78°F to reduce complaints. However, the owner was very cooperative and interested in balancing the building. Therefore, it was decided to try to balance the building again during the 85-86 heating season, when even more attention could be given to it. The method outlined above was used. The reasoning was that if this building could be balanced, any building could. The key to understanding this building was the radiator survey and resident/temperature survey. These survies revealed that the four coldest apartments had significantly less heating capacity than the other apartments because radiators had been removed. By moving a radiator from an overheated apartment to a cold one, adding three others, and installing additional TRV's and radiator air vents, the building was balanced and a 12.4% energy reduction was achieved.

MULTIZONE HOT WATER HEATING SYSTEMS

Operation of the Outdoor Reset and MZHW Building

Hydronically heated apartment buildings normally have one or more main heating distribution loops from which separate baseboard loops run into each apartment. 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. The boiler is typically 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°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. The outdoor cutout turns off the heating system on spring and fall days when the outdoor temperature is high enough that extra heat is not needed. The outdoor reset and cutout have been shown to provide savings of 10-18% compared to constant temperature operation[2].

Energy Savings

The energy savings of eight of the 18 buildings in the MFPP were measured using PRISM analysis[6] in order to compare this group installed by contractors not monitored by office staff with the more closely controlled installations reported earlier. All buildings showed savings with an average of 9.1%, see fig. 4. The average cost was $631 and the median payback was 1.9 years[7]. This was less than the previously reported average of 15%. Several possibilities for this exist including statistical error, occupancy rates, and the control of the outdoor reset setting. The effect of the outdoor reset ratio was investigated.

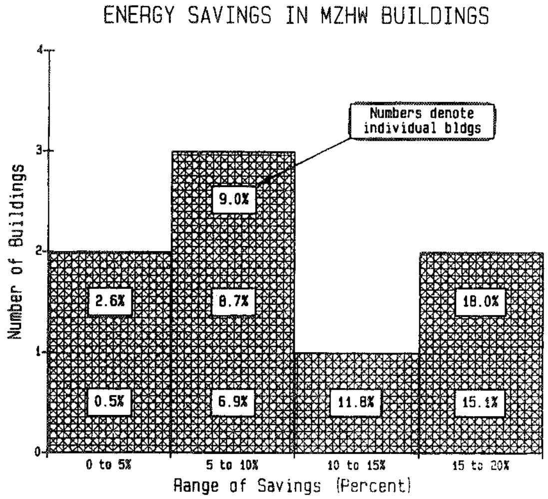

Figure 4

Table II **MZHW sample disposition**

18	Original cases
- 8	Poor or insufficient pre-data
- 2	Vent damper tests being conducted
8	Remaining cases with reliable Pre & Post results

Reset Ratio

The reset ratio of an outdoor reset is the ratio of the change of outdoor temperature to the resulting change of boiler water set point temperature. A ratio of 1.0:1.5 means that for every degree colder outside the boiler water temperature is increased 1.5 degrees. The proper reset ratio is building dependent and is controlled primarily by the installed design condition water temperature. Most buildings in Minneapolis were originally designed for 180° water on the coldest days. However, the actual temperature necessary can vary from 160 to 220°F. Few buildings need heat when the outside temperature is above 55°F, and the outdoor cutout is usually set to turn off the boiler at this temperature. The practical limit of reset to protect the boiler and provide some heat to the apartments that need it is about 110°F water temperature at the cutout point. Therefore, this point and the water temperature required at design conditions determine the ideal straight line reset ratio.

Some outdoor resets have a fixed ratio, fig. 5, where only the cutout intercept can be shifted up or down parallel to accomodate the individual building. Others can adjust both the reset ratio (slope) and the cutout intercept, fig. 6.

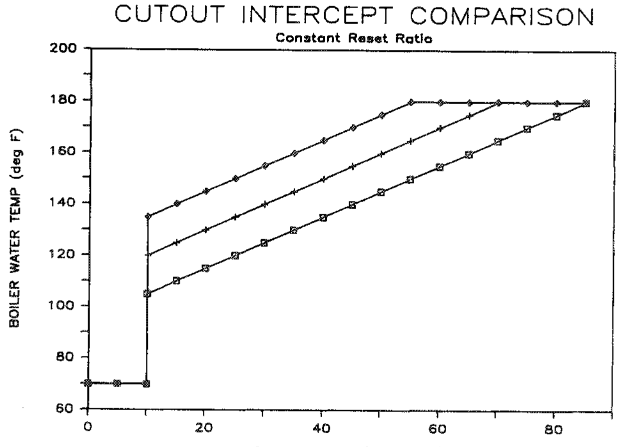

Figure 5

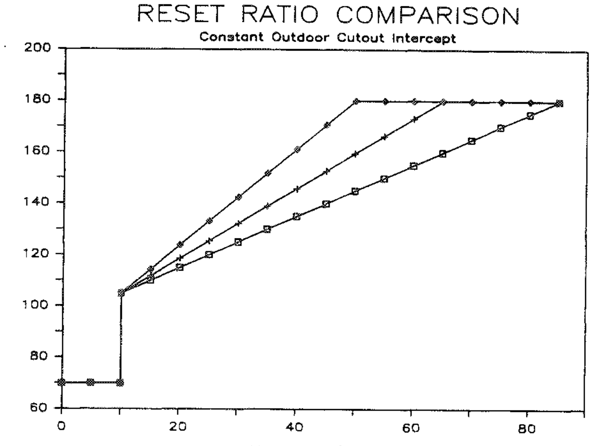

Figure 6

A computer analysis was done to determine approximately how large of a performance degredation is incurred when the reset ratio used varies from the ideal. If the reset ratio is too high the water temperature will increase more quickly than optimal and reduce the savings, fig. 7. However, since MZHW buildings are designed to function with water temperature at the high limit even on mild days, no tenant complaints or system problems will result. If the reset ratio is too low, fig. 8, as the weather gets colder the building

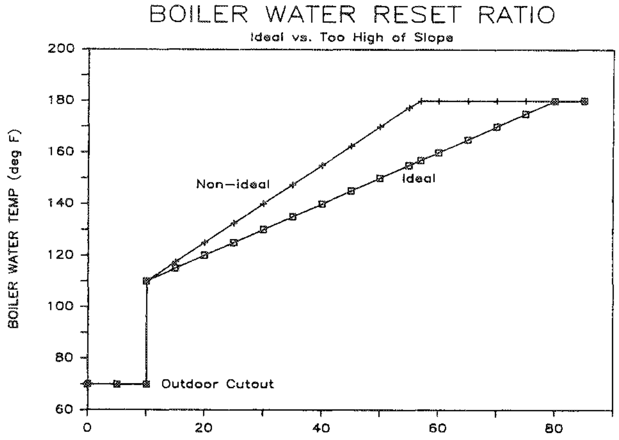

Figure 7

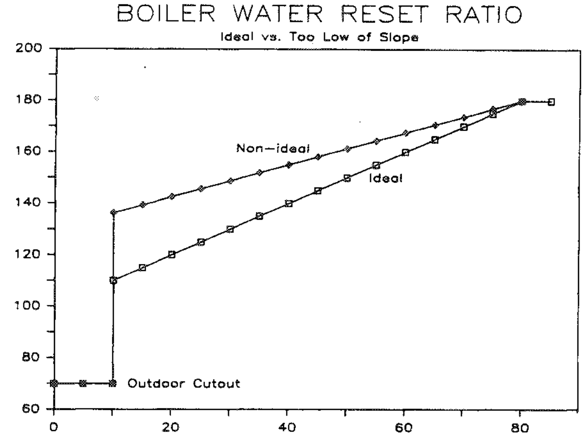

Figure 8

will not be able to maintain temperature and tenant complaints will be generated. By raising the reset line in a parallel manner, i.e. raising the temperature at cutout, sufficient heat will again be provided, but the excessive water temperatures during mild weather will reduce potential savings. While the building will always heat adequately if the boiler water temperature is equal to or greater than the minimum necessary, energy savings are maximized when it is kept to the minimum.

The analysis simulated the performance of resets with various ratios starting from field measured data from an intensively monitored building[2]. The gas use of the building had been measured for both the constant temperature and reset modes over a two year period. Second order polynomial equations that correlated gas use to degree days had been fit to the data, fig. 9. The normalized annual space heating use was calculated by multiplying the gas use calculated from the equations at each degree day value by the normal frequency of occurrence of that degree day value in a typical heating season.

The reset had a 1:1 ratio and was set to give 110°F boiler water at the cutout temperature of 55°F. For the simulation, this was assumed to be the ideal straight line reset ratio for this building, giving a water temperature at a -15°F design condition of 180°F. The savings from any reset were assumed to be directly proportional to the decrease in boiler water temperature. Thus to calculate the savings for reset ratios other than the ideal, the savings from the ideal reset were multiplied by the ratio of the non-ideal to ideal reduction in boiler water temperature (B/A in figure 10). This was done at each degree day value and normalized over the heating season. For non-ideal reset ratios it was assumed that ratios that were too high or too low would intersect the ideal curve at the cutout or design conditions respectively, fig. 7 and 8. Thus the boiler water temperature would be the minimum in excess of the ideal for the given reset ratio.

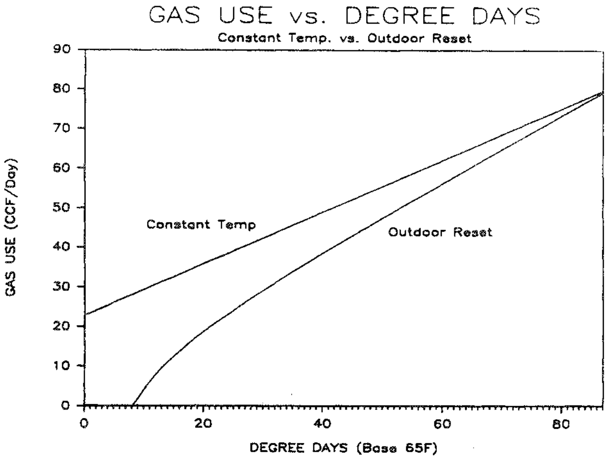

Figure 9

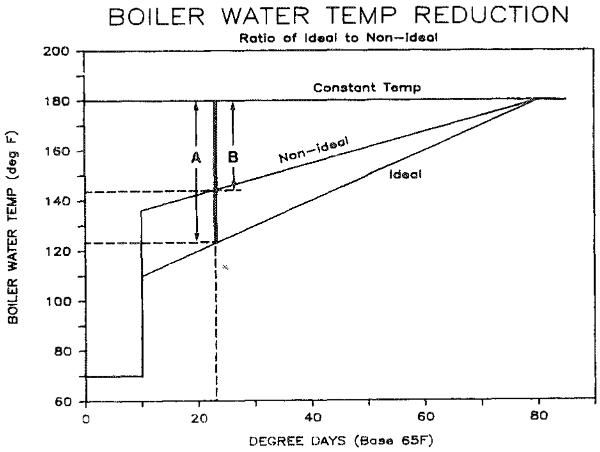

Figure 10

The simulation showed that a significant reduction in savings can result when the reset ratio differs from the ideal, fig 11. It is common practice for contractors to install the higher reset ratios because they tend to generate fewer complaints. If the ratio is off by 25%, a 15% performance degradation or 3% overall savings decrease can exist. Some contractors routinely install a ratio as high as 1:2 which could result in about a 50% decrease in realized savings.

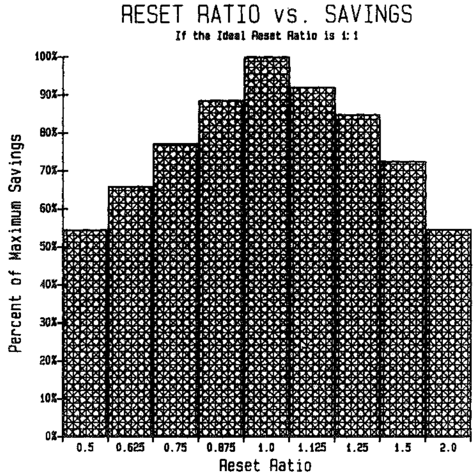

Figure 11

The MFPP used an outdoor reset with a 1:1 ratio. However, field experience has suggested that the median ideal reset ratio for Minneapolis may be 1:1.25. Thus, it appears that the potential degradation of savings due to a non-ideal reset ratio is of the same order of magnitude as the discrepancy between savings reported here and earlier values, and could be an important factor. Future tests are planned to determine the ideal reset ratio on a number of Minneapolis buildings and an audit diagnostic technique to determine it.

ACKNOWLEDGEMENTS

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