REDUCING TEMPERATURE IMBALANCE
IN
SINGLE-PIPE STEAM BUILDINGS

John Katrakis, Bruce Burris, Tom Catlin, Daniel Fish
Center for Neighborhood Technology

ABSTRACT

Temperature imbalance among apartments in multifamily buildings can result in space heating costs up to 15% higher than found in properly balanced systems. It is determined that there are 20,000 single pipe steam buildings in Chicago and nationwide. This paper reports a methodology for correcting steam distribution imbalance whereby diagnostic techniques and the opportunity retrofit options are organized into a decision tree procedure. The approach presented will be useful for energy consumption service groups and mechanical contractors who wish to address the problem of imbalance in single-pipe steam systems.

Detailed diagnostic testing procedures were set up to enable a community based or private service group to perform standardized tests to spot steam distribution and boiler problems. The instrumentation necessary varies from manual pressure gage readings to an on-site data acquisition system with multiple sensors. Some of the procedures can be carried out, depending on the instrumentation available, by balancing contractors. Even without instrumentation, building owners could conceivably carry out several of the standardized tests.

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INTRODUCTION

In the past several years energy conservation services throughout the country have begun to focus on the needs, economics, and technologies of the larger multifamily buildings. In Chicago the Community Energy Savers Fund (CESF) program is providing technical and financial assistance to owners of 5-unit or larger multifamily buildings. These buildings, totalling about 20,000, represent two thirds of the non-public housing stock in the city. The majority of these multifamily buildings, as in the other northern cities in the United States, were built over 50 years ago and have single pipe steam distribution systems and a central boiler. About 90% of the buildings applying to the CESF program are of this type.

In this paper we present the results and recommendations of ongoing research on one of the potentially most cost-effective Energy Conservation Measures (ECMs) for these buildings--balancing the heat distribution to reduce overheating. The research is sponsored by the Gas Research Institute (GRI) and is meant to provide the necessary information to improve the dissemination of this technology. The recommendations apply all phases of the energy conservation professonal's acitivities: field diagnostics during the site assessment; savings projections used in the energy audit; specification and implementation of the measure; monitoring subsequent performance.

CNT will use the results to update the existing training programs for both the building owner and balancing specialist, and to help guide future research work.

BACKGROUND

Description of Single Pipe Steam Heating Systems

Good descriptions of a typical single pipe steam system are available in the literature (G. Peterson, 1982), (Gay and Fawcett, 1951). Low pressure steam exits from the boiler into the distribution lines, forcing residual air out air vents located in the main line distribution system and on each radiator unit in the apartments. The steam condenses in the radiator releasing heat into the apartments. Condensate is returned to the boiler by gravity through the same pipe used for steam distribution. Each air vent has a thermally activated mechanism that upon sensing a high temperature closes and prevents steam from entering the apartment. After the boiler shuts off, the air vents cool and reopen, allowing air to reenter the system.

The typical boiler control is a high limit thermostat attached to one of the return lines and a time clock. The time clock is meant to be periodically adjusted by the building engineer to compensate for changes in weather. When the time clock lets the boiler operate, the high limit thermostat acts to cycle the boiler on and off to avoid overheating. There is a pressure limit control which often is also used to cycle the boiler.

Balancing Service Development

The problem of temperature imbalance has been addressed by some building owners in the Chicago area (Katrakis, 1982) and by energy conservation research groups in Mineapolis (Peterson, 1985) and in St. Paul. The basic method consists of treating the heating system by a) installing appropriately sized replacement main line and radiator vent venting capacity, and b) replacing the existing boiler control with a system which is more responsive to changes in indoor air temperature. Where necessary, envelope tightening is done to reduce cold drafts that may affect the occupants' reaction to the changes in indoor temperature or where the mechanical system treatments are not sufficient.

Until the fall of 1985, CNT's efforts to implement balancing consisted of conducting a site inspection and predicting savings and costs using the CESF energy audit program (Evens, et. al., 1986), specifying replacement boiler controls, replacement mainline vents, giving the building owner verbal guidelines on replacing radiator vents, and making further mainline vent changes as necessary. The follow-up inspections clearly showed that the verbal guidelines from the energy auditor did not provided enough guidance to the building owner and that the expected results were difficult to define and document. We concluded that there is a need to provide the building owner with more specific information and assistance to better define the balancing process. We have also become aware of the difficulties encountered by other energy conservation services in Minneapolis and St. Paul in balancing these buildings (CNT, 1985).

CNT has also attempted to identify and develop balancing consultants or contractors who can provide assistance to the building owner. Existing balancing specialists are not available to handle the level of work being generated by the CESF program. There are few contractors who specialize in the balancing of single-pipe steam buildings. We know two in Chicago and one in St. Paul, Minnesota. Because this work is very labor intensive and the procedures and results are not clearly defined, heating contractors do not include balancing as part of their services.

In order to overcome these barriers CNT has taken the following steps: a) reduce the magnitude of predicted savings and increase the cost estimates associated with vent treatments; b) prepare instructional manuals for the building manager and for the balancing specialist; c) train the energy auditors in the CESF program to also be consultants for their clients; d) hold workshops for the owners on heating system operation and maintenance with an emphasis on controlling building temperatures; e) focus on monitoring and evaluating the various vent treatment and thermostatic control strategies and on developing diagnostic and implementation procedures as part of the research program sponsored by the Gas Research Institute (GRI).

One of the goals of the research program is to develop procedures for predicting the cost-effectiveness of balancing and for specifying its application at a specific building. As part of this effort eleven single-pipe steam multifamily buildings were instrumented and monitored over the 1985-86 heating season. Computerized data acquisition systems (DAS)s were placed in each building to continuously monitor indoor temperature parameters, boiler gas usage, and temperatures at various points in the distribution system which could aid in determining the appropriate balancing treatments. Various vent treatments and boiler control interventions were applied and monitored in four buildings. The results of these activities form the basis for the following observations and recommendations.

BALANCING PROCEDURE DECISION TREE

The current CESF technical services consist of four phases: energy audit; specification preparation; ECM installation; performance monitoring. In each of these phases there are diagnostic procedures, actions, and questions which are pertinant to the balancing ECM. The following Decision Tree presents our current recommended outline of balancing related activities for the first three phases of the technical services. Each activity is identified by "D" for diagnostic, "A" for action, or "Q" for question.

<u>Audit Phase</u>. The following activities are recommended for the audit phase.

D1 Perform the preliminary assessment. This includes client interview, tenant survey, apartment temperature survey, diagram of steam distribution piping.

Q1 Is the building owner conscientious? i.e. Are the coldest apartment temperatures in compliance with city codes (68°F in daytime and 63°F at night) or are the occupants satisfied with the temperatures? If yes, go to Q2. If no, then go to A1.

A1 Explain to owner that balancing will most likely result in code compliance and improved comfort for the occupants rather than energy savings.

Q1a Does the owner want to continue with a balancing service?. If yes go to Q2. If no, stop considering balancing for this building.

Q2 Is the average building temperature less than 74°F, or is the extent of imbalance less than 5°F? If yes, go to D2. If no, go to Q3.

<u>Specification and Implementation Phase for Basic Balancing Service</u>.

D2 Identify steam main line loops servicing the coldest apartments and those servicing the warmest apartments.

A2 <u>Basement</u> actions include: replace faulty main line vents; install larger main line vents on loops servicing colder apartments; insulate these same loops if necessary; install new boiler pressure guage and pressure limit control if necessary.

<u>Apartment</u> actions include: replace/repair faulty radiator vents and valves; increase radiator vent capacity in cold apartments, reduce vent capacity in overheated apartments; use thermostatic inlet valves in overheated apartments (optional); repair radiators and replace missing radiators in cold apartments; tighten envelope in cold apartments.

Management actions include: reducing setpoint of boiler controls to allow a lower average building temperature; establish an ongoing occupant participation program including installing thermometers in each apartment; provide occupants with a building management contact for temperature control problems; train management and maintenance staff and turn over to building owner responsibility for ongoing balancing.

Q3 Is burner controlled by an indoor thermostat? If yes, go to Q4. If no, go to Q3a.

Q3a Does the owner want a programmable indoor thermostat with a single remote sensor or a multi-point averaging indoor thermostat?

A3 Install the desirable replacement boiler control option. Go to D3.

Q4 Does owner want the ability to remotely monitor indoor temperature in one or more locations? If yes, go to Q3a. If no, go to A4.

A4 Change thermostat sensor location if necessary. Go to D3.

D3 Conduct following diagnostic tests: a) pressure versus time profile; b) steam travel time; c) one-week temperature monitoring with min-max or continuous temperature recording in each apartment and in basement; upgrade steam distribution diagram to include location of all risers, radiator capacities, capacity and condition of each main line vent. go to Q5.

Q5 Does pressure versus time curve have characteristic sharp rise? If yes, go to Q6. If no, go to A5.

A5 Examine and correct as necessary the following: distribution system steam leaks, boiler firing rate and efficiency; available total main line and radiator vent area. Go to D3 and repeat it.

Q6 Do all supply loops get steam? If yes, go to Q7. If no, go to A7.

A7 Examine and correct as necessary problems in piping distribution such as improper pitch, dips, blockage. Go to D3 and repeat it.

Q7 Does the shortest and longest steam travel time vary by more than 30% and is the average steam travel time more than 3 minutes? If yes, go to A8. If no, go to A9.

A8 Install larger main line vents on loops with slowest steam travel times. Replace other faulty main line vents.

D4 Repeat steam travel time test. Go to Q7.

A9 Basement action include install insulation on uninsulated loops to cold areas; install new boiler pressure guage and pressure limit control if necessary.

Apartment actions include: replace/repair faulty radiator vents and valves; increase radiator vent capacity in cold apartments, reduce vent capacity in overheated apartments; use thermostatic inlet valves in overheated apartments (optional); repair radiators and replace missing radiators in cold apartments; tighten envelope in cold apartments.

Management actions include: reducing setpoint of boiler controls to allow a lower average building temperature; establish an ongoing occupant participation program including installing thermometers in each apartment and giving occupants a building management contact for temperature control problems; provide O&M training for building management and maintenance staff.

D5 Repeat one-week temperature monitoring with min-max or continuous temperature recording in each apartment and in basement.

D5 (Alternate) Document occupant temperature-related feedback and verify any complaints of overheating for one week. Go to Q8(Alternate).

Q8 Are apartment temperatures reduced to 4°F imbalance? If yes, go to A10. If no, go to A11.

Q8 (Alternate) Are there legitimate complaints of underheating? If yes, go to Q9. If no, go to A1Ø.

A1Ø Adjustment actions include: reduce thermostat setpoint; change apartments used in temperature averaging if necessary. Go to Q8(Alternative).

Q9 Are further corrective actions possible? If yes, proceed to All. If no, go to A12.

All Corrective actions include: up-size radiator vents in cold partments; down-size vent

Q8 (Alternate) Are there legitimate complaints of underheating? If yes,
go to Q9. If no, go to A1Ø.

A1Ø Adjustment actions include: reduce thermostat setpoint; change apartments used in temperature averaging if necessary. Go to Q8(Alternative).

Q9 Are further corrective actions possible? If yes, proceed to All. If no, go to A12.

All Corrective actions include: up-size radiator vents in cold partments; down-size vent the building occupants and maintenance staff provide essential information on: temperature distribution in the building and average building temperature (especially useful during non-heating season audits when temperature measurements are not possible); maintenance needs of the radiators; envelope tightening opportunities; occupant and staff reactions and potential roles in the balancing process. The interviews also provide an opportunity to educate and enlist the support of the occupants and maintenance staff.

Our current practice is to interview the occupants while walking through a sample of two to three apartments with a digital thermometer to document spatial indoor temperature distributions. It is always interesting to compare the occupants' perception of indoor temperature with the measured temperature.

We recommend suplementing the current practice with giving surveys to each of the occupants in the building. These surveys would be analyzed if the owner chose to go with the full balancing service.

Distribution Piping Diagram

We recommend making an accurate distribution piping diagram before any attempts are made to balance the temperature distribution of a single-pipe steam heating system. This drawing should locate the boiler, supply lines, return lines, risers, and main line vents. The manufacturer and size of all vents should be noted as well as the condition of the basement steam distribution piping. The length and number of piping loops should be determined from the drawing. We have developed a convenient notation to associate distribution loops, main line vents, and apartment locations (CNT, 1987). Figure 1 is a sample distribution piping diagram for one of the single pipe steam buildings in our program.

Steam Pressure Profile

This test is done by letting the boiler run continuously until reaching 2 psig, letting it cool for one hour, and then restarting it. Boiler steam guage pressure versus time is recorded in 30 second intervals until the cutout pressure is reached. Figure 2 illustrates such a profile for a boiler with a 3 psig cutout pressure. The pressure-time curve of a properly operating system remains flat for several minutes until steam fills all the main lines in the basement and the main line vents close. The curve rises sharply as steam travels up the risers, fills the radiators, and causes all the radiator vents to close. According to one balancing contractor the heating system is working properly when the boiler pressure is at 1psig when the indoor air thermostat shuts off the boiler (C. Peterson, 1985).

Indoor Temperature Characteristics

There are several parameters useful in characterizing the temperature distribution and balancing opportunities at a given building. Average building temperature, TIBA, is based on measurements of indoor air dry-bulb temperature in each apartment and in the basement areas. The CESF energy audit program projects energy savings due to balancing when there is a reduction in average building temperature. Therefore this is an important parameter. If energy savings is the prime goal we recommend not proceeding with any balancing measures if TIBA is less than 73°F, doing a moderate program if TIBA is less than 76°F, and doing a full balancing service in buildings where TIBA is equal or greater than 76°F.

Minimum building temperature is based on measurements of the average indoor air temperature of the coldest apartment. It is used as an indicator of the comfort level in a building. Minimum temperatures of less than 68 °F are considered an indication of underheating in some part of the building unless the boiler control is clearly on a night setback schedule.

Range is based on measurements of the average difference between the air temperature of the coldest and warmest apartments. This difference is a direct indication of the degree of imbalance in a building. A well balanced building is considered to have an average range of 4 ° F or less. Unbalanced buildings have seasonal average ranges of up to 14°F and hourly averaged ranges as high as 19°F (Katrakis et. al., 1986).

Skewness is a measure of apartment temperature distribution. It is derived by calculating the difference between the building average temperature and the building minimum temperature and dividing this by the range. A skewness less than 0.5 indicates that less than half of the apartments are warmer that the average apartment temperature.

Location of coldest and warmest apartment can be determined by conducting a histogram analysis of the indoor temperature data from each apartment to evaluate the percent of time each apartment is the coldest and the warmest. Current practice during the energy audit field work is to assume that the warmest apartments are next to the boiler and the coldest apartments are at the end of the longest steam main line. Our preliminary review of the temperature data from the eleven buildings in the research project indicates that there often are exceptions to this rule. Locating and treating these apartments is an important part of the balancing process.

As mentioned earlier the current practice during the energy audit is to measure indoor air temperatures at a sample of 2 to 3 apartments using a hand-held digital thermometer. The auditor attempts to visit the coldest and hottest apartments. Our results from the research buildings indicates that these "spot" measurements, even if taken in each apartment, can be used to estimate seasonal average building temperature within +/- $4^{o}F$ and seasonal average range within +/- $7^{o}F$. This precision is barely adequate for evaluating the balancing ECM at specific buildings.

We recommend leaving min/max thermometers in each apartment for one week as part of the balancing implementation process. Our preliminary results indicate that weekly readings from min/max thermometers have approximately the same precision as hourly averaged and weekly averaged values from the DAS at each of the test buildings (Katrakis, 1986).

Ongoing monitoring of indoor temperatures can also become a spinoff from installing a thermostat with multiple remote sensors. There are several devices on the market which allow multi-point temperature averaging to control the boiler while at the same time allow the manager to view apartment temperatures.

Steam Travel Time Plots

Steam travel time measurements have been used to measure the elapsed time from steam first entering the supply line to reaching each main line vent (Peterson, 1984). Cold start versions of the test are done by assuring that the boiler has been off long enough to allow distribution pipe temperatures to approach ambient conditions. Warm start tests are done be letting the boiler run continuously until reaching 2 psig and then allowing it to cool down for one hour.

We have documented at one building that reducing the steam travel times between loops and reducing the average steam travel time of all the loops improves the temperature balance and results in energy savings (Katrakis et. al., 1986). One of the goals of the on-going research in this area is to further develop the steam travel time measurement process to the point where it can eliminate the need to take continuously monitor indoor air temperature. The following two methods are currently used.

Manual Method. Manual steam travel times can be obtained by stationing personnel at each main line vent to record the elapsed time between boiler startup and when steam reaches the vent.

Portable DAS. The DAS at each of the eleven research buildings includes integrated circuit temperature transducers, a 16 channel analog to digital converter, and a 128 kilobyte single drive desk-top microcomputer. Later in the program, a portable data acquisition system was developed by substituting a 32 kilobyte "lap-size" microcomputer for the larger desk-top PC. This battery powered system was designed to record 6 channels at a 15 second sampling rate for up to a 90-minute test. Software was written to analyze data brought back and uploaded to an office microcomputer.

With a computerized data acquisition system available, temperature sensors can be placed on distribution piping to obtain many accurate temperature readings during the entire boiler cycle. Temperature sensors should be placed at the supply header, approximately 10 feet from the boiler and at each return line vent. Placing sensors at different return line orientations are useful for detecting various phenomena. Locating the sensor on the side or underside of the steam lines is good for measuring steam front velocity, for detecting standing water in the return line, or for detecting condensate flow. When the steam front reaches the location of the sensor there is a sharp increase in pipe surface temperature of approximately 50 °F in less than 30-seconds. A sample of steam travel time plots is illustrated in Figure 3.

SURVEY OF BALANCING TREATMENTS

There are a number of treatments which contribute to balancing the temperature distribution in a single-pipe steam building. Successful balancing is only possible when there is a building owner or manager who is a conscientious manager and who is interested in being actively involved in the balancing process. We also feel that it is necessary for the building manager to be able to obtain technical assistance on applying the diagnostic procedures and on selecting and specifying the appropriate balancing treatments. The following methods of correcting imbalances are based on observations obtained from detailed monitoring of single pipe steam buildings in Chicago and discussions with others involved in the balancing of such buildings.

Correcting Distribution System Problems

Distribution piping problems can be responsible for a variety of heating problems in single pipe steam buildings. Typical problems include: missing or inoperative main line and radiator vents; improperly pitched or sagging main lines; undersized boilers. Missing or leaky vents are easily detected if they can be observed throughout the boiler cycle. Indirect evidence of these problems includes moisture on windows, rusty vents and shallow rising pressure/time plots. It is important to eliminate these problems.

Plugged radiator and main line vents, although not as harmful to the system as missing or leaking vents, are a common cause of inadequately heated apartments and are most easily found by a complete walk-thru or occupant survey.

Improperly pitched or sagging main lines can trap condensate from previous steam cycles which prevents the efficient flow of steam to certain risers. They can often be detected by visual inspection during the preparation of the steam piping diagram. Steam travel plots can clearly show cooling or very gradual heating due to the passage of condensate from a previous steam cycle. Steam pressure may be sufficient to push through the condensate, however the steam travel is hindered. The longer and deeper the dip, the greater the volume of residue condensate. In extreme cases, boiler steam pressure may not be sufficient to push the condensate through and therefore certain end risers may not get steam.

It may be that an apparent dip or incorrect slope will have no effect on steam distribution and it may not be worth the expense and risk to correct it. The steam travel plots provide a convenient method to determine the appropriate action.

Main Line Vent Changes

Main line vent changes are the most effective way to equalize the steam travel times between loops of the distribution system. Steam travel time plots can be used to examine the characteristics of various main line vents. Notice the sharp temperature rise of the custom-steam traps (Figure 3) compared to the conventional-medium sized vents in Figure 4. The same two figures demonstrates the ability to equalize and shorten the steam travel times by replacing existing conventional medium-sized vents with the larger custom-steam traps.

Larger main line vents have a desirable effect on system pressure. They usually cause the system to spend more time at a lower average operating pressure and to and yet to reach 1 psig faster. The reason for this is that at low operating pressures less steam is necessary to cause all the radiator vents to shut off. It is likely that at higher pressures, above 1 psig, steam goes up the risers near the boiler and delivers heat to the apartments in these stacks while steam is still traveling through the other parts of the distribution system. Therefore more steam is necessary to fill the entire system and shut off all the radiator vents. Faster pressurization means that the entire system responds more quickly to a call for heat and that the furthest apartments get heat sooner in each cycle and are therefore likely to be more comfortable.

At one building substituting larger main line vents for smaller vents also affects on the indoor temperature parameters. Figure 5 documents how the above parameters vary with outdoor temperature. The large main line vents have two desirable affects; they lower the temperature range and increase the minimum temperature. Surprisingly, the vent substitution had a negligible effect on average building temperature. The larger vents tend to lower TIBA in colder weather and to raise it in warmer weather.

Radiator Vent Changes

Radiator vent treatments have a strong effect on the average temperature of individual apartments. This was documented by noting that a third floor north apartment went from 4 to 6 degrees F below the apartment average to 5 to 6 degrees F above the apartment average by replacing moderate-capacity adjustable vents with large-capacity adjustable vents.

Radiator vent treatments may be particularly important in buildings operating at very low boiler pressures. It appears that in these buildings steam can bypass the risers to some of the radiators unless a proper radiator venting capacity is maintained. If vents in the upper apartments are much larger than in the lower apartments, the steam can actually by-pass the lower apartments and cause the apartments with high venting capacity to heat up more quickly.

Radiator vent treatments consist of placing slower vents on radiators in the overheated apartments and faster vents on radiators in the underheated apartments. Changing radiator vent treatments is a labor intensive task requiring many iterations before proper balance is achieved. Therefore it is best to first apply the best possible main line vent treatments. Then radiator vent replacement should be done gradually beginning with the areas which are most over- or under-heated.

Burner Control Modifications

The indoor air thermostat usually provides better control than a time clock with return line aquastat since the thermostat operates the boiler based on temperatures in the heated space. It also is a convenient instrument for adjusting the average indoor temperature level. A properly balanced building will allow a lower thermostat setpoint than a poorly balanced building. The poorly balanced building requires a higher thermostat setpoint to assure that the cooler apartments maintain a comfortable temperature.

There are several conditions to be met in order for the single thermostat to be an effective boiler control. The thermostat must be installed in the proper location--typically in the consistently coolest apartment throughout the heating season. Typically this is the apartment to which steam travels furthest. In an uninsulated building it would be a third floor apartment. In a building with attic insulation it would be the second or first floor apartment.

The occupants of the thermostat apartment must be sufficiently satisfied with the temperature levels to not have to resort to using stoves or space heaters for auxilliary heating. When this happens it results in underheating of the rest of the apartments. In these situations multi-temperature averaging thermostats appear to be preferable to the single or two-parallel sensor thermostat.

Spot Insulation and Infiltration Reduction

Temperature balance within a building can be improved by envelope measures as well as mechanical methods. The inverse is also true, in that a recently implemented envelope improvement may bring a previously balanced building out of balance. A good example of this is installing attic insulation and noting third floor overheating the next heating season.

Due to differences in heat loads of various rooms and apartments, changing radiator vent treatments may not eliminate cold rooms or apartments. For these apartments that remain cold after radiator vent changes, spot insulation and infiltration reduction should be applied. This is especially important as the average building temperature is reduced down to the threshold of comfort.

PREDICTING ENERGY SAVINGS DUE TO BALANCING

The current savings projections are based on the assumption that each degree reduction in the average building temperature over the heating season results in a 4% decrease in energy used by the space heating system. This value has been corroborated by sensitivity studies done using the building simulation component of the current CESF computerized audit program. It also has been documented by multi-variable regressions of gas usage against inside and outdoor air temperature from several of the eleven test buildings. However the energy savings have been documented at one building due to changes in main line vent treatments without any discernable change in average apartment temperature. Therefore, we have yet to demonstrate the connection between energy savings and change in average building temperature.

FUTURE RESEARCH & DEVELOPMENT NEEDS

There still is sparse data on the effect of various balancing treatments on gas usage and indoor temperature characteristics. The few available results are proof of the concept of balancing. However it has not been repeatedly applied and monitored in a sufficient number of buildings for us to be confident in the current methods of predicting its cost-effectiveness, specifying its application, applying it to buildings. It is especially important to document the effect of outdoor air temperature on the indoor temperature parameters.

The research and diagnostic tools which have been described above will provide the necessary information to answer the following questions. What is the appropriate main line venting capacity for a given building? When is it worth having different capacity main line vents in various parts of trhe distribution piping? Are the custom-modified steam traps worth the extra cost? How should the CESF program monitor the balancing ECM? What is the correct split of responsibilities between the building owner and the balancing contractor? Do we have an adequate model for predicting building specific-performance?

SUMMARY AND CONCLUSIONS

Diagnostic procedures, corrective measures, and a decision tree are being developed for balancing temperature distribution in single-pipe steam buildings. They are useful in obtaining the documentation needed to turn some of the methods developed in a research setting into practical techniques to be used by the energy auditors in the CESF program and by balancing contractors. Feedback from their use in a service mode will likely result in further modifications, additions, and deletions to the procedures.

Continued research and development effort is necessary to establish guidelines for evaluating the contracted balancing work and the owners' efforts to maintain temperature balance in the building, for predicting building-specific performance and for specifying the correct vent treatments at a given building.

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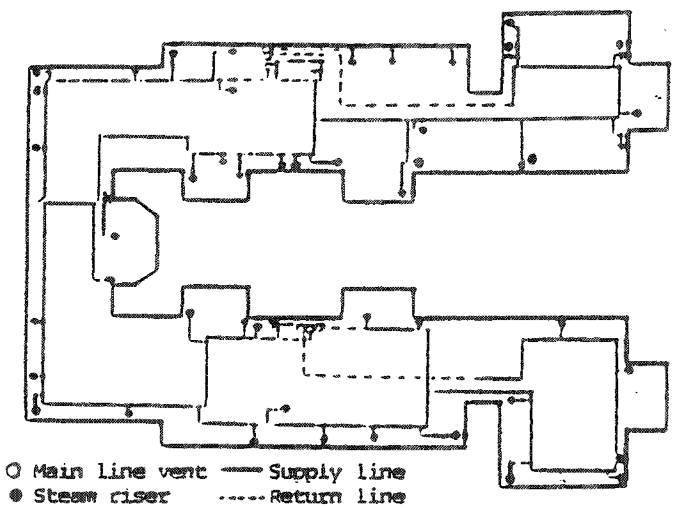

Figure 1. Distribution piping diagram

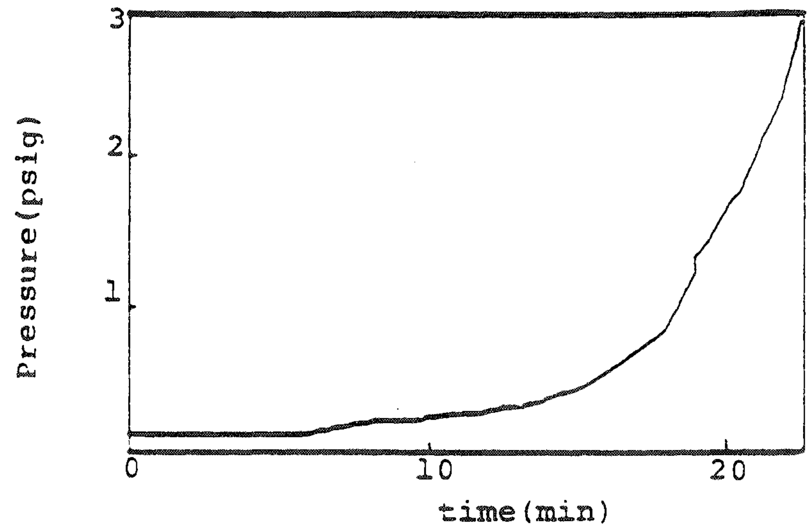

Figure 2. Pressure/time plot

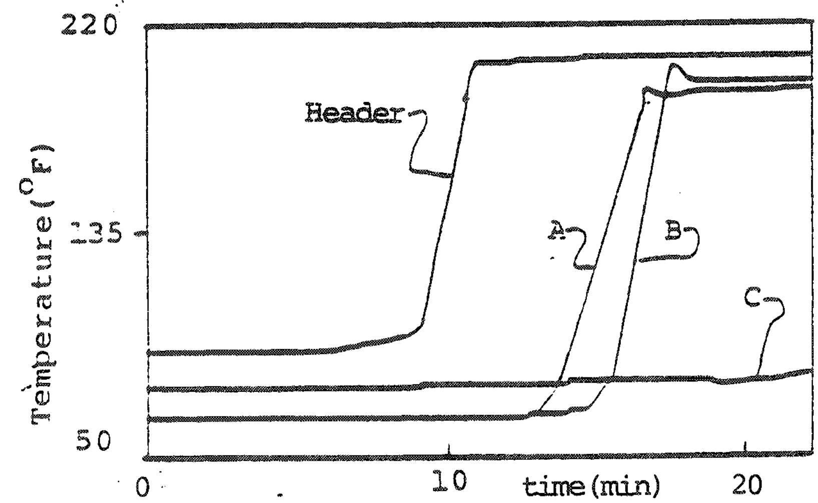

Figure 3. Steam travel time
Moderate sized vents

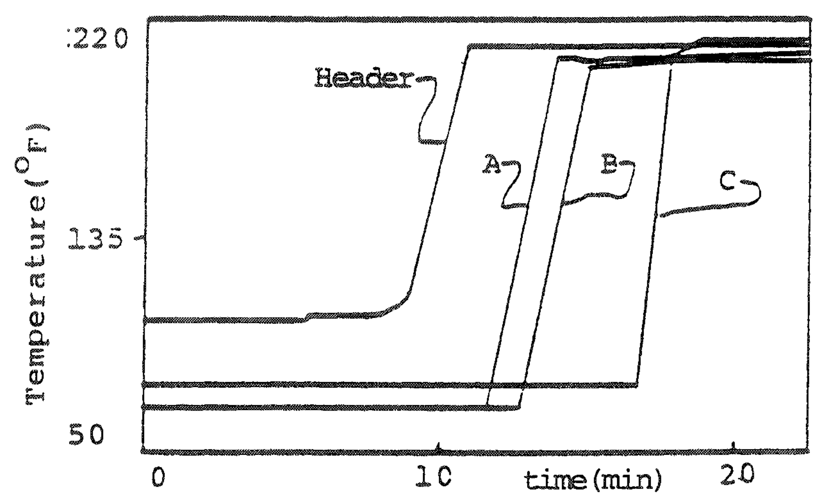

Figure 4. Steam travel time
Custom modified vents

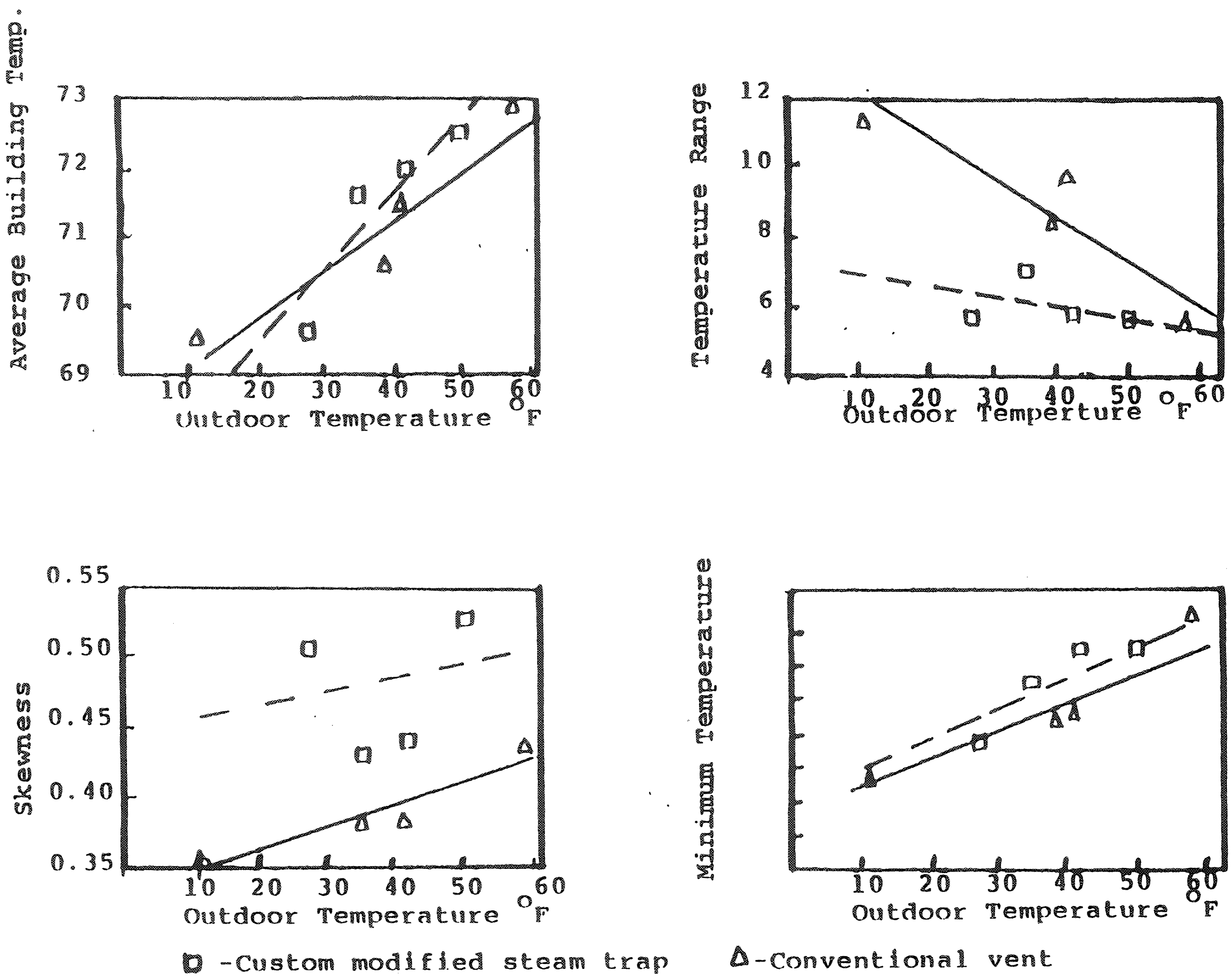

Figure 5. Change in indoor temperature parameters due to main line vent replacement.