by Henry Gifford

How to Make a TWO-PIPE STEAM HEATING System Really Work

Using radiator inlet orifices to optimize two-pipe steam heating systems

Many people think of steam heating systems as so old fashioned and inefficient that the best way to deal with them is to tear them out and replace them with pumped hot-water heat. It is hard to argue in favor of keeping a one-pipe steam system, but a few simple improvements can make a two-pipe steam system work well enough to rival a hot-water heating system's ability to deliver heat where and when it is needed at a reasonable cost. In this article, the first in a series of articles under the "How to Make a Two-Pipe Steam Heating System Really Work" title, I will detail the use of radiator inlet orifices to optimize two-pipe systems.

This five story row house, heated with two-pipe steam, was retrofitted with radiator inlet orifices.

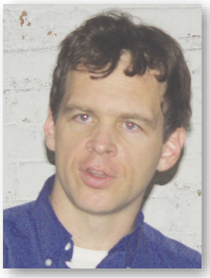
Background

Two-pipe steam heating systems are used in many old buildings today and are still being installed in some new buildings. "Two-pipe" is taken here to mean two pipes connected to each radiator or heater, as opposed to just one pipe as used in some steam heating systems. Two-pipe steam heating systems have one pipe to bring steam to the radiator and a second pipe to carry air and water away from the radiator.

However, two-pipe steam heating systems have many disadvantages that have contributed to their decline in popularity. The main disadvantage is the difficulty of maintaining the steam traps. When some of the steam traps in a system do not work, the heat is terribly uneven, with some rooms getting overheated and some rooms getting underheated at the same time. Much energy waste is caused by most two-pipe steam systems being controlled in a way that turns the steam heat on or off building wide. The sunny, downwind side of the building gets as much heat as the shady, leeward side of the building, need it or not, which leads to overheating part of the building.

Using radiator inlet orifices

The advantages of installing radiator inlet orifices include: elimination of radiator steam trap maintenance, lower fuel con-



Henry Gifford is the president of Gifford Fuel Saving Inc. in New York City. He is the author of numerous articles on boiler system optimization, including "When Is That Old Boiler Shot," published in HPAC Engineering *in October, 2001. He can be reached by fax at 212-316-9377.*

sumption, less overheating, and reduction of the size of the boiler necessary for heating the building.

Not all steam systems are two-pipe steam systems. One-pipe steam systems have only one pipe connected to each radiator, which serves the dual purposes of supplying steam to the radiators and carrying condensate back from the radiators. Radiator inlet orifices cannot be used on one-pipe steam heating systems.

In one-pipe steam heating systems, water and steam can flow in opposite directions in the same pipe at the same time if the pipe is large enough to keep the velocities reasonably low, but the need for large piping limits the use of one-pipe steam systems to smaller buildings. At some point, systems get so large that it is cheaper to install two smaller pipes than one large pipe. In New York City, one-pipe steam systems using pipe larger than 2 in. are unusual, which probably has something to do with 2 in. being the largest size pipe that can be threaded by a hand powered machine. As a result, two-pipe steam heating systems are found in many old apartment houses and office buildings taller than six stories, and in many old schools, hospitals and government buildings, and in new buildings tall enough to make hot water heat problematic.

Two-pipe steam heating systems have two pipes connected to each radiator. A supply pipe is connected to the inlet of each radiator and supplies steam to each radiator. A second pipe is connected to the outlet of the radiator, typically at the end opposite the inlet, and carries air and condensed steam away from the radiator. The condensed steam is liquid water, and is known as condensate.

Radiator inlet orifice with the hole drilled.

How a radiator inlet orifice fits between the curved faces of a union. This orifice is blank, that is, the hole is not drilled yet.

Radiators installed in two-pipe steam heating systems typically have a steam trap installed at the outlet of each radiator. A few very old two-pipe steam heating systems were installed without traps before traps were invented, but can also benefit from the same improvements recommended here for systems with traps. A steam trap is a valve that automatically opens and closes the flow of whatever is trying to get through the trap. A properly working trap remains open to permit air to pass out of the radiator into return piping so steam can enter the radiator, and stays open to permit condensate to pass through the trap and into the return. A properly working trap will close to prevent steam from passing into return piping.

The type of steam traps typically found on radiators contain a thin-walled copper or stainless steel capsule that contains a substance such as an alcohol and water mixture that boils and expands when steam enters the trap, pushing a pin into a hole and closing the trap. When condensate surrounds the capsule, and cools via heat loss out of the trap body and nearby piping to the surrounding air, the alcohol and water mixture condenses, permitting the capsule to shrink and open the trap and permit condensate to pass. As soon as the condensate drains, which might take less than a second, steam enters the trap and closes it again, starting the cycle over.

Properly working steam traps maintain a pressure difference between the supply and return sides of a two-pipe heating system. The supply piping and the radiator are at a pressure about equal to the pressure in the boiler (minus friction losses in the piping), and the return piping should be at about the pressure in the condensate tank, which should be at atmospheric pressure.

It is correct and accurate to describe the parts of a two-pipe steam heating system as the "supply" and "return" sides, but it is equally accurate and more illuminating to describe the parts as the "high pressure side" and the "low pressure side." This viewpoint has the added potential of revealing the nature of problems associated with parts of the piping system becoming improperly pressurized. Improper pressurization is usually caused by traps that are broken and, therefore, do not close when they should.

Traps cycle open and closed many times every minute that the system is in operation and, as can be expected with any moving part, they eventually fail. When they fail in the open position, as the type used at the outlet of radiators usually does, they allow steam to pass through the outlet of the radiator and pressurize the return piping. When the return piping is pressurized by a broken trap, pressures in the supply and return piping remain about equal. This causes radiators elsewhere in the system to become airbound because the steam pressure on each side of those radiators is equal, with no pressure difference to move air out and move steam into the radiator. Or, steam can travel through return piping to the outlet end of a steam trap and close the trap, preventing air from leaving the radiator served by that trap. The radiator with the broken trap gets hot while "no heat" calls come from rooms served by radiators whose traps might be working fine, making it difficult to find the cause of the problem.

There are ways to figure out which traps are working and which are not, but doing so requires a skilled person bringing the right equipment and going back and forth from one radiator to another to find the problem.

Unfortunately, another popular approach is to give up on trap maintenance altogether and turn the steam pressure up to 6 or 7 psig, which compresses the air in the system enough to force steam into enough parts of the system to heat most parts of the building. Unfortunately, this method results in some parts of the building being overheated and others being underheated, which leads to windows being open in some apartments while electric heaters are heating others. In some buildings, such as the one I live in, even open windows do not provide enough cooling in overheated apartments, and windows are not thermostatically controlled, so people run air conditioners in the dead of winter.

Inlet orifice being inserted into union part of the radiator inlet valve.

How do radiator inlet orifices work?

An orifice is a restriction in the piping that limits the amount of steam that passes that point in the piping. The type of orifice most suited for installing on an existing two-pipe steam system is a copper plate that can be inserted across the union that is part of the shutoff valve on the inlet to the radiator. Plate orifices can be purchased "blank," meaning with no hole, and drilled with the correct size drill bit at the time of installation.

The size of the hole limits the steam entering the radiator to an amount the radiator will condense, which means large radiators get orifices with large holes and small radiators get orifices with small holes. All the steam entering the radiator condenses in the radiator, which prevents steam from entering the return side of the system. There is no need to spend time and money doing anything to the traps. They can simply be abandoned in place.

An increase in pressure difference between the high side and the low side of the system will cause steam to make its way into the returns, so once a system is converted over to radiator inlet orifices the system pressure setting should not be changed.

Origins of inlet orifices

Radiator inlet orifices and steam pressure controls are both old technologies. Combining them in place of steam traps was apparently done years ago, but never caught on until recently. Certain proprietary steam systems use radiator inlet orifices to balance the flow of steam, but still use steam traps on each radiator. Back in the days before steam traps were invented, inlet orifices were sometimes used, but fell out of favor after steam traps were invented. Maybe the difficulty of accurately controlling steam pressure in the days of coal and shovels had something to do with it, but mechanical pressure controls for coal boilers did exist and electric pressure controls have been around for about as long as gas and oil burners.

Mark Twain knew what he was talking about when he said: "I'm all in favor of progress. It is change I don't like." For years, I wondered why people didn't use some kind of limiting device at the inlet of radiators instead of steam traps at the outlet. I asked around and got crazy looks from people, but no explanation, except variations on "If that would work, people would have been doing it for years."

The first time I used inlet orifices was in the mid-1990s, in an apartment building with all-too-typical tenant complaints: too hot in the winter so windows are left open, others too cold, and lots of banging pipes. The owner considered purchasing a new boiler. I fought for keeping the existing boiler and installing radiator inlet orifices and thermostatic radiator valves throughout the building and won.

No more banging pipes, and no more underheated or overheated apartments. While I never received any exact fuel data, I saw the superintendent a couple of years later. He told me that the building used to burn two tanker truck loads of oil a week in the very cold months. After the retrofit, the oil delivery truck only had to come around once every two weeks in the extreme cold. This building burns No. 6 oil, which is sold by the 6,000-gal. truckload.

Since then, I and other people have converted numerous other buildings to radiator inlet orifices, some with thermostatic radiator valves and some without, and I have never heard any claims that it did not give good results.

Switching a system to radiator inlet orifices

Switching a system to orifices is simple. Supply houses can order blank (undrilled) orifices. They come sized ½-, ¾-, 1-in., etc., with ¾-in. being the most common size for two-pipe steam heating systems. One inlet orifice should get installed at the inlet to each radiator or heater in the system.

The size of the hole is determined by looking up the heat output of that radiator on a chart, such as the one in Table 1, and by cross-referencing this table to see what size hole will pass that amount of steam at the pressure difference at which the system is intended to be operated. Convector ratings can be obtained from other sources.

I chose 2 psi gauge pressure for the first system done like this, and that's what I have been using since. I reasoned that higher pressures require smaller orifices that would be more prone to clogging and might make whistling noises, while lower pressures might make the difference in pipe friction between close and faraway parts of the system significant. Two psig works fine in all the systems I know of where it has been used. I have not heard any reports of clogged orifices or noise.

Each orifice should get the right size hole drilled for the radiator on which it will be installed. A cap, a union, and 6-in.-long nipple can be screwed together and used to hold the orifice while drilling it. The nipple and cap function as a handle and keep metal shavings off the floor. This would be a good time to use a battery-powered drill if you have one.

To install the orifice, the steam system should be first turned off at the boiler or other source, and all piping and radiators cool to the touch. A wrench or channellocks can be used to unscrew the nut on the union on the radiator's inlet valve. The orifice should be inserted into the union between the curved faces that form the seal. After making sure the orifice is centered, the nut on the union should be screwed back on and tightened. That's it, nothing else to do. The orifice is made of soft copper with curled up edges that make a good seal inside the union. After a few orifices are installed, the steam should be turned on to check for leaks. As mentioned earlier, existing steam traps can be left in place.

Scheduling the work

There is no need to install orifices systemwide. It is possible to adjust the system's operating pressure to 2 psig, install orifices in the part of the system that is perceived as needing it the most, and gradually install more orifices as time or money or access to radiators allows. Because the system will run well while radiator inlet orifices are installed on only some radiators, it is possible to do the installation during periodic shutdowns during the heating season. Working during the heating season offers the additional advantage of being able to run the system to test for leaks without causing occupant complaints.

The only catch is making sure the existing system will deliver decent heat while running at 2 psig. The system should be run at 2 psig for a couple of days to see if there are massive complaints. If the system condition is so bad that it needs the air compressed to a pressure higher than 2 psig to deliver heat, radiator inlet orifices should be installed throughout the system during one quick shutdown during the winter. Otherwise, the work should be postponed to the summer.

Table 1: Orifice chart for two pipe steam heating systems with 2 psig on supply side, approximately zero psig on return side:

Drill size (inches)	Square ft EDR (240 Btu per square foot)
7/64	15-19
1/8	20-25
9/64	26-30
5/32	31-37
11/64	38-44
3/16	45-51
13/64	52-59
7/32	60-67
15/64	68-76
1/4	77-86
17/64	87-97
9/32	98-108
19/32	109-120
5/16	121-133
21/64	134-145

Controls

Controlling the steam pressure at 2 psig is easy. Just set the pressure control on the boiler. The pressure can exceed 2 psig for a short time without sending steam into the returns as long as the average pressure does not exceed 2 psig. This is because during the time the pressure is lower than 2 psig, the radiators partly cool off, and the cold part of the radiator condenses the "extra" part of the steam passing through the orifice while the pressure is higher than 2 psig. An on/off burner can be set to go off at 2.5 psig and on at 1.5 psig.

With a large boiler equipped with a modulating burner, the modulating control should be set to hold the burner at 2 psig. With a high/low fire burner, the high/low pressure control should be set to cycle the burner to low fire at about 2 psig, and high fire at about 1.5 psig, and the on/off pressure control should be set to turn the burner off at 2.25 psig and on at 1.5 psig. These settings can be adjusted if steam is finding its way into returns or only partly heating radiators.

Steam heating system controls that use a temperature sensor on a return pipe to sense circulation can be fooled by installing orifices because the return pipe will not be as hot as it used to be. This problem can be avoided by replacing the temperature sensor with a pressure sensor on the boiler or supply piping set at 2 psig, or by adjusting the setting of the sensor on the return pipe to a lower temperature. If thermostatic radiator valves are installed they can cause the return pipe temperature to vary wildly, so a pressure control is the best way to sense circulation with thermostatic radiator valves.

Making the return side of the system work

Condensate can probably return to the boiler the same way it was returning before inlet orifices were installed, but many two-pipe steam heating systems have suffered through so many desperate attempts at solving the symptoms of broken traps that there is no longer any way for air to leave the system. Steam systems such as vapor systems that never had traps present other problems related to removing air and returning condensate to the boiler. These are not new problems created by installing radiator inlet orifices. They are simply the last hurdle to getting the system working.

Other Benefits

Radiator inlet orifices can also be used to downsize radiator capacity. For example, some people like to limit the temperature in entrance hallways. Installing an orifice with a hole smaller than that radiator's "correct" size will limit the heat output from that radiator. Buildings with radiators that are

SIZING A STEAM BOILER

Sizing a boiler for a sample steam heating system with and without radiator inlet orifices: *(Assume no domestic hot water load)*

Without radiator inlet orifices:

1,000,000 Btuh combined output from all radiators and piping
x 1.6 factor for pickup
1,600,000 Btuh necessary boiler output
Divide by 0.8 to account for boiler efficiency of 80 percent *(20 %chimney losses)*
= 2,000,000 Btuh necessary boiler input

With radiator inlet orifices:

1,000,000 Btuh combined output from all radiators and piping
x 1.1 estimated pickup factor for piping
1,100,000 Btuh necessary boiler output
Divide by 0.8 to account for boiler efficiency of 80 percent
1,375,000 boiler input necessary

Radiator inlet orifices reduce the size of a boiler used only for space heating from 2,000,000 to 1,375,000 Btuh, a reduction of about one-third. The reason this works is that radiator inlet orifices limit the load on the boiler to the amount of heat the radiators can put out, which is smaller than the pickup load associated with warming cold radiators up as fast as full open piping can supply steam to the radiators.

oversized as a result of new energy-efficient windows or increased insulation can benefit from "undersized" orifices in the same way. The smaller orifice has an effect similar to installing a smaller radiator, but at a much lower cost.

Another benefit of installing inlet orifices is reducing the size of the boiler necessary to heat all the radiators in the system. The peak load on a steam heating boiler installed in a steam heating system without radiator inlet orifices is the load associated with warming radiators up from room temperature to the temperature to which steam heats them. Because cold radiators condense steam at a higher rate than hot radiators, the peak load on the boiler occurs at warmup. A steam heating boiler needs to be sized to meet this peak load, and this peak occurs every time a steam system cycles on, regardless of outdoor temperature. Later, as the radiators are all as warm as they will get, the load is less than what it was when the radiators were cold. Therefore, a properly sized steam heating boiler is sized to meet the output from all the radiators plus a pickup factor of about 30 percent to 60 percent of the total of all the radiator outputs, a number that varies depending on whom you ask. A smaller pickup factor is associated with radiators with a smaller thermal mass, such as steel convectors, and a higher pickup factor is associated with radiators with a higher thermal mass, such as cast iron radiators.

There is much confusion about pickup factor in the industry, with some people incorrectly believing the pickup factor is a safety factor intended to account for some unknown. With orifices on each radiator sized to limit steam entering a radiator to an amount that radiator will condense, steam cannot enter the radiator at a rate exceeding the radiator's heat output. Therefore with radiator inlet orifices installed, the peak load on the boiler no longer exceeds the output from the radiators and piping, except for a small pickup factor for the piping. After orifices have been installed any future replacement boiler can be reduced in size. The money saved by installing a smaller boiler and related equipment can more than pay for installing radiator inlet orifices.

Results that can be expected

Because a radiator with an inlet orifice will not warm up as suddenly as a radiator without an orifice, the temperatures in a building equipped with radiator inlet orifices will be more even than before, even if there were no problems with the traps. Pressure will build up in the supply piping long before all the radiators are hot, and this pressure will cause steam to go to faraway radiators sooner than it would without orifices. No longer will all the sections on a radiator near the boiler be hot while a more distant radiator has yet to receive any steam. In cold weather, when the system runs for long periods, all the radiators will heat most or all the way across, while in mild weather, only a few sections will heat before the system shuts off. This prevents much of the mild-weather overheating associated with steam systems that do not have inlet orifices.

Potential problems

It is possible for orifices to clog with pipe-thread compound or rust, but none of the orifices installed by myself or colleagues in more than 1,000 apartments in the New York City area over the last five years has clogged yet. Of course, if an orifice clogs, it would be easy to find the problem because its radiator simply would not heat. Steam traps are rumored to sometimes fail shut, but none so far has been found clogged or failed closed when left in place at the time of conversion to an orifice system. Presumably, the talk about traps failed shut was caused by radiators that were airbound or by traps that were held closed by steam entering from the return side.

Products are sold that replace steam traps with small orifices on the outlet of the radiator, which depend on the difference in volume between steam and condensate to limit the amount of steam entering the returns. Unfortunately, those orifices need to be drilled so small that there are problems with clogging, despite the use of filters. These devices are not in widespread use in steam heating systems. However, the U.S. Navy uses them on ships, presumably because of the certainty of not needing spare parts when the nearest supply house is 5,000 miles away. I recommend installing orifices on the inlet side of steam radiators and do not recommend installing orifices on the outlet side of radiators.

Convectors fed from the bottom are a problem because in a pipe feeding steam vertically up, water might be held above the orifice by the steam flowing through the orifice. I have seen radiator inlet orifices installed on a few convectors that made a small gurgling noise. The occupant said the slight noise was not objectionable, but someone who did not suffer through the overheating before orifices were installed might have a different opinion. Many convectors that each let some water drain back into the boiler when the steam shuts off might raise the boiler waterline significantly, which could cause trouble in a building full of up-fed convectors. This problem can be minimized by installing the orifice as close to the convector element as possible.

Conclusion

Because all sorts of idiocies take place with heating systems over time, and over a series of mechanics, superintendents, engineers, plumbers, and meddlers, there is always a chance that someday, someone, for some unknown reason, will cause problems by removing an orifice. However, the chance of a steam trap failing someday is 100 percent—that is, 100 percent for each and every trap in the system. The problems caused by someone removing orifices are minimal compared with problems caused by traps breaking.

For the same unknown reasons, someone might play with the pressure settings on the boiler. One way to attempt to prevent this is to post a sign explaining that the system is an orifice system and needs to be run at 2 psi. This can reduce future headaches associated with changes in pressure settings, orifices getting removed, etc.

Inlet orifices should not be installed on fan coils, steam heated unit heaters with fans, steam coils in water tanks, and many other steam-heated devices that are not suited for conversion to radiator inlet orifices simply because the load varies too much. The heating capacity of a radiator shown in the chart assumes a certain indoor temperature inside the building; therefore, the load is theoretically constant, and in actual practice, is constant enough. If an orifice is installed on the inlet of a fan coil and sized for the capacity when the fan is running, and the fan shuts off, the heating capacity of the coil will drop to almost zero, and steam will pass into the return side of the system. Therefore, installing inlet orifices on steam-heated devices other than radiators that heat buildings is not recommended.

Over five years of experience with radiator inlet orifices in steam heating systems has shown that the long term headaches associated with orifices are nearly nonexistent, and the benefits are huge.

Future articles in this series will describe how to avoid problems with traps in basements by either making them easy to test without special skills or equipment, or by eliminating the basement traps; how to control temperatures room by room by installing inexpensive but effective thermostats on each radiator in a two-pipe steam heating system; and, if unavoidable, how to select and install a condensate pump that will require the absolute minimum maintenance.