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Measure Guideline: Steam System Balancing and Tuning for Multifamily Residential Buildings

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Partnership for Advanced Residential Retrofit

April 2013

Building America
U.S. Department of Energy

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Prepared for:
The National Renewable Energy Laboratory
On behalf of the U.S. Department of Energy's Building America Program
Office of Energy Efficiency and Renewable Energy
15013 Denver West Parkway
Golden, CO 80401
NREL Contract No. DE-AC36-08GO28308

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Prepared under Subcontract No. KNDJ-0-40346-00

April 2013

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Unless otherwise indicated, all figures were created by the Partnership for Advanced Residential Retrofits.

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Definitions

Btu	British thermal unit
CNT	Center for Neighborhood Technology
EUI	Energy use intensity
HDD	Heating degree day
NBP	Near boiler piping
TRV	Thermostatic radiator valve

Executive Summary

This guideline intends to put some context and structure around the process of balancing and tuning one-pipe steam systems to help practitioners begin to garner the potential in energy savings that this measure presents.

This guideline was written as a resource for professionals involved in multifamily audits, retrofit delivery, and program design, as well as for building owners and contractors. It is a guide for those looking to evaluate and improve the efficiency and operation of one-pipe steam systems.

In centrally heated multifamily buildings with steam or hydronic systems, the cost of heat for tenants is typically absorbed into the owner's operating costs. Highly variable and rising energy costs have placed a heavy burden on owners. In the absence of well-designed and relevant efficiency efforts, increased operating costs would be passed on to tenants who often cannot afford them. Misinvestment is a common problem with older heating systems—multiple contractors may inadequately or inappropriately upgrade parts of systems and reduce system functionality and efficiency, or the system has not been properly maintained. The primary reasons for the lack of proper investment in the steam-heated multifamily building stock are:

- Deferral of maintenance in the absence of capital funds
- Lack of knowledge about steam systems
- Lack of properly trained superintendent or maintenance staff
- Misdiagnosis of problems in steam systems.

System balancing and tuning can often be a very cost-effective energy saving opportunity. However, building owners are often not aware of it and contractors do not commonly offer it. The associated comfort improvements, utility cost savings, and contractor methodologies are thus rarely taken advantage of in the marketplace.

Progression Summary

Measure: Steam Balancing

This chart presents a simplified step-by-step guide to steam balancing.

Do Not Proceed if:

- Temperatures in the building are balanced
- Steam system is in such disrepair that it requires substantial rehabilitation
- Asbestos material is found on fittings and pipe runs
- Unsafe conditions that would be hazardous to the audit staff, contractors, or residents are found

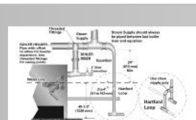
WALKTHROUGH

1 **Conduct initial system assessment:** Conduct a walkthrough inspection and interview maintenance staff and tenants to identify significant issues with the heating system.

IN DEPTH ANALYSIS

2 **Diagnose system:** Conduct an in-depth analysis of the piping layout, temperature distribution, boiler controls, venting condition and capacity, boiler cycle, and other parameters.

INSTALL MEASURE



3 **Finalize the project scope with the contractor and complete the work.**

QUALITY ASSURANCE

4 **Inspect the installed work to ensure quality and completeness.**

MEASUREMENT AND VERIFICATION

GAS ACCOUNT DETAIL

Service ID #: 3048629005
Rate Schedule: G1 S Residential Service
Billing Days: 32 days

Serial	Meter #	Prior Meter Read	Current Meter Read
W	60605161	1,051	1,083

5 **Examine utility bills following steam balancing to measure the efficacy of the installed work.**

1 Introduction

Old steam systems in multifamily residential buildings often suffer from significant temperature gradients, with differences between units reaching up to 15°F. As a result, some tenants complain of being too hot and others too cold. Providing a balanced building, where heat reaches all the apartments in a timely fashion, minimizes wasted heating fuel and is therefore an opportunity for cost savings. Additionally, a balanced building improves tenant comfort. Katrakis et al. (2010) reported energy savings of 5%-10% with a payback of 0-2 years for installing larger main line air vents and savings of 3-5% with a payback of 0-3 years for utilizing control systems to reduce boiler short-cycling. Peterson (1985) reported that balancing a steam heated building can reduce space heating costs by as much as 15%-25%.

This measure guideline provides building owners, professionals involved in multifamily audits, and contractors insights for improving the balance and tuning of steam systems. It provides readers an overview of one-pipe steam heating systems, guidelines for evaluating steam systems, typical costs and savings, and guidelines for ensuring quality installations. It also directs readers to additional resources for details not included here. Measures for balancing a distribution system that are covered include replacing main line vents and upgrading radiator vents. Also included is a discussion on upgrading boiler controls and the importance of tuning the settings on new or existing boiler controls. The guideline focuses on one-pipe steam systems, though many of the assessment methods can be generalized to two-pipe steam systems.

2 Decision-Making Criteria

2.1 Uneven Heat

A building can initially be considered a good candidate for steam balancing if the manager or tenants report uneven heating. Figure 1 shows a brick three-story walk-up courtyard building with a steam system that was in need of balancing, as evidenced by reports from the owner about uneven temperatures. Some tenants complained of being too cold; others opened their windows in the winter.

Figure 1: Typical brick three-story walk-up in Chicago. This building type commonly has a steam system and can be out of balance.

(used with permission from CNT Energy 2011)

The first important step in a steam balancing project is to conduct a comprehensive assessment of the building. The inspector should complete an assessment report, such as the one in Appendix A. More guidelines on this assessment are found in Section 3.

2.2 Existing Boiler Condition

The boiler condition and information about its regular maintenance should be assessed both from information collected during the site visit and by a steam heating contractor, in tandem with the decision about whether balancing the building will be cost effective and beneficial to tenant comfort. If the boiler is in poor condition and slated for replacement, the balancing work should not be attempted until after the boiler is replaced.

Building owners should also confirm the return piping does not leak, especially in buried returns. This can be done by installing a water meter on the boiler feed water make-up line and monitoring the amounts of fresh water that are introduced to the boiler each week. Supplying large amounts of fresh, oxygenated water to a boiler will drastically shorten its lifetime.

Figure 2 shows a cast-iron sectional steam boiler in good working condition. Though cast-iron sectional boilers are largely used in steam systems today and are therefore the focus of this guideline, firetube boilers are also sometimes used to produce steam.

Balancing a system can often be less cost prohibitive than replacing an entire heating system. Though hot water systems and individual forced-air furnaces can have higher rated efficiencies, the initial investment (and inevitable follow-up costs) of overhauling an entire system can be cost prohibitive. Table 1 summarizes typical costs found for each of the following measures for the Chicago region: (1) adding and/or replacing the main line air vents, (2) replacing the radiator vents, (3) upgrading or adjusting the boiler control system. The average cost of a heating system replacement would, by comparison, be much higher.

Figure 2. A cast-iron sectional steam boiler in good working condition in a building that could benefit from balancing

(used with permission from CNT Energy 2011)

Table 1. Average Costs for Common Steam Balancing Measures

Measure	Average Cost ($)
Adding or Replacing Main Line Air Vents	1,800
Replacing Radiator Vents	3,680
Upgrading Boiler Controls to System With Hard-Wired Indoor Sensors and an Outdoor Sensor	5,060

Note: Appendix B provides a detailed cost breakdown of measures implemented by CNT Energy in a Partnership for Advanced Residential Retrofits Building America study on steam system balancing in Chicago between December 2011 and January 2012. Costs are based on contractor bids for 10 buildings with 15–30 units and include labor and materials.

2.3 Building Owner and Tenant Cooperation

Regular communication with tenants and maintenance staff (both to ensure minimal tampering with the temperature data and for ready access to the apartments) is crucial to the success of a project. Biederman and Katrakis (1986) noted that ensuring tenant awareness in advance of and during a steam balancing project increases its success and facilitates a smoother process.

Access to units and tenant cooperation are required for collecting information about radiators and for replacing vents. Building managers should give tenants notice before each visit and letters explaining the upgrade project (a sample of which can be seen in Appendix C) should be distributed. It is helpful for tenants and building owners to understand the potential comfort benefits that will result from their cooperation, so this should be emphasized in these communications. These are important steps to take in any balancing project.

Some balancing work might be done by a building's maintenance staff. As long as the proper steps are taken to determine sizing for radiator vents (see Section 3.1.6), these vents can be replaced in-house. This enables owners to avoid the extra work and potential costs involved in coordinating between their tenants and a contractor.

3 Technical Description

3.1 Assessment of One-Pipe Steam Heating Systems: What To Look For

After a building in need of balancing has been identified, its heating system should be subjected to testing and analysis to determine its current effectiveness. Steam performance must be thoroughly assessed to properly evaluate the effectiveness of a package of steam balancing measures. To provide this analysis, comprehensive measurements and monitoring of system components are essential before and after the packages of steam balancing measures are installed. This section is divided into subsections to (1) indicate which system components particular data relate to; and (2) outline the guidelines for studying the behavior of a particular component. All these system components should be carefully examined when a building is being balanced.

3.1.1 Overview of One-Pipe Steam Systems

One-pipe steam heating was one of the best options for buildings constructed between 1900 and 1930 in cold continental climates. Though the boilers have been converted from coal to natural gas or oil and many have been replaced or undergone other smaller upgrades, the distribution systems remain largely the same as when they were first installed. One-pipe steam systems were designed for longevity but not for energy efficiency (Peterson 1985). Steam system efficiency is limited by the fact that a steam boiler cannot have a rated efficiency > 83%.

Old one-pipe steam systems are often controlled by a timer or by a single thermostat. When the thermostat or timer calls for heat, the boiler comes on, heats the water, and generates steam. The steam moves through the piping that is initially full of air, heating the metal and pushing the air out through vents on the main distribution lines and radiators. As steam reaches each vent, the vents close so no steam escapes. Within each radiator, the steam condenses and releases latent heat, allowing more steam to enter. The water that has condensed inside the radiators runs back (through the same pipes that carry the steam) to the return lines and down to the boiler. When the building is heated according to the thermostat's or timer's specifications, the boiler shuts off.

The boiler can also be regulated by a pressuretrol that will shut the boiler off if the pressure in the boiler builds to greater than the allotted amount. One-pipe steam systems should typically operate at ½–1½ psig of pressure. It is important to adjust pressuretrols to these settings. Incorrect pressure settings can result in short boiler cycles and distribution problems.

As the radiators cool, the air vents open and allow air to re-enter the system. A schematic of this entire system is shown in Figure 3. This is a gravity return system, meaning that the return condensate relies on gravity to return from the radiator through the piping back down to the boiler. Some systems use condensate pumps to return the condensate to the basement. These systems would have steam traps in the basement along with a condensate tank that feeds water back into the boiler.

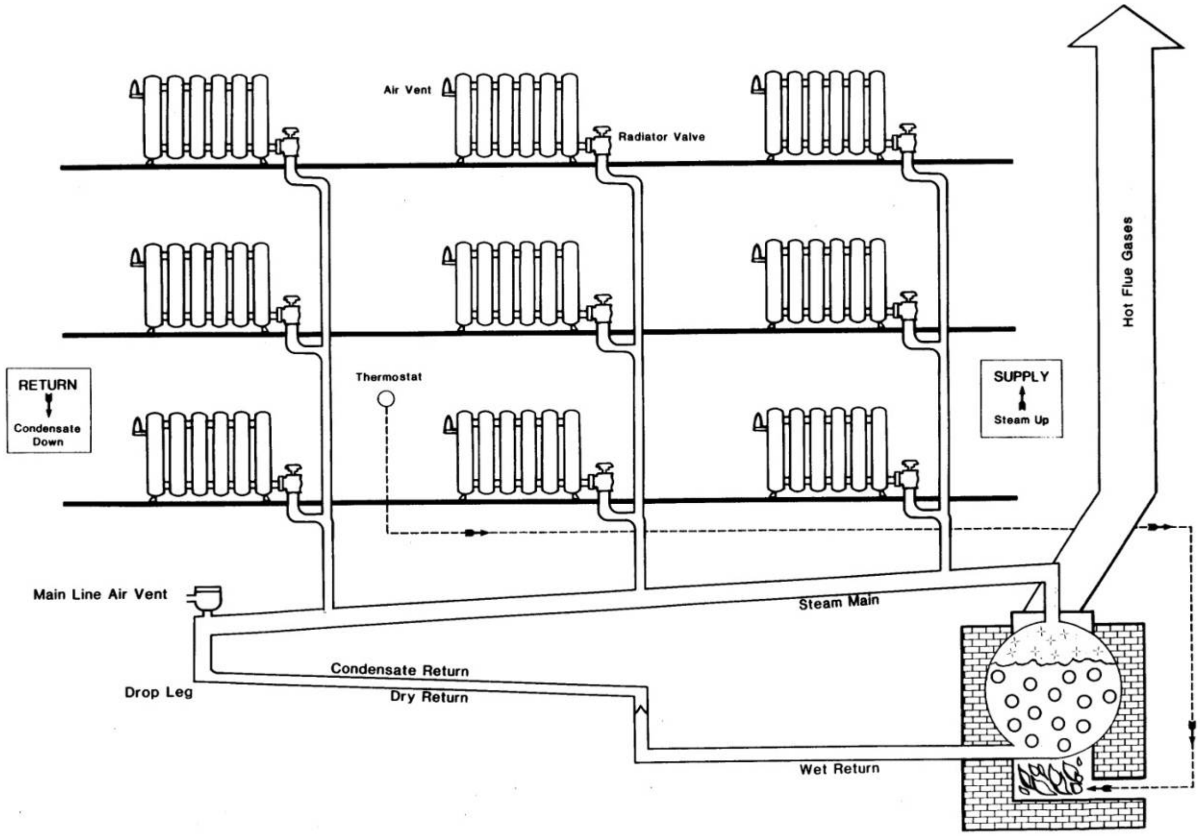


Figure 3. Schematic of one-pipe gravity return steam system

(adapted and used with permission from Peterson 1985)

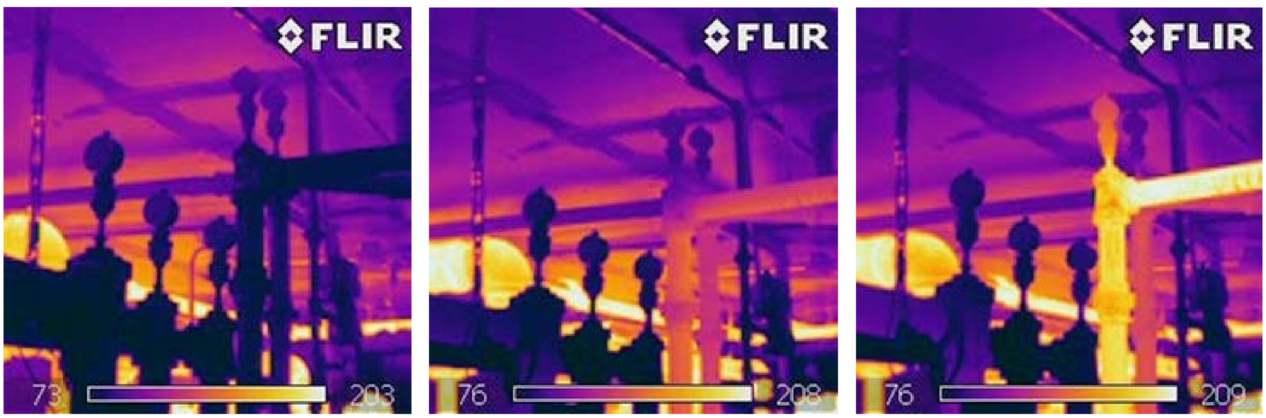
Insufficient venting, large differences in steam arrival times, excessively short boiler cycles, lack of zone control or temperature averaging, and variable steam main lengths can all contribute to uneven heating in a building (Peterson 1985). When considering how to deal with these issues, the following factors should be assessed.

3.1.2 Main Line Air Vents

3.1.2.1 Guidelines

The purpose of main line air vents is to rapidly vent the large amount of air in the steam lines. These vents lower the back pressure during the fill part of a boiler cycle and aid the flow of steam down the main distribution pipes. Without main line air vents, all the air in the lines must be purged at the radiators, in which case steam would fill the radiators closest to the boilers much faster than those furthest away. This can cause uneven heating, particularly if the boiler shuts off before the whole system is full. As such, there should be at least one main line air vent per steam line. Main line air venting should be completely separate from radiator venting. In an ideal system, steam would fill each main line in approximately the same amount of time; the steam would then fill the radiators by pushing air out through vents that have been properly sized for the radiators. Proper air venting can be used to control the relative speed of steam delivery to pipes leading to radiators in various parts of a building. Main line air vents are found on the main distribution lines after the last riser and before the dry return drops into the wet return. The valve in the air vent is open until the steam reaches it, at which point it shuts and prevents steam from escaping through it (Peterson 1985).

In many buildings, the main lines still have the same air vents as when they were coal systems. In coal systems, large boilers were constantly lit and producing steam. The air in the main lines was constantly being pushed out by steam at a slow and steady rate and there was little off-cycle time for the lines to completely refill with air. Therefore, smaller capacity vents were sufficient for these systems. In one-pipe systems today, which run on either natural gas or oil, smaller boilers frequently cycle on and off. The main distribution pipes cycle between being full of air and having to rapidly vent air to allow steam to move through them. Upgraded vents are required to vent this air quickly enough.



Boiler turns on | **8 min** | **30 min**

Figure 4. At the beginning of a boiler firing cycle, the main lines are filled with air and quite cool, meaning that the steam must heat a large mass of piping and push air out of the air vents. As time passes, the main lines fill with steam and become hot. In an unbalanced system, some of the steam lines may never heat up during the boiler cycle.

(Used with permission from CNT Energy 2011)

3.1.2.2 Method

Measurements for the main line piping should consist of:

- A census of all the main lines in the building
- The approximate length of each main line
- Varying thickness of pipe for each main line
- Pipe insulation for each main line
- Positions of risers on each main line
- Positions of vents on each main line
- Sizing and condition of main line vents.

An infrared camera can be a useful tool for timing how long the main lines take to fill with steam. The main lines that receive heat the slowest can be visually determined (Figure 4). A main line that is not filling with steam within the length of a boiler cycle (and therefore not supplying heat to its designated section of the building) may need increased venting.

Figure 5. Main line air vents installed on a steam line.

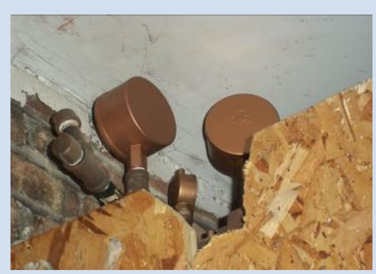
(used with permission from CNT Energy 2011)

Each basement must be inspected and the number and condition of the main line air vents determined for each building. Figure 5 shows main line vents installed on a steam line in a basement. The main line air vents should always be installed at least 15 in. from the last elbow, on a 6- to 10-in. nipple. If they are too close to, or right on top of, the elbow at the end of the line (as all the vents are in Figure 4), the vent can be easily damaged and therefore rendered ineffective. If condensate is in the lines when high-velocity steam is propelled through them, the water is carried by the steam and slams into the end of the line. This phenomenon is called *water hammer*. The resulting shock wave can move straight up the tee and crush the float inside the vent (Holohan 1992).

The e-booklet "Balancing Steam Systems Using a Venting Capacity Chart" (Gill and Pajek 2005) is a useful resource for sizing main line air vents. Information about the vents should be relayed to a heating contractor to determine which vents need to be replaced or whether vents need to be added to the distribution lines.

Hidden Main Line Vents

Vents are often hidden in unused basements or storage facilities in multifamily buildings; a thorough inspection of each accessible basement must be conducted to assess the current efficacy of the venting.



3.1.3 Near Boiler Piping

3.1.3.1 Guidelines

The quality and effectiveness of steam heating can be affected as much by the near boiler piping (NBP) as by the boiler or main line pipes. The recommended size and configuration for this piping (as detailed by each boiler manufacturer) ensure that the steam will be as dry as possible when it leaves the boiler and the NBP and moves through the rest of the distribution system. Dry steam has the most latent heat and delivers heat most efficiently. When steam boilers are replaced, their accompanying piping often remains unaltered or the replacement piping is incorrectly sized. It is very important to consult manufacturer specifications when installing a boiler and determining the correct size for the NBP. It should never be assumed that the existing piping is correctly installed. Figure 6 shows an example of an insufficiently sized header.

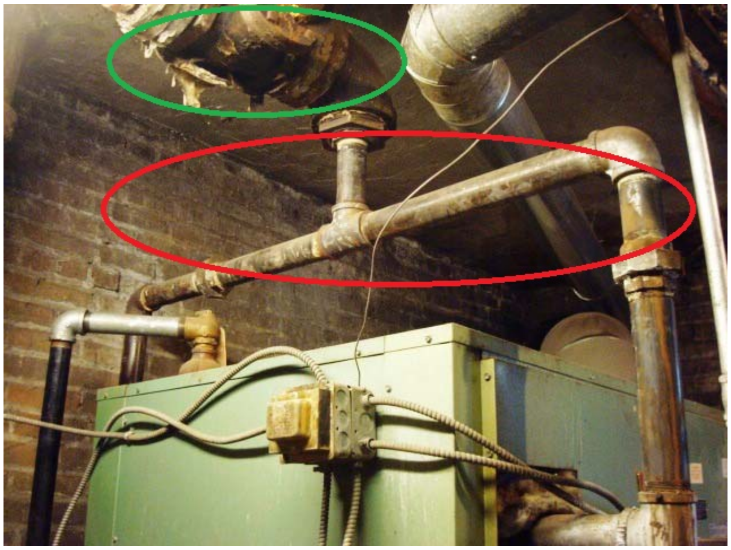


Figure 6. The header piping is smaller than the boiler manufacturer's specifications.

(used with permission from CNT Energy 2011)

Figure 7 shows that the distance between the boiler water line (or the center of the gauge class) to the bottom of the steam header must be at least 24 in. long. Also, the supply line leading from the header should not be directly aligned vertically with any of the risers or with the equalizer. This configuration ensures that the steam that is rising out of the boiler cannot carry large quantities of water from the boiler into the header. The result of water carried into the header is wet steam, which decreases the amount of latent heat available from the steam and therefore decreases the efficiency of the system. If there is more than one riser from the boiler leading into the header piping, the take-off from the header should be located past the last riser, not between the two risers (which would result in a "bullhead tee" configuration). This ensures that the steam coming out of the two risers, once it reaches the header, is traveling in the same direction toward the riser rather than creating two colliding streams. The boiler shown in Figure 2 has correctly sized and configured header piping.

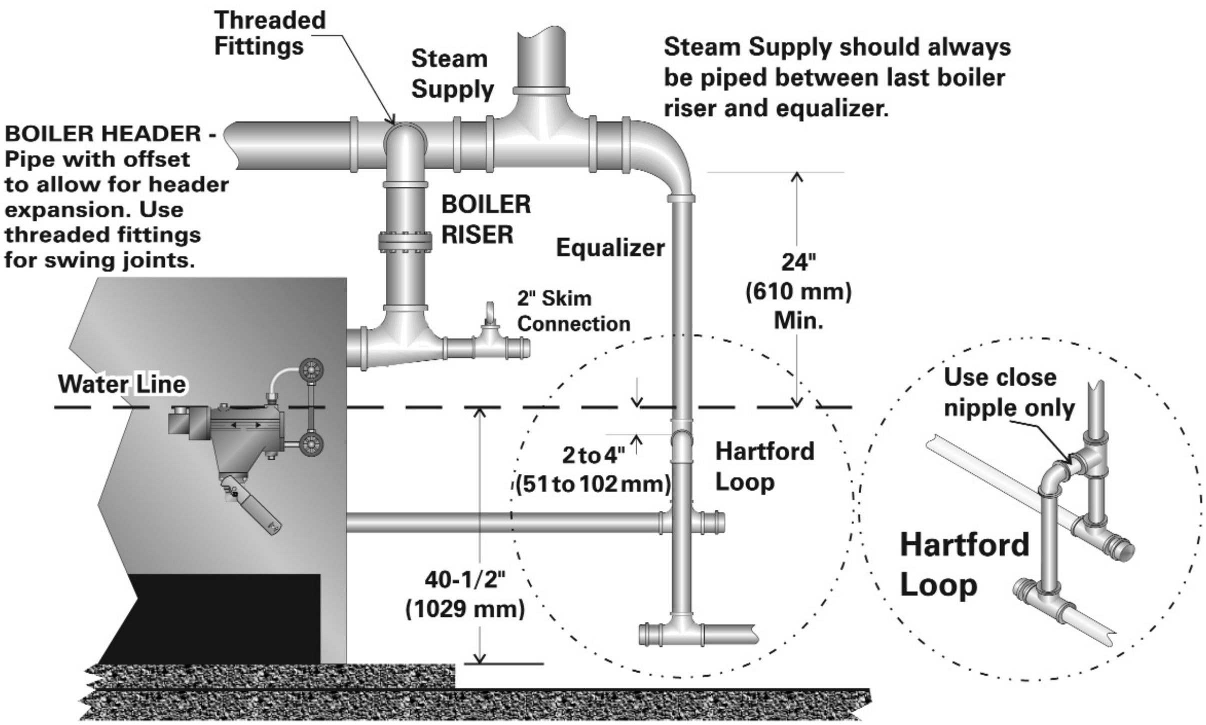


Figure 7. Specifications for how to pipe a Series 211A™ natural gas steam boiler by Peerless® Boilers

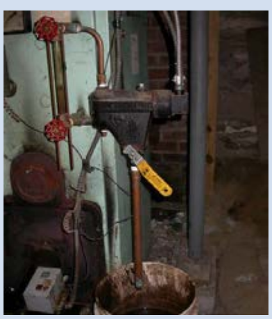
As shown in the diagram, the boiler risers should always be at least 24 in. long and the steam supply should always be piped between the last boiler riser and the equalizer.

(used with permission from Peerless® Boilers)

The NBP should also include a Hartford Loop, which consists of an equalizing pipe connecting the steam header to the condensate inlet at the bottom of the boiler. It acts as a backup safety measure to the low-water cutoff by allowing steam pressure to build in the boiler without forcing water into the return line and protecting the boiler against low water in the event of a return line leak (Ahlgren 1994). If there is a leak in a return line, water can only back out of the boiler to the point where the wet return line connects into the equalizer. The loop acts as a siphon that runs out of water, stopping the boiler from emptying completely, which allows for additional time to

Testing the Low-Water Cutoff

It is very important to test the low-water cutoff often and maintenance staff should be trained to do this regularly. However, introducing fresh, oxygenated water into the boiler can increase corrosion in the boiler andpipes. This can significantly decrease the lifetime of the boiler and distribution system. Therefore, when testing the low-water cutoff, the water should only be drained until the safety engages and the boiler shuts off so as to introduce the minimum amount of fresh water necessary.



notice a leak and have it fixed (Holohan 2010a). This reduces the chance of a boiler dry-firing, which can be extremely dangerous as well as cause damage to the equipment. Local codes should always be consulted when considering boiler re-piping.

3.1.3.2 Method

Measurements for the NBP should consist of:

- Height of the header piping
- Width of risers and header
- Descriptive geometry of the NBP.

The NBP should be examined at each test building and, if necessary, corrected before any temperature or fuel use data are collected, as well as before any other steam balancing measures are installed.

3.1.4 Pipe Insulation

3.1.4.1 Guidelines

Many steam pipes are not insulated because the original asbestos insulation was removed and never replaced. Uninsulated steam lines can allow heat from the steam passing through the pipes to dissipate into unheated basement spaces before reaching units. Uninsulated piping loses about five times the heat of an insulated pipe (Holohan 1992). This can contribute to a building's steam system becoming unbalanced. To minimize these losses, all steam distribution lines in basements should be insulated.

3.1.4.2 Method

Calculations for pipe insulation should take into account the length, thickness, and diameter of uninsulated pipes, the ambient temperature in the space, and the temperature of the steam in the pipe. Pipe insulation can be installed by skilled maintenance staff if cost considerations are paramount, but care should be taken to cover fittings and valves, as they have larger surface areas and often contribute to increased heat loss. Figure 8 shows heating pipes that have been properly insulated.

Asbestos Pipe Insulation

Pipes used to commonly be insulated with asbestos, a known health hazard. Pipes often remained uninsulated after the asbestos was removed and never replaced with another insulation product (pipes today are usually insulated with fiberglass). If asbestos is observed on pipes, it should not be disturbed and an asbestos abatement professional should be consulted before moving forward with any balancing work.

Figure 8. Insulated heating pipes

(used with permission from CNT Energy 2011)

3.1.5 Boiler Controls

3.1.5.1 Guidelines

Steam heating systems are often controlled by a single thermostat, or an aquastat and time clock. These controls do not consider temperature variations within a building. If a thermostat is located in a warmer area of the building, the boiler cycle might end before the colder units are satisfied. If a thermostat is in a cooler area of the building, certain areas of the building will be overheated as the boiler will not shut off until this cooler area reaches the temperature set point. Control systems that have indoor temperature sensors and cycle the boiler on and off according to an average building temperature can help prevent these issues. Maintenance staff often switch the boiler on and off manually, depending on tenant feedback. The steam systems accompanying these controls are usually unbalanced, so some apartments are 10°–15°F too warm while others receive little to no heat. Figure 9 shows a time clock control for a steam boiler.

Figure 9. Time clock control for a steam boiler

(used with permission from CNT Energy 2011)

3.1.5.2 Method

Measurements and data for the boiler and boiler controls should consist of:

- Rated boiler capacity (Btu/h)
- Boiler size (number of sections)
- Burner condition
- Boiler firing pattern
- Combustion analysis (steady-state efficiency, carbon monoxide, carbon dioxide, oxygen)
- Description of control type
- Daytime and nighttime set points
- Observation of how maintenance staff operate controls.

For a boiler that heats water for heating only, a runtime sensor and data logger can be wired to the boiler in each test building to assess and monitor the patterns of the current boiler controls. The loggers used should be able to sense when an alternating current is running between the current control system and the boiler and log the duration until it shuts off so as to determine the boiler cycle patterns. The boiler steam pressure could also be monitored to verify whether the boiler is shutting off based on pressure before a boiler cycle is complete. Missing main line air vents can result in a boiler operator increasing the system pressure in an effort to heat the building. This higher pressure can cause the boiler to short cycle, reducing the efficacy and efficiency of the system. Looking at the intervals when the boiler is on can provide valuable information about the average length of a boiler cycle and how much heating fuel the boiler is using. In addition to information about the controls, basic information about the boiler is important for analysis and should be recorded during the early site visits. Figure 10 shows a sample boiler plate containing some of this information.

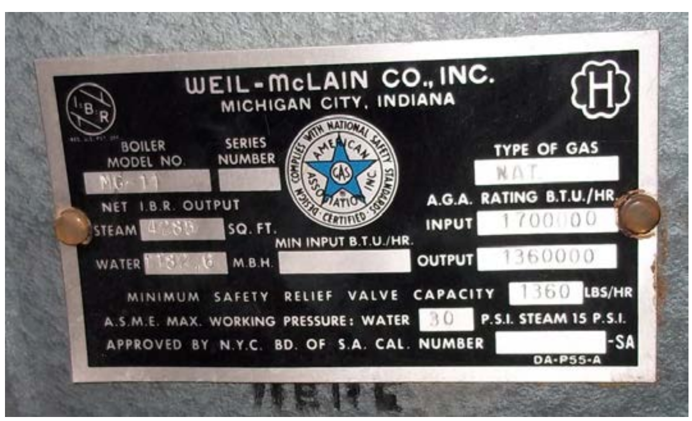


Figure 10. Sample boiler plate for a natural gas boiler that contains information about boiler specifications

(used with permission from CNT Energy 2011)

3.1.6 Radiator Vents

3.1.6.1 Guidelines

Just as the distribution of steam heating is affected by the condition of the main line air vents, it is also affected by the condition of the radiator air vents. If an apartment is too cold, the heat input must be increased or the heat loss decreased; often this can be achieved by replacing radiator air vents that are blocked or not functioning properly (Peterson 1985).

If no steam ever reaches one or more radiators, the radiator valve should be checked to see if it is open and operating properly. Radiator valves should always be completely open or completely closed and were not designed to be frequently throttled. Tenants should be informed that these valves should typically not be tampered with. If the valve does not completely open or shut, it may need to be replaced. Having a partially closed valve will not allow the condensate to properly drain out of the radiator, which will obstruct steam from entering the radiator.

If the vent is loudly whistling when the radiator fills with steam, its orifice may be too small and in this case, the vent should be replaced. A whistling vent could also be indicative of debris clogging the opening or the boiler operating pressure being higher than necessary. Alternatively, if an apartment is too hot, the steam reaching the radiators can be slowed by a smaller vent. Though studies have shown that there is a point at which an increased orifice size has little influence on fill time (Peterson and Otterson 1985), proper air venting can be an effective way to largely control the relative speed of steam delivery to various radiators. Figure 11 shows an example of a radiator vent that comes in different models of varying orifice sizes.

Figure 11. Gorton No. 4 angle radiator vent. Gorton models are made in No. 4, 5, 6, C, and D, ranging from 4 with the smallest orifice (for warm apartments) to D with the largest (for cool apartments)

(used with permission from CNT Energy 2011)

As stated in Section 3.1.2, the air in the main lines should be vented independently of the radiator vents. The radiator vents should only be responsible for venting air from the radiators. If they are also charged with venting the air out of the main lines, the air will not vent out of the lines quickly enough to make way for the steam, which will condense and release its latent heat before reaching the radiators.

The size of the radiator is important when considering the appropriate vent size. Big radiators contain more air than small ones, so big radiators need larger air vents to fill with steam more quickly. Two vents can be used on oversized radiators; a second vent can be positioned a few inches lower than the first and the two vents will work together to vent the air. Once the steam reaches the first vent and closes, the second air vent will continue to vent air. The oversized radiator will thus heat more completely (Holohan 2010b).

3.1.6.2 Method

Information collected about the radiator vents should consist of:

- Sizes of radiators in the building
- The size and condition of radiator vents.

The radiator air vents should be removed and tested; if a vent is not passing air, it should be cleaned or replaced. Figure 12 shows the common problem of a radiator vent that has been painted over and no longer works.

Figure 12. Painting over radiator vents is a common oversight that can have a serious effect on the heating in an apartment. Blocked radiator vents must be cleaned or replaced.

(used with permission from CNT Energy 2011)

The condition of the radiator vents in a sample number of units should be examined and an assessment made to determine whether to replace some or all of the vents. Although adjustable air vents are available, they can be more expensive and subject to tampering by tenants (negating their usefulness of being able to adjust to the location and size of the radiator). The condition of the building and attitude of the tenants should be assessed when deciding to use these. Removing, rearranging, or replacing radiators can be difficult and expensive processes but could be examined as possible measures.

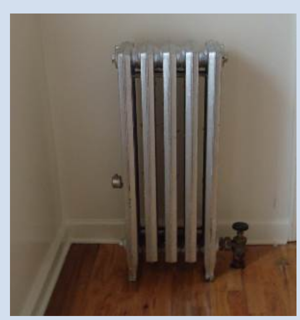
A radiator census is important for calibrating radiator air vent size and for determining a total equivalent direct radiation for a building, to properly size a boiler at the time of replacement. Steam systems can use radiators, convectors, or baseboards, all of which use different types of air vents.

The e-booklet "Balancing Steam Systems Using a Venting Capacity Chart" (Gill and Pajek 2005) includes resources for determining the amount of air in a radiator and the venting capacity of different air vents.

Thermostatic radiator valves (TRVs) can help to prevent overheating. These should be installed between the air vent and the radiator. Using a straight-shank rather than angled radiator vent with the TRV will allow the condensate to drain out of the radiator. A TRV has a nonelectric adjustable thermostat that contains temperature-sensitive fluid. As the radiator heats, the fluid expands and closes the valve, effectively blocking air from escaping through the air vent. This keeps air from escaping out of the radiator, which means that steam can no longer enter the radiator (Holohan 1992). Though these relatively simple controls enable tenants and building owners to prevent radiators from overheating, tenants must be educated on how to properly use them and their limitations. They cannot draw more heat to radiators, only prevent them from overheating.

Equivalent Direct Radiation Estimations

Benchmark values that can estimate equivalent direct radiation based on number of sections and radiator height are available for the two most common radiator types, column and thin-tube (Holohan 2010a).



3.1.7 Temperature

3.1.7.1 Guidelines

Many factors influence the temperature of an apartment unit; for example, tenants often open windows to cool their overheated apartments, even during winter months. However temperature measurements over the heating season are important for studying the distribution of heat in a steam-heated, multifamily building. Identifying the patterns of temperature change over these time periods can help researchers infer exactly how the heating distribution is failing.

3.1.7.2 Method

Matching the temperature in a broad cross-section of units with the rest of the data acquired for a building—outside temperature, boiler firing pattern, venting—

enables a thorough analysis of steam heating systems and the effects of steam balancing measures. The data should be recorded for at least one month before and after the steam balancing measures are installed, ensuring a broad picture of system behavior and enabling control of abnormal climactic variation. The pre- and post-measure logging periods must be during the heating season.

Temperature data loggers should be placed in units and calibrated to record the temperature at least every 5 minutes. The loggers must be placed in units directly above the boiler and in units that are furthest from the boiler on at least two floors to capture the diverse temperatures in a building. They should be placed uniformly at around 5 ft from the floor, and should not be placed on external walls, above radiators, or in kitchens or bathrooms.

Temperature loggers and boiler runtime loggers should also be placed in the boiler rooms; an external logger can be used to measure outside temperatures. Several models of suitable data loggers are available; Table 2 lists sample models of logger equipment that can be used to collect the necessary data. Figure 13 depicts a sample building and a typical setup for the data logger placement. Schematics of each building and detailed locations of the loggers must be recorded.

Table 2. Sample Logger Equipment

Measurement	Model	Description
Outdoor Air Temperature	HOBO U23 Pro v2	Outdoor temperature/relative humidity data logger
Indoor Air Temperature	HOBO U10-003	Indoor temperature/relative humidity data logger
Boiler Firing Pattern	HOBO U9-001	State logger
Alternating Current/Boiler State (On/Off)	CSV-A8	Alternating current switch/sensor

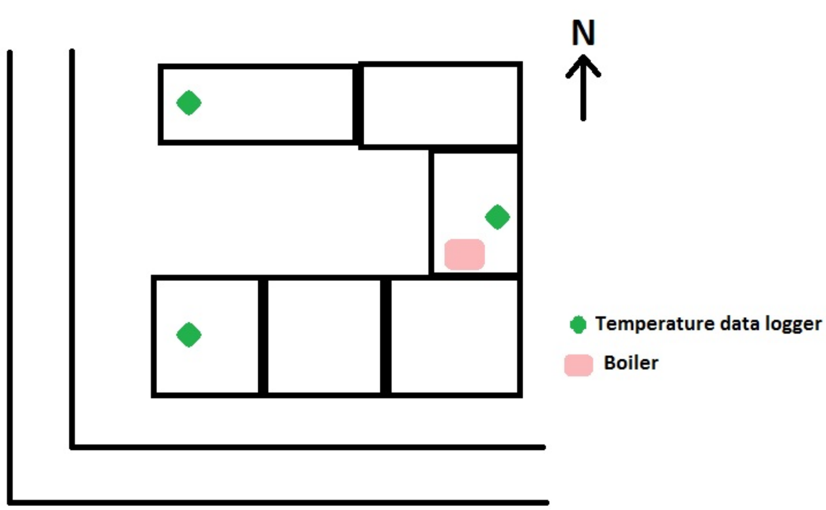


Figure 13. Schematic building plan showing possible data logger placement

3.1.8 Tenant Comfort

3.1.8.1 Guidelines

The tenants and building manager should be interviewed to enable a comparison of temperature data to the residents' perceptions of the heat. These interviews are also useful in explaining abnormalities in the temperature data. If a unit far from the boiler, and therefore predicted to be cold, shows higher than average (or than expected) temperature readings, the tenants may be using space heaters or the oven to supplementally heat the unit. If a unit close to the boiler, and therefore predicted to be warm, shows lower than average or expected temperature readings, the tenants may be opening their windows. Tenants should be surveyed to determine which parts of the building are too cold and which are too hot, especially in the absence of sensors. A survey of open windows can also be performed from outside the building.

3.1.8.2 Method

A tenant survey is an inexpensive method of understanding tenants' perceptions of the heating in their apartments and information about how the system operates (Peterson 1986). A tenant comfort survey should be conducted when the pre-measure temperature data are collected (before any steam balancing measures are done) and when the post-measure temperature data are collected (after the steam balancing measures are completed by the contractor). A sample survey is shown in Appendix D. The field auditor collecting the data can administer the survey and record the responses. Alternatively, the building owner should be enlisted to help with collecting survey responses.

3.2 Measurement Methods

Although most of the data (other than the temperature data and boiler runtime data) can be collected by observation during the site visits, some additional equipment may be necessary. Table 3 outlines the equipment needed for data acquisition.

Table 3. Measurements and Equipment

Measurement	Equipment Needed
Census of Radiators	Observation
Radiator Vent Size	Observation
Radiator Vent Condition	Observation
Census of Main Lines	Observation
Main Line Lengths	Laser distance meter
Thickness of Main Lines	Calipers
Vertical Tier Position	Laser distance meter
Position of Vents	Laser distance meter
Main Vent Size	Observation
Main Vent Condition	Observation
Main Line Steam Time	Infrared camera
Rated Boiler Capacity (Btu/h)	Observation
Boiler Size (sections)	Observation
Burner Condition	Observation
Boiler Combustion Efficiency	Combustion analyzer
Header Piping Height	Laser distance meter
Riser and Header Width	Calipers
NBP Geometry	Camera
Return Line Condition	Observation
Description of Boiler Controls	Observation
Number of Functioning Sensors	Observation
Daytime/Nighttime Set Points	Observation
Current Boiler Operation	Observation

4 Measure Implementation

Scope of Work

A. Assess and add or replace main line air vents.
B. Assess and replace radiator vents.
C. Upgrade boiler control system to averaging system with indoor and outdoor sensors.

Working closely with steam contractors is highly recommended when developing a final scope of work that is highly detailed. The contractor proposals should include itemized costs and descriptions of each steam balancing measure.

For main line and radiator vents, proposals should include (but are not limited to):

- Whether and how many obsolete vents are to be removed
- Specific details on where vents to be removed or replaced are located
- How and where new openings and fittings will be cut and fitted
- Details about the number and types of vents that will be furnished

For boiler controls, proposals should include (but are not limited to):

- Type of controls system to be installed
- Number of indoor and outdoor sensors
- Where sensors will be installed
  - Note: if possible, specific details on, and photographs of, the sensor locations should be included.

Ongoing Inspections

Follow-up visits should be conducted throughout the installation process to ensure adherence to the specifications in the scope of work. These should include a walkthrough of the installed measures with the contractor. If necessary, the scope of work should be revised.

5 Verification Procedures and Tests

5.1 Temperature Control and Steam System Behavior

The air temperature data provides useful insights to the building steam delivery system performance. More uniform air temperatures will theoretically lower energy bills and improve tenant comfort as there is no longer a need to overheat apartments close to the boiler to ensure that there is adequate heat for distant apartments.

Tenant surveys can indicate whether tenants are using space heaters or ovens for additional heat. Electricity and gas bills may also reveal whether tenants are using supplemental heat. This would potentially raise or lower the average temperature of the units. In analyzing the temperature of the units, information from the tenant surveys should be used as much as possible to determine the validity of the temperature readings obtained.

5.1.1 Possible Results

Buildings respond very differently to steam balancing measures. Pre-upgrade conditions and building operations are usually drastically different from building to building, so different buildings will see varying results from balancing work. Some of the possible differences between the pre- and post-upgrade temperature data are:

- Changes in the diurnal temperature patterns within units (different schedules throughout each day of when the units were warmest and when they were coolest)
- Smaller temperature differentials between the hottest and coldest units.

Indoor and outdoor sensors as well as more advanced temperature set point control capabilities (allowing for nighttime, daytime, and differential set points) enable a building owner to regulate the heating schedule. If heating times do not improve, the control operation should be checked.

In addition to the schedule change, the temperature differential between the hottest and coldest units might decrease. This suggests that heat is being more evenly distributed, reaching units that were previously not receiving as much heat. Two possible reasons for decreased temperature differences are that the indoor averaging temperature controls are regulating the boiler to stay on longer, until heat reaches the further units, and that the upgraded venting (both main line and radiator) allows steam to travel faster through the mains and into the radiators. A more even distribution of heat is expected to also result in greater resident comfort.

Middle-range temperature units may become more uniformly heated to a comfortable temperature, but outliers may remain after the balancing work is done. In these buildings, issues with controlling the heat to the hottest and coldest units need to be investigated and addressed further.

5.2 Boiler Cycles

From the data recorded by the boiler runtime loggers, the numbers of times that a boiler cycles on each year can be determined. This can also be accomplished through a utility bill analysis (making sure to separate fuel used to heat domestic hot water from the fuel used for heating).

Using the weather-normalized average boiler on cycle count per year and the average length of boiler cycles, the number of hours that the boiler was on per year can be calculated (Equation 1). A weather-normalized natural gas use can then be calculated using the known input rating of the boiler (in kBtu/h) (Equation 2). This method would not be valid for a boiler equipped with modulating burners. Another possible, more accurate, method of measuring the gas input would be to install a calibrated meter in the gas supply piping.

$$D = C \times L \quad (1)$$

$$N = I \times D \quad (2)$$

Where

$N = weather - normalized\ natural\ gas\ used\ in\ a\ year\ \left(\frac{kBTU}{yr}\right)$

$I = input\ rating\ of\ boiler\ \left(\frac{kBTU}{hr}\right)$

$D = weather - normalized\ time\ boiler\ on\ in\ a\ year\ \left(\frac{hrs}{yr}\right)$

$C = weather - normalized\ average\ boiler\ on\ cycle\ count\ per\ year\ \left(\frac{cycles}{yr}\right)$

$L = average\ length\ of\ boiler\ cycle\ \left(\frac{hrs}{cycle}\right)$

5.2.1 Possible Results

The balancing and tuning work can have varying effects on the length and frequency of the boiler cycles. Some buildings might see shorter cycles and some might see much longer cycles post-retrofit. Some might see more boiler cycles and some might see fewer. Several trips and adjustments are often needed after the initial round of balancing and tuning work is done.

5.3 Cost Effectiveness

A main focus of applying measure packages to upgrade these buildings is the cost effectiveness of the project. The proposals for steam balancing from the contractor to the building owner should include itemized costs.

Natural gas savings can be measured in two ways:

- Data from a runtime logger or gas meter can be used to calculate how much gas the boiler is using before and after steam balancing. This gas use should be normalized by heating degree day to determine weather-normalized natural gas savings.
- The pre- and post-upgrade energy use can be compared via utility bill analysis.

The second method of analysis cannot be done until the heating season is complete, as it is recommended that at least one year of data be available before the natural gas use is calculated.

The total cost effectiveness of the steam balancing package tested (upgrading or replacing controls, installing main line vents, replacing radiator vents) can be evaluated by calculating simple paybacks from projected yearly financial savings and measure costs.

Long-term monitoring of building performance should be conducted to examine whether a building owner would see sustained savings from steam balancing measures. This is accomplished by applying a utility bill analysis for at least two years following the steam balancing work.

5.3.1 Possible Results

Before steam balancing is done, building owners commonly overheat their buildings to compensate for units that are not receiving heat quickly enough. By distributing heat more evenly and allowing steam to be more quickly delivered to units (rather than being dissipated in the basement because of insufficient main line venting), the balancing work saves fuel and reduces energy costs. Choi et al. (2012) investigated test buildings in a steam balancing study and calculated that buildings can save an average savings of 10.2% on their heating load natural gas use. The benefit of tenant comfort (which would begin immediately after a building is properly balanced) should also be considered as an important added value.

5.4 Tenant Perceptions

Records of tenant complaints about the heat should be used in conjunction with logger data when determining how to balance a building. These often indicate where heat is not reaching.

5.4.1 Possible Results

Once owners stop overheating their buildings (because new controls were installed or venting adjusted), major heating imbalances become more obvious. The units that were slower to receive heat might initially receive even less heat after the temperature set points are turned down or adjusted, so heating deficiencies in particular units are more recognizable when the entire building is not overheated. Also, because many tenants are used to having their units overheated (often up to 80°–85°F), they are more likely to complain once set points are adjusted properly and they notice they are receiving less heat than before. Buildings whose post-retrofit surveys show decreased tenant comfort may be suffering from this phenomenon or they might simply still be overheated. The number of open windows should be checked after the balancing work is done. Though the venting has been adjusted, buildings may still require more follow-up visits to further assess the distribution systems.

6 Final Considerations

Several points emphasized throughout this guideline are particularly important when deciding to balance and tune a building:

- **Balancing is a multistage process.** A thorough assessment must first be conducted on a building thought to be in need of balancing. Once a building has initially had steam balancing measures installed, the effectiveness of the retrofits should be assessed based on conversations with the building manager and tenants, temperature and boiler data, and utility bill data. Even if the boiler controls have not been upgraded, the set points and schedules should still be adjusted after the distribution balancing work is complete. Then the building may need to be rebalanced, reassessed, and perhaps further adjusted.

- **Unit locations and building layout are important to consider when assessing and balancing a building.** Each building will have different hot and cold spots and will require different venting configurations and placement of control sensors.

- **Tenants and building managers need to be informed about the balancing process and that its success will require time and cooperation.** The balancing work will be most effective when tenants and building managers cooperate. For example, tenants should be informed that using space heaters drives up the temperature that the indoor averaging system uses to control the boiler. This means that the boiler will not come on in a building even if some units are substantially below the set point and the temperature monitoring will be inaccurate. Tenants should also be told that they should not throttle their radiator valves. Building managers should be properly instructed about how to use the newly installed controls and tenants should be informed that the balancing work will require their cooperation and occasional access to their units.

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Appendix A: Sample Field Data Collection Form*

CNTenergy

Steam Balancing and Tuning Field Sheet
(For one-pipe central steam heating systems)

Original auditor:
SB auditor:
Date:

Building Information

Street Address:
City, State ZIP:
Building Contact:
Phone Number:
# of Units:
Square footage (ft^2):
# of Heated Stories:
Ceiling Height (ft):
Number of Occupants:

Notes:

Boiler controls

Type:
Daytime setpoint:
# of sensors:
Nighttime setpoint:

Boiler

Boiler on from: ______ to ______
# of main line air vents:
Pipes insulated? Y N Some
Thickness:
Header pipe diameter: ______ in.
Make:
Age:
Model:
Boiler condition: New Good Fair
Boiler size: ______ Btu/hr
# of sections:

Boiler maintenance notes:

Units

radiators/apt:
Radiator size (# sections):
Radiator vents: Present? Y N Some - percent missing:
Functional? Y N Some - percent broken:
Radiator placement:
Avg apt square footage:

*Note: Additional fields will need to be added based on the building type and steam heating system type. Examples of additional fields include distribution type (radiator, baseboard, convector), wet or dry return system, gravity or pump return.

CNTenergy

Header piping diagram (show how piping connects to boiler, note important pipe diameters):

CNTenergy

Distribution system diagram (show a floorplan of the basement/footprint of the building; note the locations of mainline air vents and mark the locations of the risers):

Appendix B: Detailed Measure Costs

Following is a cost breakdown of measures implemented by CNT Energy in a PARR Building America study on steam system balancing (between December 2011 and January 2012).

Building	Measures Completed	Individual Measure Costs ($)	Total Cost ($)
1	Main line vents Radiator vents Boiler controls (RD AH207 – 6 indoor sensors, 1 outdoor sensor)	4,695 5,842 6,955	17,532
2	Main line vents Radiator vents Boiler controls (RD AH207 – 6 indoor sensors, 1 outdoor sensor)	1,560 5,200 6,995	13,755
3	Main line vents Radiator vents Boiler controls (RD 1404T – 4 indoor sensors, 1 outdoor sensor)	1,540 2,820 4,500	8,860
4	Main line vents Radiator vents Boiler controls (RD 1404T – 4 indoor sensors, 1 outdoor sensor)	895 2,195 4,698	7,788
5	Main line vents Radiator vents Boiler controls (RD RF207 – 6 indoor sensors, 1 outdoor sensor)	1,295 2,295 3,900	7,490
6	Main line vents Radiator vents Boiler controls (RD 1206 – 6 indoor sensors, 1 outdoor sensor)	1,570 5,500 4,500 (est)*	11,570
7	Main line vents Radiator vents Boiler controls (RD RF207 – 6 indoor sensors, 1 outdoor sensor)	1,495 2,395 3,900	7,790
8	Main line vents Radiator vents Boiler controls (RD 1204 – 4 indoor sensors, 1 outdoor sensor)	1,798 3,589 4,000	9,387
9	Main line vents Radiator vents Boiler controls (RD 1404T – 4 indoor sensors, 1 outdoor sensor)	1,500 3,295 4,500	9,295
10	Main line vents Radiator vents Boiler controls (RD 1206 – 6 indoor sensors, 1 outdoor sensor)	1,678 3,695 4,000 (est)*	9,373

*The boiler control costs for Buildings 6 and 10 are estimated costs because the owner had installed these prior to the start of the project and CNT Energy did not receive the formal proposals for these installations.
Note: All sensors were hard-wired.

Appendix C: Sample Tenant Letter

CNTenergy

Dear Tenant,

On ________________________, 2011, we installed a temperature data logger in your apartment unit. We are working with your landlord to find and address any heating issues within the building; this data logger provides information for that work.

We ask that you do not remove or disturb the logger. It will allow us to collect useful information that should improve your comfort during the heating season.

We will need to access your apartment again in about **4 weeks** to collect the temperature data and reset the data logger. You will be notified again by your landlord prior to our next visit.

We very much appreciate your cooperation. If you have any questions, please contact your landlord or building manager.

Sincerely,

The Energy Savers Team
CNT Energy
<Phone Number>

Appendix D: Sample Tenant Survey

CNTenergy

Pre-Measure Occupant Comfort Survey – Steam Balancing and Tuning

Address: ____________________________________ Date: __________

Unit: ____________________________________

How long have you lived in the unit?

Overall temperature comfort:

Uncomfortable ○ ○ ○ ○ ○ Comfortable

How cold it gets:

Too cold ○ ○ ○ ○ ○ Comfortable

How warm it gets:

Too warm ○ ○ ○ ○ ○ Comfortable

Temperature shifts:

Too frequent ○ ○ ○ ○ ○ Constant Temperature

Your ability to adjust the room temperature:

Poor or no controls ○ ○ ○ ○ ○ Works well

Do you use the oven or space heaters to additionally heat your apartment?

Do you ever open your windows to cool down your apartment during the heating season?

Other comments about the heat:

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DOE/GO-102013-3851 ▪ April 2013

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