Correcting Uneven Heating in Single Pipe Steam Buildings: the Minneapolis Steam Control System

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Abstract

Uneven heating causes serious energy waste in older steam heated apartment buildings, a common problem in Minneapolis. Rebalancing can reduce space heating costs by as much as 15 to 25%. This paper describes the development and operation of the Minneapolis Steam Control System, an integrated control strategy that shows promise for correcting this problem.

Since 1981 the Minneapolis Energy Office has been testing control strategies for single pipe steam (SPS) heating systems. A 14,000 square foot coop apartment building was extensively instrumented to gather information on heating system performance and space temperatures. At the start of the tests, the warmest apartment averaged 74°F with only four of its ten radiators turned on. The coolest apartment averaged 65°F with all ten radiators on. Thirty-five minutes were required to fill the entire system with steam from a typical starting condition, but the average boiler on-time was only eight minutes. Thus the radiators nearest the boiler received steam on every cycle and were nearly always hot, whereas the radiators further away received steam only occasionally.

A new control strategy was developed with the goal of filling the system completely with steam on every boiler cycle. A relay was attached to the boiler circuit to hold it on after the thermostat calls for heat. The boiler is turned off by a sensitive pressuretrol only after the system is full and the pressure starts to rise. With all radiators filling on every cycle, the difference in the steam arrival time becomes unimportant. The rate of heat transfer to the radiator-room system is 4 to 5 times higher when the metal is heating up than when the radiators are already full. Since all radiators now experience the high heat transfer fill period, the additional heat received by the near radiators at lower steady state rates is not enough to unbalance the system. In addition, large main line air vents were installed which cut the maximum difference in steam arrival time in half.

After the addition of the main line air vents and modified steam cycle controller, all apartments now heat to 68°F with all radiators on. The porches at the far end of the building, which previously were cool, are noticeably warmer, and the basement, which had been overheated, dropped 15° in temperature.

The coop residents of the test building had kept areas underheated to reduce energy costs. Rebalancing redistributed heat from overheated to underheated areas rather than reducing the average temperature which would have resulted in fuel savings. In a typical rental building, where controls are adjusted to keep the coolest apartment at 70°F, this control strategy can reduce space heating costs 15 to 25%. The controls cost $500 to $2000 per building, they are commercially available, and they are simple to install and maintain. In Minneapolis buildings the simple payback for these controls would be about 2 years.

CORRECTING UNEVEN HEATING IN SINGLE PIPE STEAM BUILDINGS: THE MINNEAPOLIS STEAM CONTROL SYSTEM

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INTRODUCTION

One third of the dwelling units in Minneapolis are in buildings of 5 or more units. There are basically two styles: steam heated apartment buildings built between 1900 to 1930 and hot water heated buildings built in the 1950-60's. Of the 2864 total buildings, 1655 are steam heated. These buildings provide 29,750 dwelling units, about 19% of the total, and are an important component of the residential housing stock in the City. They are generally well-built and often have beautiful interior woodwork and stately exterior brickwork.

Single pipe steam (SPS) heating systems were the best choice for these buildings when constructed. Only after WWII did reliable electric pumps lead to the hydronic systems standard in modern apartment buildings. The physical condition of the steam heating systems in most cases is quite good. The distribution systems are intact and in most the original boilers are still operating, having been converted from coal to gas. SPS systems were designed for long life with low maintenance but not for energy efficiency.

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 radiators, see Figure 1. 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 radiator, 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, it turns the boiler off. As each radiator cools the air vent opens, allowing air to re-enter the system.

A major and almost universal cause of energy waste in these 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^{o}F, Figure 2. Higher temperatures cause much greater conduction heat loss through the walls and roof, and of course windows opened to relieve the overheating incur severe infiltration losses. In Minneapolis the cost of higher internal temperatures is generally estimated as 3% of space heating costs per 1^{o}F. An apartment building in which the hottest apartment is overheated 14^{o}F and the building as a whole averages 7^{o}F too hot will cost 21% more to heat than one that is well controlled. This amounts to over $2000 on the $10,000 heating fuel bill for a typical 32-unit apartment building. Figure 1 illustrates how the uneven heating raises the average temperature and therefore also the cost of heating.

In June 1981 the Minneapolis Energy Office began the development of an energy conservation program for multi-family buildings under a HUD Innovative Grant. A literature search was done and numerous manufacturers and heating contractors were contacted to determine the state of the art. While problem areas were fairly obvious, the techniques for solving them and the estimates of potential resulting savings were not generally agreed upon. A number of the products on the market to address the problem of uneven heating in steam buildings were installed on two apartment buildings, but performed poorly.

The poor performance of these installations, the lack of other research on the issue, and the general lack of agreement in the industry indicated the need for a more extensive testing project to support the multi-family conservation program. This project was begun in the summer of 1982, with extensive data collection beginning in March 1983. During the remainder of that heating season the normal operation of the system and the effect of main line air vents on steam distribution were investigated.

Following completion of the preliminary work a concerted effort was made during the winter of 83-84 to develop a solution to the problem. The increased knowledge of system operation led to development of a new control strategy, the Minneapolis Steam Control System (Mpls SPS). This system was installed, tested successfully and shows promise as an effective and inexpensive solution to the problem. This paper describes the strategy, discusses the engineering basis for its effects, and reports our test findings to date.

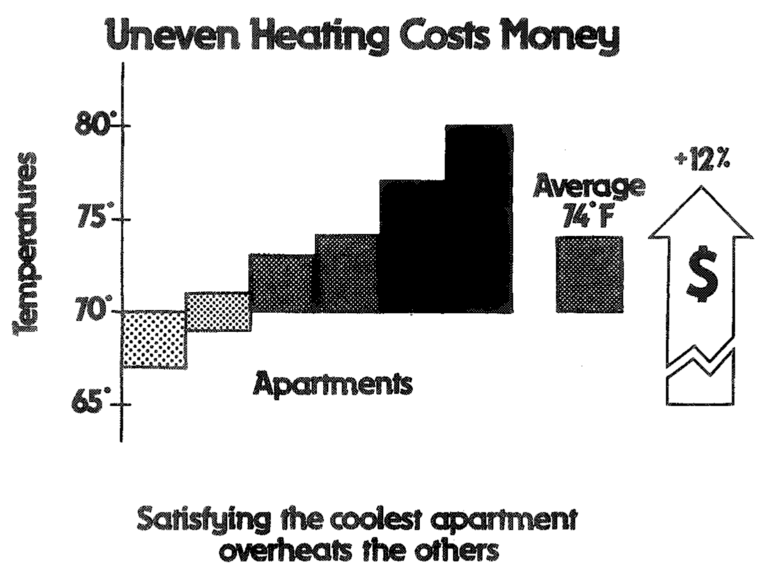
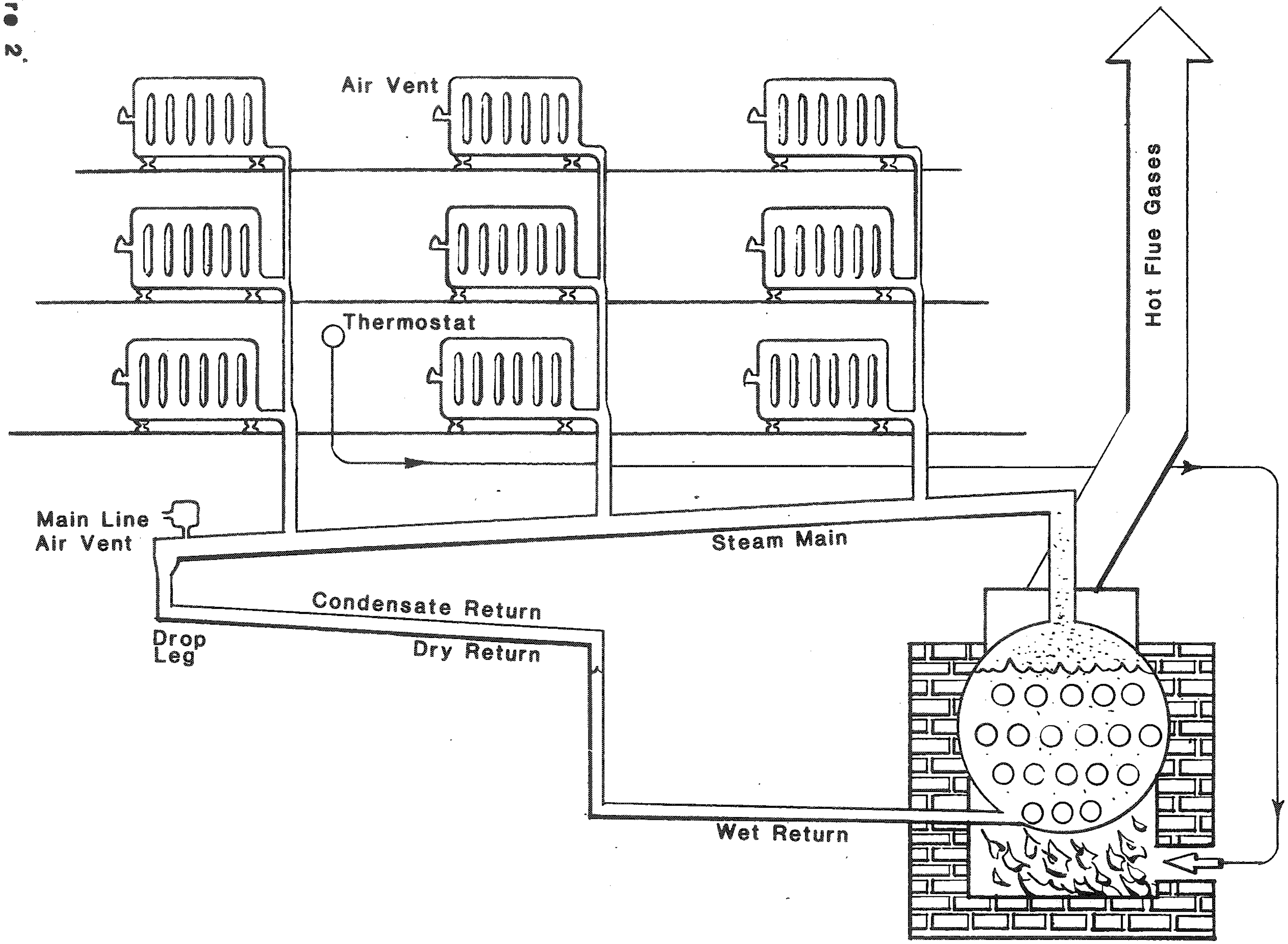


Figure 1

Figure 2

Schematic of Single Pipe Steam System



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TEST SITE

The main test site was the Bryant Ave. Coop, a three story 14,000 square foot cooperatively owned apartment building in south Minneapolis. Several factors made the building an ideal test site. The occupants owned the building, paid the heat bill, and they were very interested in the tests, helpful, and pleasant to work with. There are only seven units but these are large, about 2000 square feet each so that the physical size of the building and heating system are similar to a moderately large building.

The Bryant Avenue building was built in 1910. The original brickset firetube boiler is still in place and has been converted to gas with a 1.3 x 10^6 Btuh input. Figure 3 shows a plan view of the basement distribution piping with the take-offs for the risers that feed the radiators on the upper three floors. An important feature is the exterior rear stairwell which necessitates that the north distribution main loop back making it significantly longer than the south main. Each riser serves one, two or three radiators which has been labeled for identification.

TEST DESIGN

Devices and Control Strategies Tested

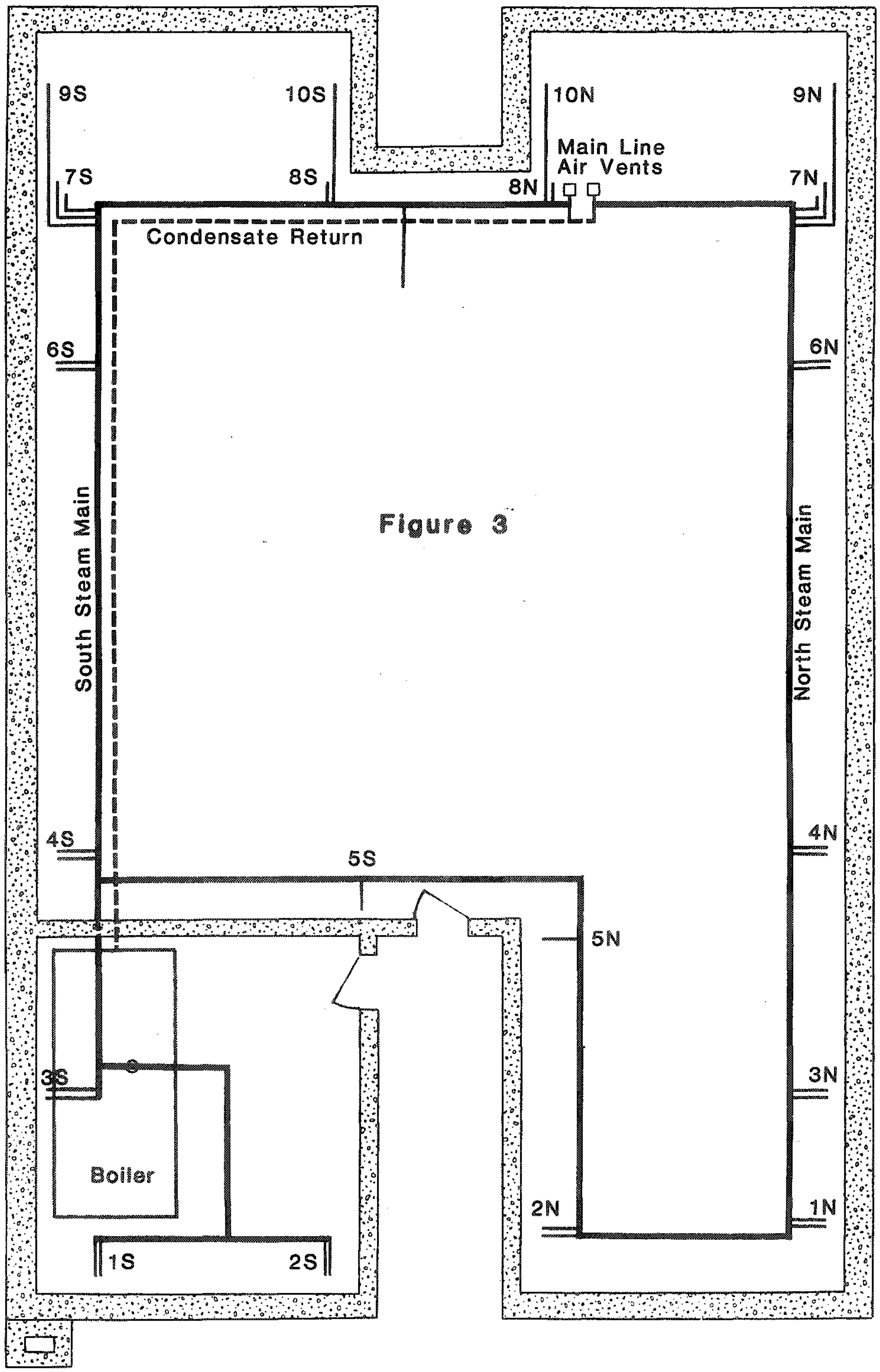
The ultimate objective of the research project is to provide uniform space temperatures in all of the apartments, and to do it with the lowest possible energy use and equipment costs. The devices and control strategies under investigation are listed in Table I. When feasible the various modifications made to achieve this have been installed in ways that allow them to be tested individually or in any combination.

Table I. Modifications.

	Testing Year		
	82-83	83-84	84-85
Control of Radiators			
Main line air vents*	x	x	
Variable air vents	x	x	
Thermostatic radiator vents*		x	x
Thermostatic inlet valves*		x	x
Control of Boiler Cycle			
Heat anticipator adjustment*	x		x
Conventional steam cycle controller		x	x
Mpls cycle controller*		x	x
Other Conservation Strategies			
Boiler tune up	x		
Reducing Off-cycle losses			x
Vent damper			x
Boiler replacement			x
Boiler input/sizing*			x

* Part of the Minneapolis Steam Control System

Basement Distribution Piping in Test Building



METHODOLOGY

Data Collected

To determine the effectiveness of each of the modifications, the gas consumption and system performance were monitored intensively.

Gas Consumption. The fixed firing rate boiler was submetered to distinguish heating consumption from cooking and hot water use, and the boiler run time was recorded 1-2 times per week.

Cycling. The number of on/off cycles of the boiler were recorded. Together with boiler run times this gives an indication of the average cycle length. Cycle length can be very important in a steam system, where it takes quite some time for the steam to reach the furthest radiators.

Temperatures. Space temperatures for each apartment were automatically recorded every hour, as was the outside temperature.

Physical Parameters. Various physical parameters such as the input, steady state efficiency, and water mass of the boiler; size, surface area, and mass of the radiators were measured or calculated.

Equipment. A computerized data logger was used to read all sensors, and the information was transferred onto data tape cassettes. Type T thermocouples were used for temperature measurement. The six main apartment space temperatures and outside temperature were read with thermistors.

Experiment Design

To compare system performance between various control strategies a standard set of test runs was developed.

Cold Run. A cold run was used to measure steam delivery times and distribution patterns. To initialize the run, the system was turned off for 4-6 hours and allowed to cool down. The boiler was then turned on and allowed to operate continuously until the entire system was filled with steam and at steady state conditions. Next the boiler was shut off again and the system allowed to cool down. Thus both heat-up and cool-down were from known starting states. Every 45 seconds the temperatures at 16-26 locations along the piping system and at certain radiators were recorded along with the pressure within the boiler.

Warm Run. A warm run was used to monitor the normal operation of the system without interference. In addition to the information gathered for the cold run, data was collected on the operation of the thermostat and on/off operation of the burner. The data are collected every 1 to 3.75 minutes and a run lasted up to 30 hours.

Radiator Run. A radiator run was used to investigate the steam fill pattern within individual radiators. The temperatures at 10 locations on a single radiator were continuously monitored during the fill and cool down parts of a cycle.

THE PROBLEM OF UNEVEN HEATING

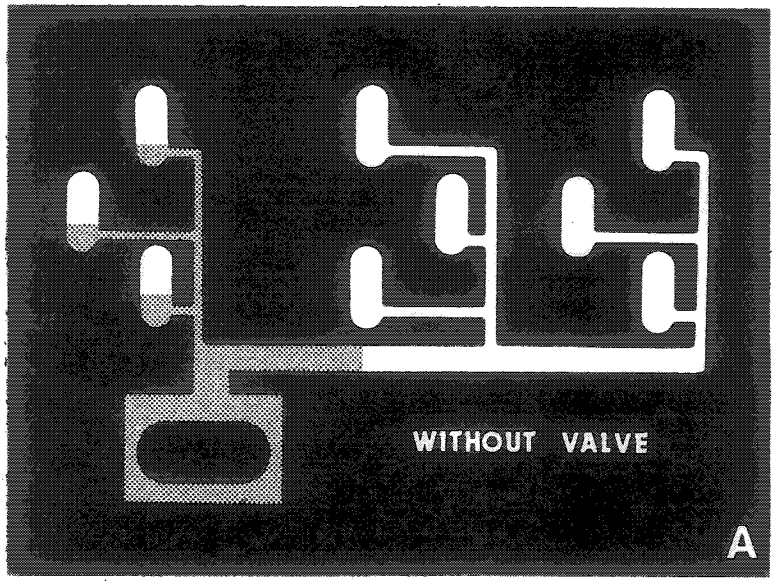
In the simplest terms, the major cause of uneven heating is that the boiler provides more heat to some radiators than to others. This happens for several reasons.

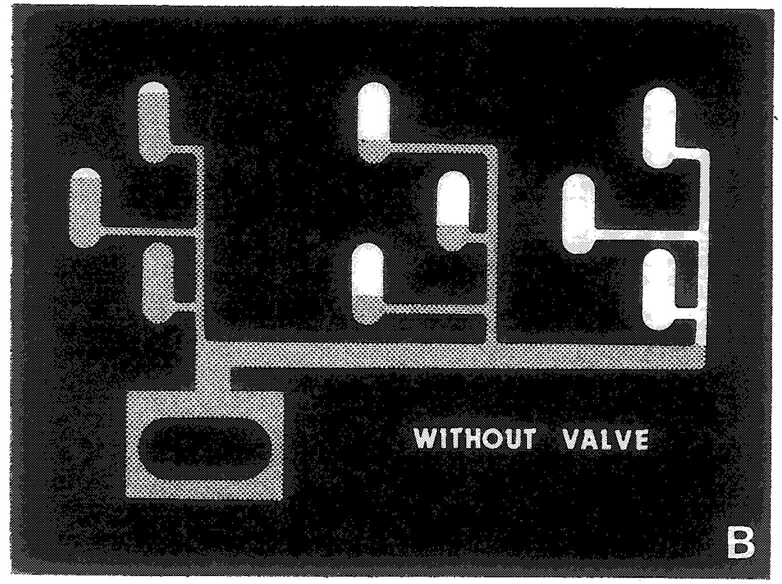
Large Differences in Steam Arrival Times

At the beginning of a boiler firing cycle the piping system and radiators are filled with air and are quite cool. The steam that the boiler produces must heat a large mass of piping and push the air out of the air vents. As a result, steam moves through the system very slowly. The further a radiator is in piping distance from the boiler, the longer it takes for the steam to reach it. At the test building the furthest radiators received steam 15 to 25 minutes later than the nearest ones. After steam reaches any radiator, the radiator takes another 10 to 20 minutes to fill completely and warm up. So the total time needed to completely fill the system is on the order of 30 to 45 minutes. Figure 4 illustrates the pattern of steam distribution during the fill cycle based on distance to the boiler.

Excessively Short Boiler Cycles

The location and operation of a typical thermostat combine to cause boiler cycles too short to fill the entire system with steam. Thus the near radiators receive steam on every cycle, but the far radiators only receive steam every few cycles, and some may never receive steam. If the thermostat is in an apartment close to the boiler, the heat given off by the radiators will satisfy the thermostat too quickly to allow the whole building to get steam. If the thermostat is in one of the further cooler apartments, as is typically the case, it will cause short cycles for a different reason. Internal to most thermostats is a "heat anticipator". Its intended function is to heat the thermostat sensing element slightly with an electric resistor. The thermostat then is satisfied and turns off the burner before the room air actually gets to the desired temperature, allowing the space to coast up from residual heat in the heat exchanger without overshooting the set point temperature. Heat anticipators are designed for and work well with forced air heating systems in single family homes where heat is distributed rapidly, but they do not meet the needs of a steam heated building. There is a significant amount of energy in a hot steam radiator for a long period of time after the burner shuts off. If the heat anticipator is eliminated or adjusted to a low setting, the residual heat in the radiators after the burner shuts off, will cause the space temperatures to overshoot. But if the heat anticipator is adjusted higher, the heat it produces alone will warm up the thermostat and satisfy it before any steam reaches the far apartments. The correct anticipator adjustment depends on the rate of steam delivery throughout the system. This varies with how warm the distribution system is at the start of the cycle, which is a function of the time since the last cycle and therefore the outside temperature. Thus a single heat anticipator setting will only work for a given outside weather condition.





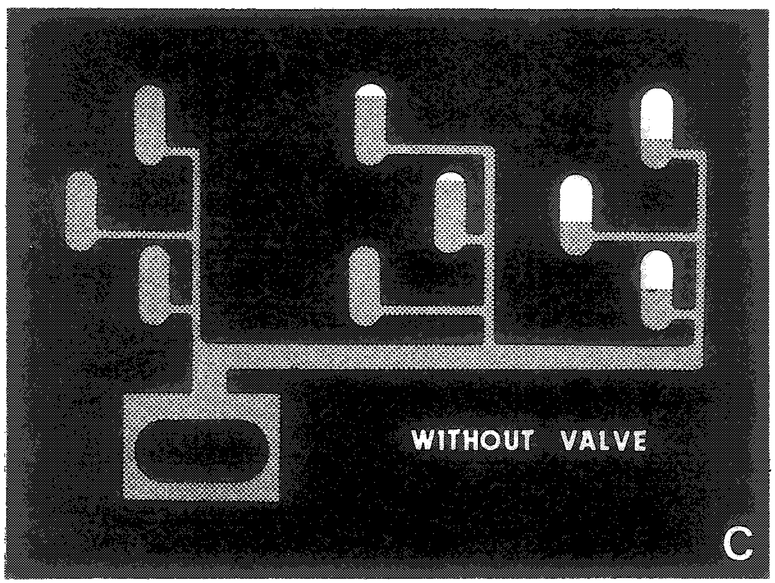


Figure 4

Steam Fill Pattern Without Main Line Air Vents

Without a main line air vents steam fills the closest radiators much faster than those further away. This can cause uneven heating, particularly if the boiler shuts off before the whole system is full.

At the test building, before modification, the thermostat would call for heat according to ambient temperature but the anticipator would cause the boiler to cycle off before steam reached all of the radiators. Figure 5 shows boiler operation and temperatures at three positions along the distribution system (basement piping close to the boiler, near radiator, and far radiator) over a 4½ hour period starting in the morning after night setback. The first time the burner cycled on, it fired for six minutes. A small

Boiler Cycling and Steam Delivery

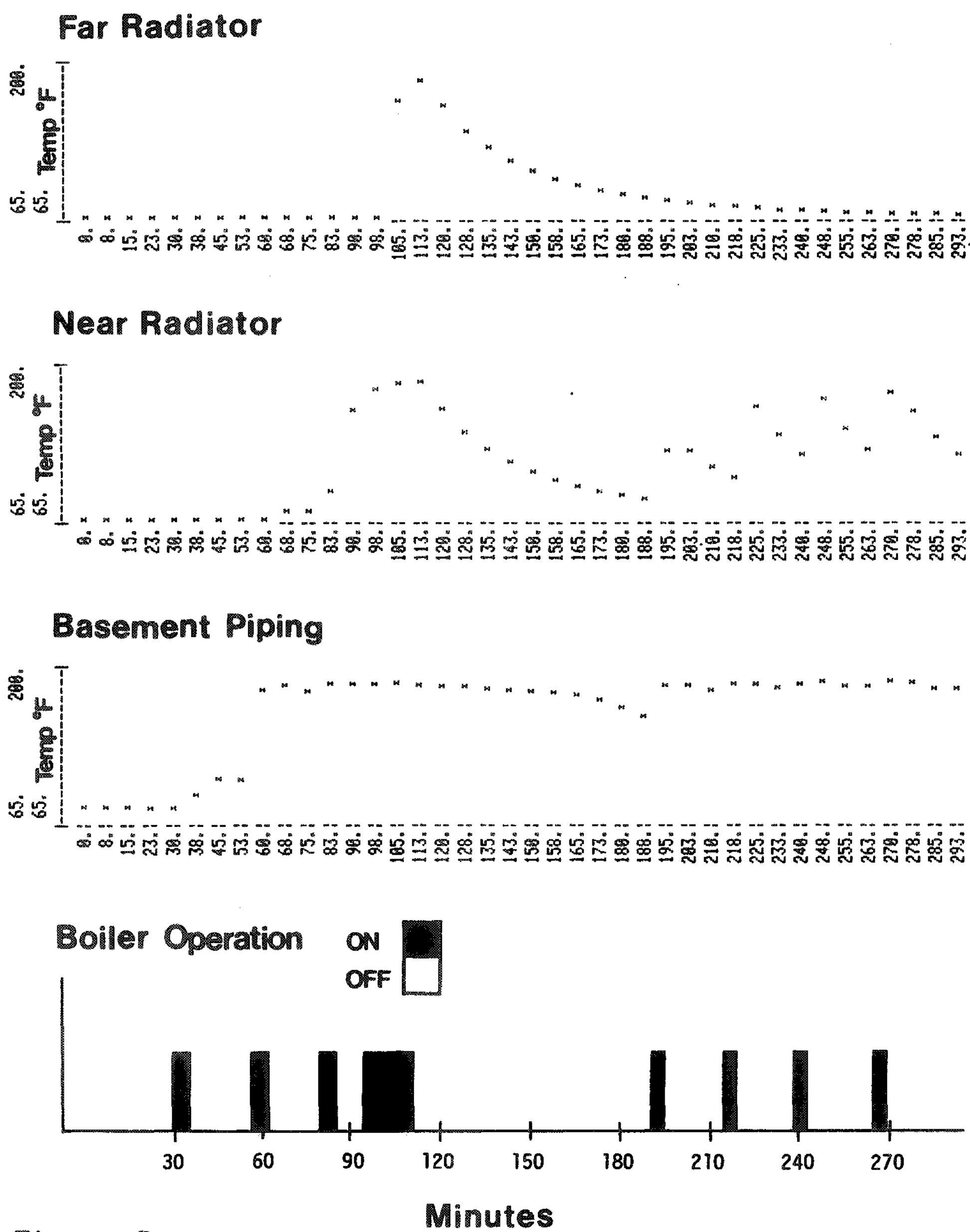


Figure 5

amount of steam was produced which began to heat up the distribution system. A few very close radiators may have been warmed, but the near radiator that was monitored was not. The thermostat, located near the far radiator, was not warmed at all by the steam, but was cycled off by the heat anticipator. The following burner-on cycles immediately sent steam into the basement distribution system, which stayed warm from then on; some steam reached the near radiator, but the far radiator remained cold. On the third cycle the near radiator began to fill with steam, but the far radiator remained cold. Only on the fourth cycle did the far radiator receive steam, warming the space around the thermostat sufficiently for the thermostat to cycle the boiler off for 1¼ hours. But once the building cooled down sufficiently for the thermostat to again call for heat, the same inefficient heating pattern was repeated. Figure 5 illustrates the difference in heat output due to radiator location which is a major cause of uneven heating.

Lack of Zone Control

Unlike hydronically-heated buildings, steam heated buildings generally have no mechanism for shutting off the supply of heat to an apartment that is already satisfied while other, cooler apartments continue to receive heat. Every apartment continues to get heat until the single thermostat for the building is satisfied.

Building and System Design

Building characteristics frequently aggravate an uneven heating problem. Often one steam main is much longer than the other, making that side of the building harder to heat. And apartments on the top floor, already suffering from heating problems due to their distance from the boiler, also suffer higher heat losses if the attic is uninsulated. Finally, depending on their heat loss, apartments may have too many or too few radiators.

ANATOMY OF A STEAM CYCLE

A major component of the Minneapolis Steam Control System is a set of controls that keeps the burner on until just after all of the radiators have completely filled with steam. To better understand uneven heating and the solution to it, a closer look at the steam cycle is necessary. The large heat capacity of the distribution system delays the tranfer of heat to the room air. When the burner turns on, most of the heat output goes into turning the water into steam and some goes into the boiler metal and brick. The steam moves into the distribution system, displaces the air and begins to heat up the metal of the distribution piping and radiators. As the metal warms up, heat is then transferred to the surrounding air. The time required to fill the distribution system is controlled by the mass and temperature of the metal in the system, the rate of heat output by the boiler, the rate of heat transfer from the distribution system surfaces to the surrounding air and any back pressure caused by venting of air from the system.

The piping and radiators in the test building have a total mass of 14,000 lbs. Two hundred and twenty-eight thousand Btu's of heat are needed to raise this much metal from 70°F to 212°F. The boiler's useful output is 1.024×10^6 Btuh. Thus even if all of the boiler's output were going into the metal, it would take 13.4 minutes for the entire distribution system to get hot.

Based on cold run tests, we learned that it took an average of 32 minutes to fill the system at the test site completely from a cold start. A careful accounting of the distribution of the energy output during a 32 minute cycle is presented in Table II and Figure 6. It verfies that at the end of the cycle, 42% of the energy produced is still held in the distribution piping and radiator metal. This suggests that a steam system takes a long time to fill because of its large heat capacity, not because of slow venting of air, as is sometimes believed. This is a critical insight in the design of a successful control strategy.

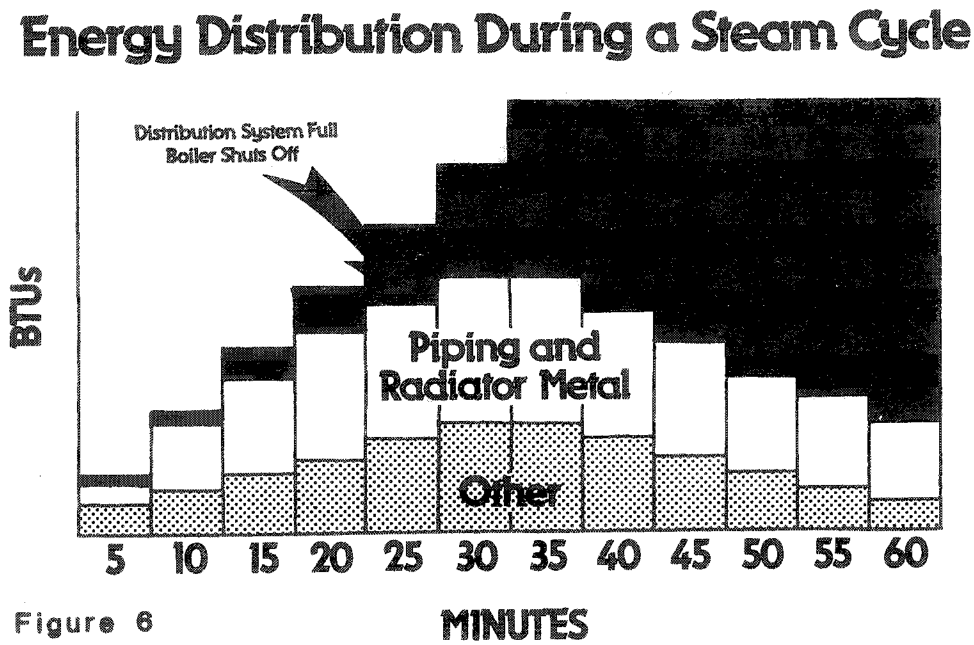


Figure 6

Table II Energy Balance During a Steam Cycle

(based on a 32 minute boiler on-time)

Component	Btu's in 1000's	Percent
Convective heat output of the distribution system	171.2	31.4
Heat capacity of the distribution system	227.9	41.7
Residual steam within the distribution system	21.4	3.9
Heat capacity of the condensate water	58.3	10.7
Unaccounted (boiler brick and miscellaneous)	67.2	12.3
Total	546.0	100.0

Pressure During the Steam Cycle

Further verification that the determinant of the steam system fill rate is its heat capacity, rather than the slow venting of air, comes from observing the system's pressure characteristics. Measurements at this building and a number of others show that SPS systems operate at very low pressures, commonly less than one half psig, see Figure 7. When the boiler cycle starts, the steam produced begins to displace the air, filling the system. A fairly sharp steam front of about two feet in linear pipe distance is produced. As the steam contacts the relatively cool pipes it rapidly condenses. The boiler continues to produce new steam which is used to heat up new sections of the distribution system and to maintain the temperature of the sections which are already hot as they transfer heat to the surrounding space. The proportion of heat being convected away increases as the system fills. The steam front travels slowly because of the distribution system's large heat capacity. The holes in the air vents readily release the displaced air. The only pressure developed is the pressure necessary to send the steam traveling down the pipes and to overcome a little resistance at the air vents. The pressure during the fill cycle is only 3-7 inches of water, or 1/10 to 1/4 psig. When a radiator fills completely with steam, the air vent on it closes. As more of the distribution system fills the steam must be pushed further and there are fewer vents open to release air, so the pressure begins to rise. When only a few radiators are still releasing air, the advancing steam front is very concentrated. More air venting back pressure begins to develop and the pressure rises faster. When the last air vent shuts, the piping becomes a closed system and pressurizes rapidly as the boiler continues to produce steam. In the test building the system was completely full before the pressure reached 1/2 psig. Thus back pressure is not the reason the system fills so slowly. This characteristic pressure curve is useful in designing a control strategy.

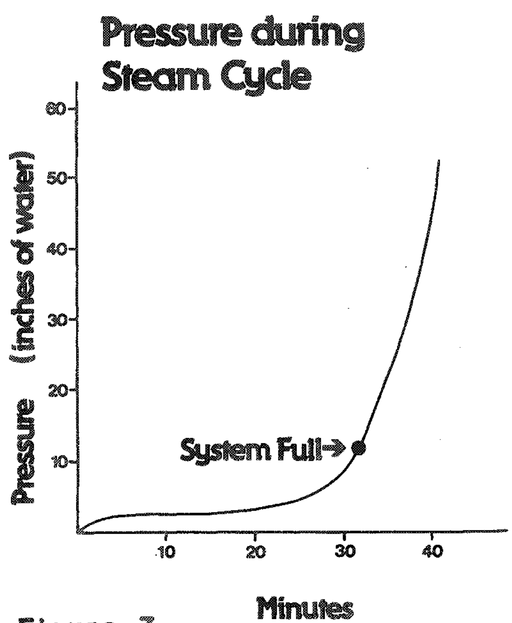


Figure 7

Individual Radiator Heat Output and the Effect of Cycle Length

A final element in understanding the operation of the steam system is understanding the pattern of heat output by individual radiators over time. When steam first reaches a radiator, it is condensed by the cool metal as rapidly as it can be supplied by the boiler. Once the radiator itself is hot and the air vent has closed, steam enters much more slowly, only rapidly enough to replace the steam that condenses as heat is transferred from the radiator to the room. Figure 8 graphs the instantaneous and cumulative heat transfer to an individual radiator. The rate of heat transfer to each radiator is very high when steam first reaches it, and much lower once it has become hot. The difference in rates can be 3 or 5 to 1.

All of the heat transferred to a radiator's metal eventually ends up in the surrounding room air. The room and radiator can be considered as one unit for analysis. Figure 9 shows the total cumulative heat output for two radiators that receive steam at different times, and the difference between their outputs. The difference in output has four phases:

1. Before the second radiator receives any steam - the difference increases rapidly and is equal to the output of radiator #1.
2. While both radiators are warming up - the difference remains constant and is equal to the output of #1's head start.
3. After the first radiator is full, but the second is still warming up - the difference decreases rapidly. Radiator #2 has rapid heat transfer while #1 is at the lower steady state rate.
4. Once both radiators are hot - a small difference remains, equal to the length of radiator #1's head start times the low steady state heat transfer rate.

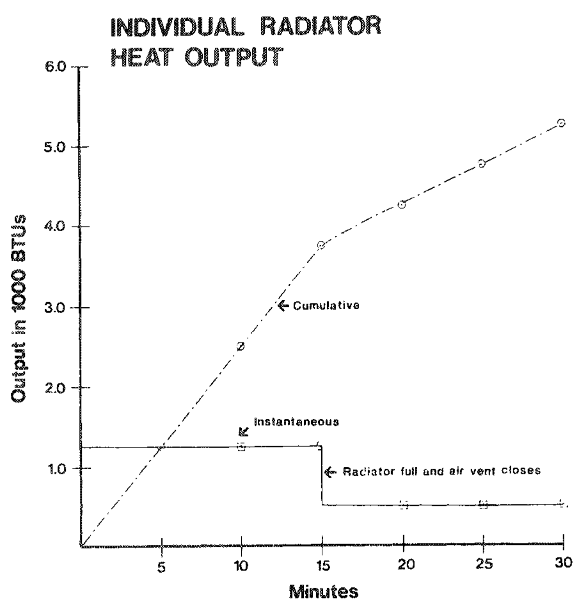


Figure 8

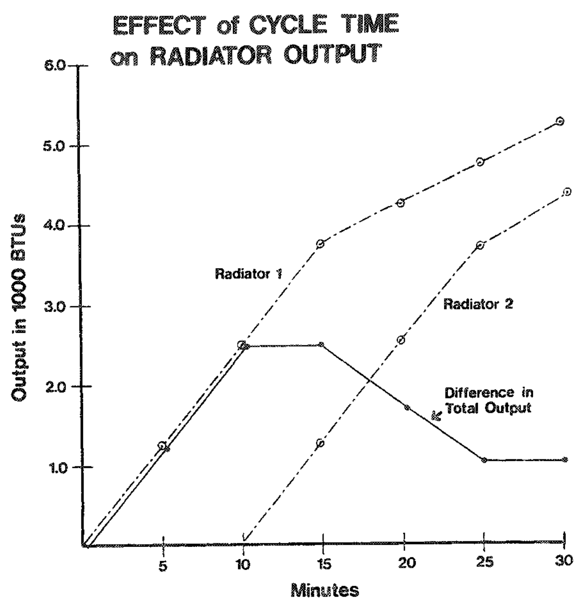


Figure 9

The short boiler cycles common in steam systems shut the boiler off during phase 1 or 2, maximizing the difference in total heat output between near and far radiators. However, in a long cycle, all radiators experience the high fill heat transfer period. The near radiators do have steam longer, but the extra time is at the much lower heat transfer rate that occurs the radiators are full. The Mpls SCS shuts the boiler off at the start of phase 4, the minimum cycle length to achieve the minimum difference in heat output.

A SOLUTION: THE MINNEAPOLIS STEAM CONTROL SYSTEM

To deal with the problem of uneven heating, the Minneapolis Steam Control System was developed. This is an integrated control system for SPS heating systems which applies existing devices in an innovative way to achieve even, controllable space temperatures. The five major components of the system are: thermostat, thermostat holding relay, controlling pressuretrol, main line air vents, and thermostatic radiator valves; all of which are commercially available, easy to install, and require little maintenance. These components work by:

1. Controlling the boiler so that all radiators completely fill with steam each boiler cycle.
2. Reducing the difference in steam arrival time between radiators.
3. Providing more individual space temperature control.

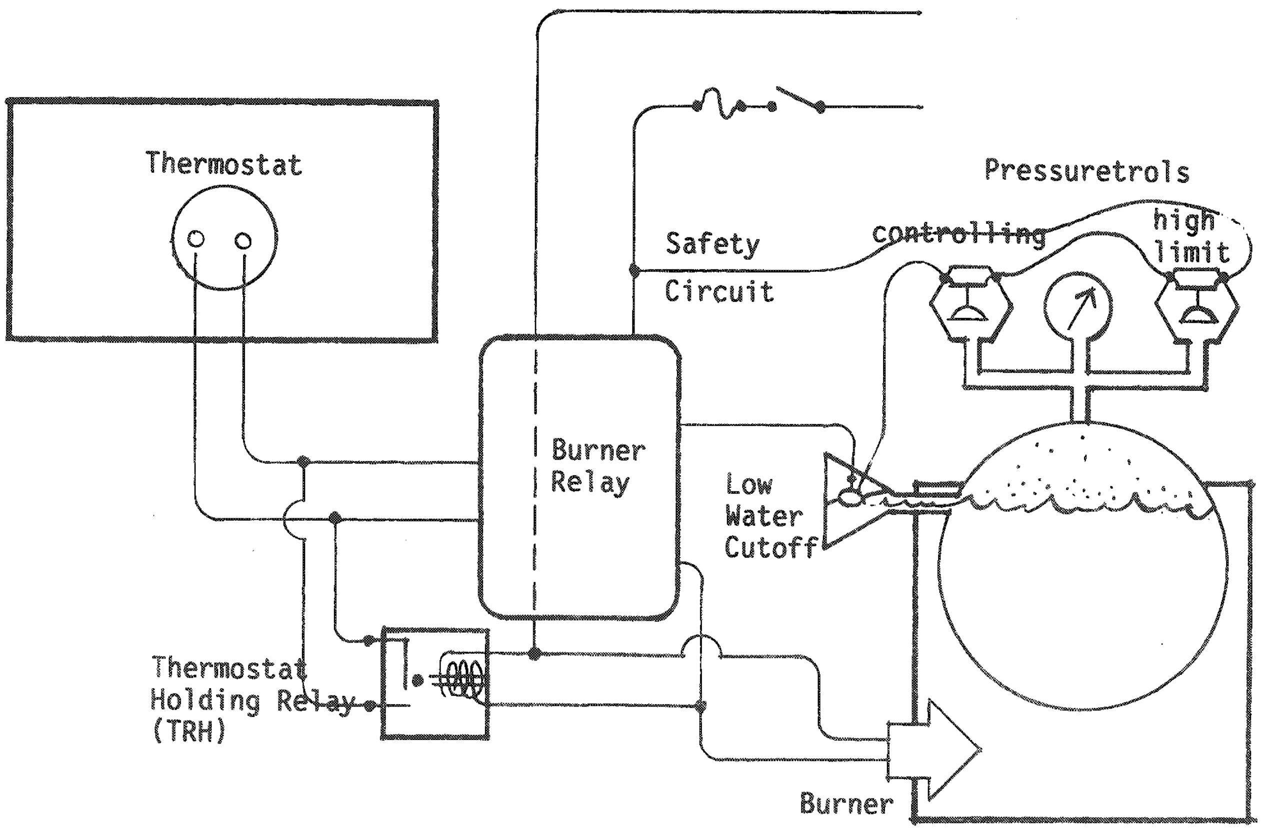
<u>Control of the Steam Cycle</u>: <u>Controlling Pressuretrol and Holding Relay</u>

In the Mpls SCS a thermostat holding relay and controlling pressuretrol work together to control the steam cycle so that it is exactly long enough to completely fill all of the distribution piping and radiators each cycle. With short cycling, near radiators are filled every cycle, but far radiators are filled only every few cycles, if ever. By forcing the boiler to stay on until every radiator is full, this problem is eliminated. Though at first it might appear that such long boiler cycles would still overheat the near apartments, since they get steam longer than the far apartments do, because the rate of heat transfer to a radiator is much lower once it is hot, the additional time that the near radiators receive heat does not account for a great deal of additional heat output.

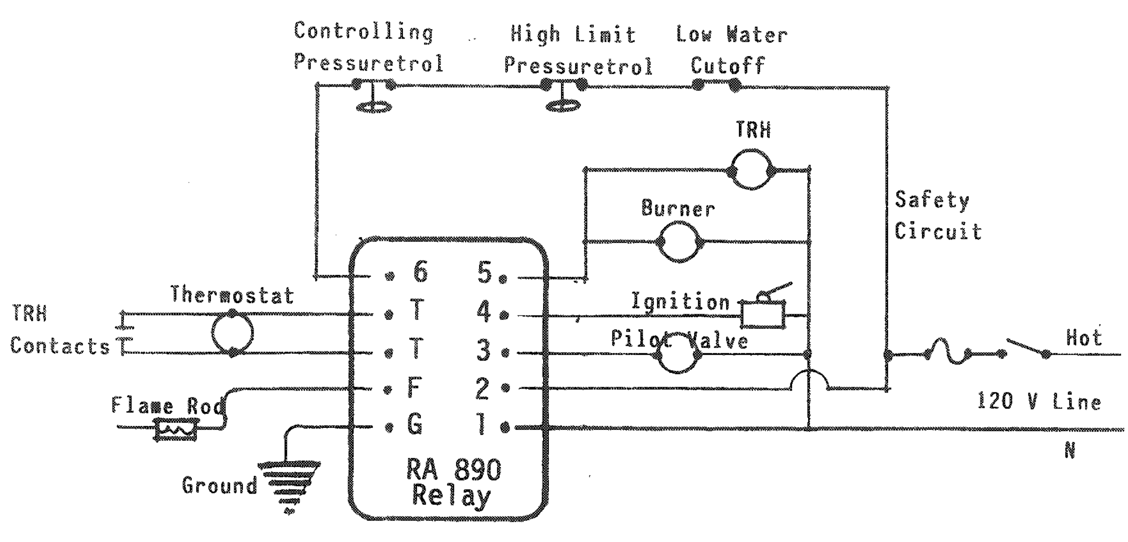
The operation of the holding relay and pressuretrol is not complex. The thermostat, burner relay and burner are wired the same as in a conventional system, see Figure 10. When the thermostat calls for heat, it energizes the burner relay, which fires the burner. In the Mpls SCS the coil side of the holding relay is wired into the burner circuit, so the holding relay is energized along with the burner. The contacts of the holding relay are in parallel with the thermostat. Once the thermostat energizes the burner and holding relay coil, the holding relay contacts are closed, completing the thermostat circuit. Thus even if the thermostat contacts are opened by ambient temperature or the heat anticipator, the holding relay continues to keep the burner on. The boiler is in effect locked on until something in the "safety circuit" causes it to shut off. A very sensitive controlling pressure-

Figure 10

Wiring Diagram



Details for connection to a RA 890 Relay common on coal to gas conversion burners.



trol is installed in the safety circuit. When the entire system has filled with steam and the pressure rises, the pressuretrol shuts off the burner and allows the holding relay to open. The boiler then stays off until the thermostat calls for heat again. It is easy to determine the pressure at which the system is full for any given building by having one person monitor the pressure while another follows the steam front through the building to the last radiator to receive steam. With this control system, each cycle exactly and completely fills all radiators.

In a given system, the only variable on which the fill time depends is the starting temperature of the distribution system. The fill time in the test building varied from 10 to 60 minutes. More time was required in warm weather because the long off times allowed the system to cool down to room temperature while during cold weather the cycles were more frequent and the system, still being warm, filled quickly. By establishing system pressure, rather than time or a heat anticipator, or the critical parameter, the burner always shuts off when the system is completely full.

While the controlling pressuretrol setting should be measured as closely as possible, there is room for error. If the set point pressure is set a little high, the run will only be a little longer than necessary, because pressure increases quite rapidly once the system is full. If the set point pressure is set a little low, the residual steam will finish filling the last radiator.

An alternative strategy used by at least one manufacturer is for the thermostat holding relay to be released when a heat sensor installed on the last radiator detects steam.

Reducing the Difference in Steam Arrival Time: Main Line Air Vents

The pressuretrol and holding relay minimize the difference in total output between radiators that receive steam at different times, main line air vents minimize the time difference itself. Although there is very little back pressure during the fill part of a boiler cycle, there is some, and these vents lower it enough to preferentially enhance the flow of steam down the main distribution pipes at the expense of flow up into the close radiators. The far radiators receive steam more quickly than before, and the close radiators receive steam more slowly.

The main line air vents in the Minneapolis SCS are large thermostatic steam traps installed on the main distribution lines in the basement after the last riser and before the dry return drops into the wet return. The valve is open until heated by steam, at which point it quickly closes preventing steam from escaping through it. Many buildings already have main line vents from the original installation, but they typically have small openings and often are clogged and inoperative. The vents used are available for about $75 ($125 to $200 installed, depending on whether they replace existing vents or require a new tap into the main). The Mpls SCS uses steam traps with a 1/2" diameter orifice for venting compared to 1/8" for conventional main line vents. The free area of these traps represents 1/3 to

1/2 of the total venting area in the system.

Several cold runs were done to test the effects of main line air vents. The main line air vents reduced the steam arrival time from 4.5 to 3 minutes at the end of the south main and from 9.75 to 6.0 minutes at the end of the north side, see Figures 11 and 12. The difference in steam arrival times between near and far radiators was reduced, see Table III. The occupants of the cooler apartments also reported improved heating after the vents were installed. Figure 13 illustrates the pattern of steam distribution within the system with the MLAV installed. The pattern is more even with than without them which can be seen by referring back to Figure 4.

Table III Effect of Main Line Air Vents on Steam Arrival Times

RADIATOR				ARRIVAL TIMES (minutes)		
Distance	S/N Main	Floor	Radiator* ID	w/o MLAV	w/ MLAV	Difference
Near	South	2	S6	3.6	5.7	+2.1
Near	South	2	S2	5.3	7.5	+2.2
Medium	South	3	S8	7.8	7.2	- .6
Far	North	2	N6	12.1	9.5	-2.6
Far	North	3	N7	19.5	13.5	-6.0

*see figure 3

Providing Individual Space Temperature Control: Thermostatic Radiator Valves

Normally there will still be some temperature variation between apartments after the pressuretrol, holding relay, and MLV components of the Mpls SCS are installed. The differences are due to radiator sizing and such time-dependent variables as solar gain, internal gains, infiltration, and wind conditions. To compensate for this, the building can be divided into a number of different zones, each with some degree of separate thermostatic control. There are several methods for accomplishing this. In the Mpls SCS thermostatic radiator vents (TRV) are installed on about 20% of the radiators. 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.

TRV's works 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 TRV's 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.

Thermostatic air vents do have some limitations. If the apartment is below the desired temperature when the boiler turns on, the vent will be open, allowing steam to enter. It has no way to shut off the flow of steam

South Run Without And With Main Line Air Vents

Furthest point of the South Run trunk line, shows the steam delivery time cut from 4.5 to 3.0 minutes.

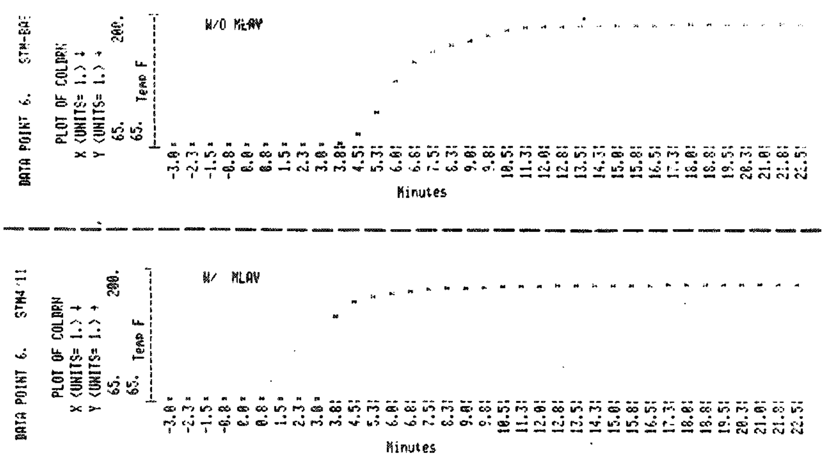


Figure 12

North Run Without and With Main Line Air Vents

Furthest point on the North Run trunk line, shows the steam delivery time cut from 9.75 to 6.0 minutes, and the shape of the steam front is clearly less diffuse.

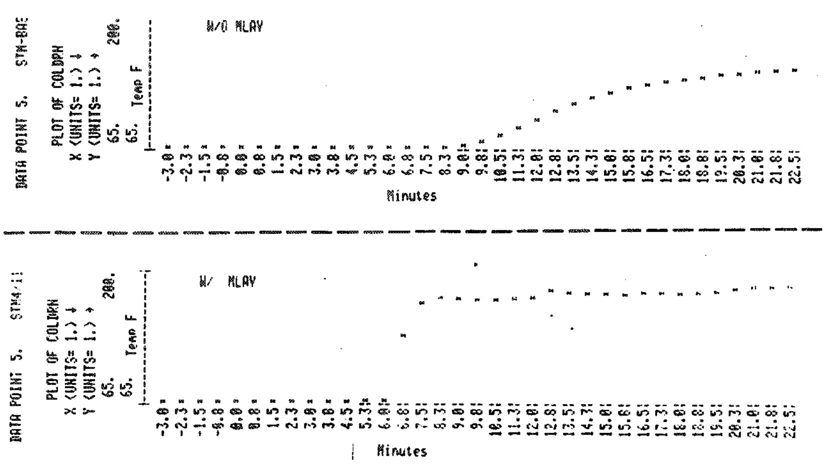
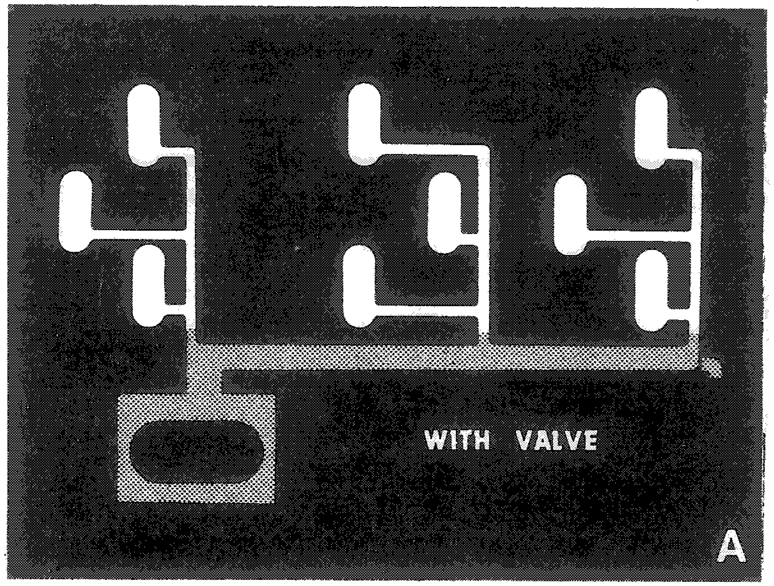
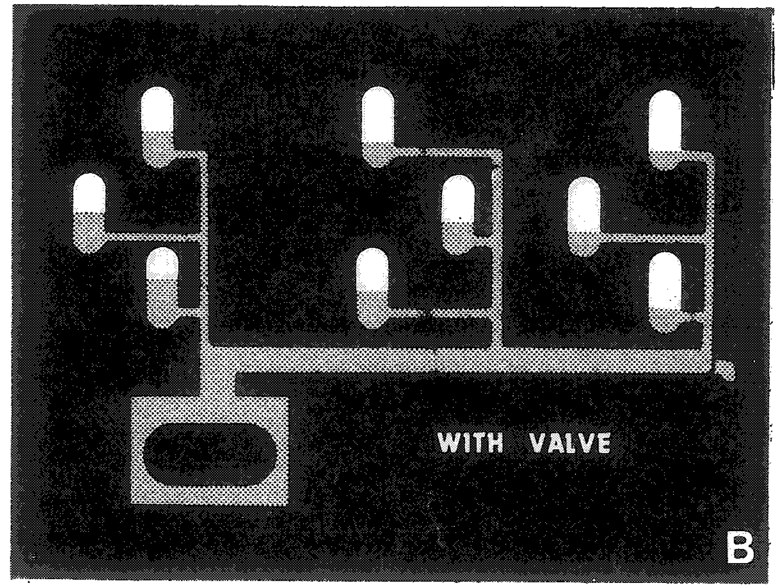


Figure 11





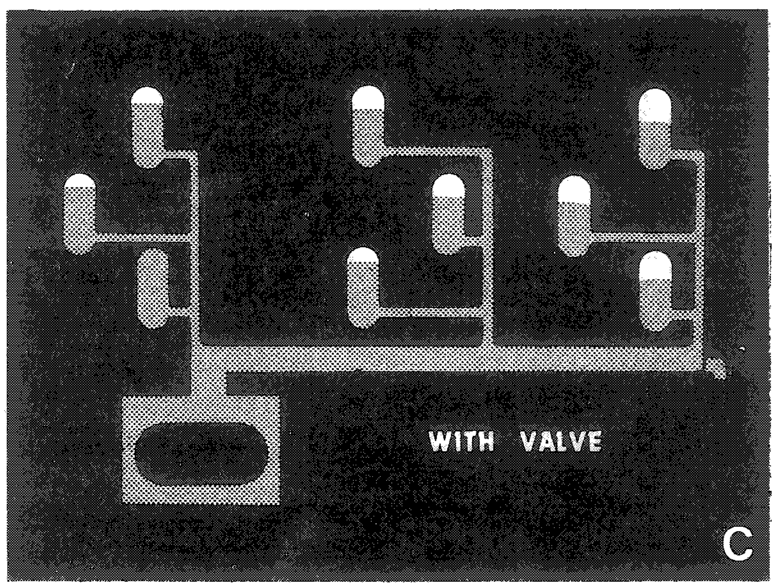


Figure 13

Steam Fill Pattern With Main Line Air Vents

With a main line air vent steam fills the main distribution loop rapidly which delays its delivery to the close radiators. Steam then begins to fill the radiator in a more even pattern.

if the desired temperature is reached in the middle of the cycle, so if the boiler cycle is too long, the apartment can overshoot the desired temperature. Note also that unlike a thermostat, a thermostatic vent cannot turn on the boiler when the apartment needs heat. It merely opens, and must rely on the steam cycle controller or central thermostat to turn the boiler on at appropriate intervals.

Basic thermostatic vents cost about $35 each. They can be installed by a contractor or maintenance personnel for about $20 each. More elaborate vents with remote temperature sensors may work better in some cases and cost up to $85 each. Placing vents only on the radiators in the areas that overheat is generally a good first step, with more vents added as necessary. When a single room has two radiators, putting a thermostatic vent on one is frequently sufficient.

Testing of TRV's is incomplete, but preliminary tests indicate that they work well as a zone control for SPS systems.

EFFECTS ON SPACE TEMPERATURE AND FUEL CONSUMPTION

The main result of the research to date is nearly complete elimination of uneven heating in the test building. At the start of the tests the warmest apartment averaged 72°F to 74°F with only four out of it's ten radiators turned on. The coolest apartment averaged 65°F with all ten radiators on. After the addition of the main line air vents and modified steam cycle controller, pressuretrol and holding relay, all apartments now heat to 68°F with all radiators on. The porches at the far end of the building, which previously were cool, are noticeably warmer, and the basement, which had been overheated by short bursts of steam down the mains, dropped 15°F in temperature.

Energy savings are expected from lowering the average temperature of a building. Since the residents of the test building had chosen to allow the two coolest apartments to underheat in order to keep their fuel bills down, rebalancing the building resulted in redistributing heat from overheated to underheated areas rather than lowering the average temperature. Analysis of the fuel data shows no change after installation of the Mpls SCS. Considering the increased comfort, this is a successful result. In a typical rental building, the coolest apartment is kept comfortable, forcing many others to be overheated. Rebalancing then allows the average temperature to be dropped. Lowering the average building temperature 5°F will subtract about 15% from the annual space heating bill.

A pilot implementation project is now underway with the goal of installing the Mpls SCS in 50 buildings for the 84-85 heating season, measuring the effect on fuel consumption, and evaluating the effects on heating system performance in a variety of buildings.

COMPARISON OF THE MINNEAPOLIS STEAM CYCLE SYSTEM WITH CONVENTIONAL CONTROL SYSTEMS

The Minneapolis Steam Control System differs significantly from regular thermostats and conventional steam cycle controllers. A conventional steam cycle controller varies the on-time of the burner proportional to the outside temperature. In milder weather with an SPS system the on-times are too short, resulting in uneven heating.

There are numerous advantages to the Mpls SCS when compared with a conventional steam cycle controller.

1) To accomplish the same task, a conventional controller and TRV's costs much more than a Mpls SCS. If TRV'S are installed on all of the radiators in a building, balanced heating can be achieved with almost any control system, including a conventional steam cycle controller. But a conventional steam cycle controller costs about $2000 installed. There are about 100 radiators in a typical 32-unit building; at $45 each the TRV will cost $4500 bringing the total to $6500. In contrast, the Mpls SCS would only cost about $2000.

2) With the Mpls SCS, control of the boiler cycle is easier since it is referenced to the temperature over which control is desired, the interior space temperature, rather than to the outside temperature.

3) It is easier to achieve a night setback with the Mpls SCS, the system is simply triggered by a setback type thermostat. A conventional controller relies a great deal on TRV's to balance the temperature, which would have to be reset to achieve setback.

4) The Mpls SCS minimizes room temperature swings by turning the boiler off as soon as steam has filled all of the radiators.

5) The Mpls SCS maintains a low total system pressure, even during very long boiler runs, thereby keeping maintenance costs low. Small leaks that would have to be repaired at 5 psig are not noticeable at 0.5 psig. Even somewhat major cracks can be safely ignored until the heating season is over and it is convenient to fix them.

6) The Mpls SCS is easy to service and maintain. All of the necessary equipment is simple, off-the-shelf items with which all heating contractors are familiar. The way they are hooked up, while innovative, is straightforward and easy to comprehend. Installation, maintenance, and repairs are simple, infrequent and inexpensive.

ECONOMICS

The economics of the Mpls SCS are expected to be good in most buildings. As illustrated in Figure 14, lowering the average building temperature will result in a cost savings of about 3% per 1^{o}F reduction. For a typical 32-unit building the installed cost of the Mpls SCS should be:

Relay and pressuretrol;	$ 350	
Main line air vents;	$ 300	($100 each)
Thermostatic Radiator Valves;	$1600	(one per apt. @ $50 each)
Total;	$2250	

The annual space heating bill would be about $10,000. If the system reduced the average apartment temperature by $5^{o}F$ and the basement temperature by $10^{o}F$ the savings would be about 15% and 5% respectively for a total of 20% or $2,000. This would give a payback of a little over one heating season. The actual payback period will depend on:

- The degree of overheating originally present
- The degree of underheating originally present
- warming up underheated spaces reduces fuel savings but this increase in tenant comfort costs less with the Mpls SCS
- Cost of the Mpls SCS for a particular building
- Special application problems
- Factors such as fuel cost (interruptible or firm gas) and weather

For buildings with moderate to severe overheating problems the payback should be 2 years or less.

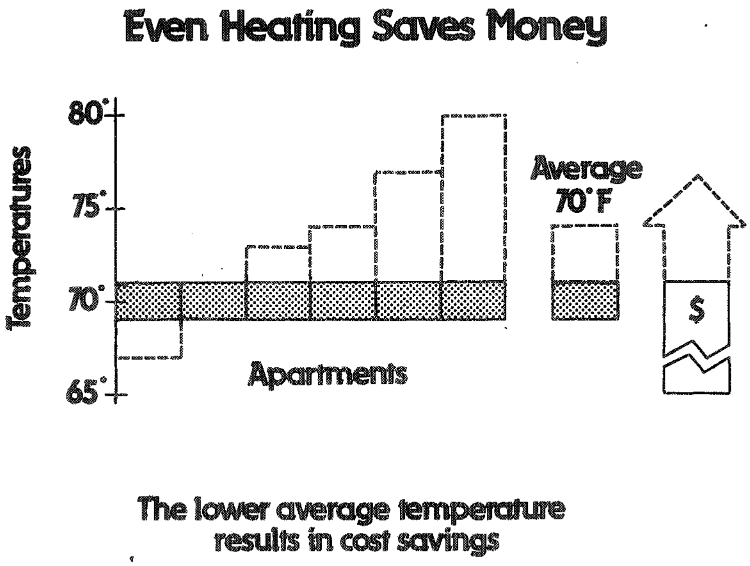


Figure 14

FUTURE DEVELOPMENT

In addition to the installation and evaluation of the Mpls SCS under the major pilot project, plans also call for continued research and development of the system components and testing of various devices that may be useful in special circumstances. This section briefly discusses some of the main item being considered for testing.

Thermostat

The ideal thermostat for many applications is a multiple point, remote sensing thermostat with an automatic setback. The device should remotely sense the space temperature in 3 to 5 apartments and close the thermostat contacts when 2 or 3 of the apartments are at or below the setpoint temperature, so that a cycle is not triggered if only a small area needs heat. The device itself can be located in the boiler room, making it highly tamperproof. While several prospects exist, as yet none have been tested and shown to meet the ideal specs.

Thermostatic Inlet Valves

In a brick set boiler during the burner firing a great deal of heat is absorbed by the interior brick work. When the burner shuts off, the residual heat in the bricks continues to slowly steam some of the water, and it rises up into the near distribution piping and radiators keeping them hot. This after-steaming lasts as long as two hours. Thermostatic air vents are not effective in this situation since control on the inlet side is needed, therefore a thermostatic inlet valve must be used.

Variable Air Vents

Variable air vents are essentially the same as a standard air vents, except that it is possible to adjust the size of the air hole. In theory the vent controls the rate at which air is released from the radiator, and by adjusting those near the boiler to allow air to escape slowly, it may be possible to further reduce differences in steam arrival time. However, testing of variable air vents has so far shown no significant effects on steam delivery time. A series of more sensitive experiments is planned to measure possible VAV effects.

Basement Apartment Temperature

One of the most dramatic effects, and potentially a source of significant fuel savings, is the lowering of the heat loss from the distribution system to the basement. However, for many basement apartments the distribution piping is also their main source of heat. If the radiation is marginal to begin with, the reduced output may lower the temperature unacceptably. This was the case in the test building. An additional radiator will be added and a system to increase the ouput from the basement radiators will be tested in the 84-85 season.

Radiator Sizing

The radiators in the test building were sized evenly for the heat loss from each room. That is, all the radiators were oversized to the same degree. The Mpls SCS changes the average overall heat ouput from a radiator from being based largely on how close it is to the boiler to being based on its physical mass. With proper radiator sizing this will produce good results. Methods to deal with improper sizing will be tested next year.