Hydronic Conversion of Older Steam Systems

Steam heating systems are notoriously inefficient. Some loft systems consume so much fuel that they may well become unusable under CO_2 regulations. Fortunately, steam systems are readily converted to hydronic operation, re-using virtually all the existing components, including boiler, radiators, and piping.

In a hydronic heating system, hot water rather than steam flows through the pipes and radiators. Hydronic systems are far superior to steam systems in both efficiency and functionality, for which reason they have been the standard in Europe for decades.

Re-use of such old components can appear counter-intuitive, but extensive experience and basic chemistry both show this approach's viability. Such conversions have been successfully performed at a number of lower Manhattan buildings that date from the early 20th century.

Hydronic conversion is a comprehensive solution. Every tenant controls their own heat, underheating and overheating are eliminated, the system is silent, and fuel expense is reduced by as much as 50%.

Converted Buildings in Lower Manhattan

Below is a partial list of early 20th century (and older) buildings converted to hydronic by Jonathan Flothow, now on staff at Steven Winter Associates:

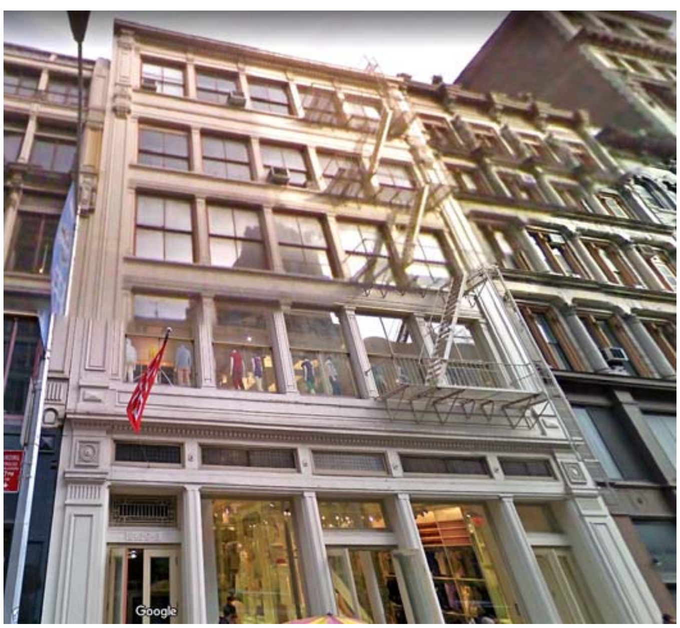
- *Noho (2011)*
This 1895 structure was originally a printing plant (photo on previous page).

- *Noho (2010)*
Adjacent to the above building, this primarily one-pipe system was converted to hydronic with modest additional piping.

- *Greenwich Village (2007)*
This pair of buildings is near Washington Square Park. The taller building is nine stories high (photo at right).

- *Soho (2009)*
The re-used original components include reverse-threaded cast-iron valves (photo below left).

- *Soho (2002)*
This six-story building is in Soho's cast-iron district (photo below right)



• *Greenwich Village (2005)*
This eight-story loft building houses music facilities (photo below right).

• *West Village (2005)*
This building houses the Westbeth theater. A critical impetus for hydronic conversion was to make the heating system silent for the theater.

• *Chelsea (2001)*
In this loft building, the original pipe coils remain the only radiation (photo below left).

• *Lower East Side (2013)*
This smaller building, owned and managed by Henry Street Settlement, had a one-pipe system. Return risers were added as part of the hydronic conversion.

• *Tribeca (2006)*
This smaller building, now residential, was also converted from one-pipe (photo above right)

• *Soho (2009)*
This was once a jewelry factory. The lofts are now residential.

Durability of Existing Piping

Hydronic systems operate at much higher pressure than steam systems. It's reasonable to wonder if century-old pipes can withstand the higher pressure.

Buried pipes certainly cannot. They deteriorate rapidly because of electrolysis, sometimes within two years of being buried.

But unburied pipes are not subject to electrolysis. When cut through, even 19th century steam pipes show no deterioration or loss of material. Empirically these pipes have proven sound: the conversions discussed above included hundreds of radiators and thousands of feet of pipe.

What accounts for this longevity? The answer can be found at the hand valves. The valves are brass, while the pipes are steel. Inside, a thin layer of water coats both. This configuration of mixed metals and water is called a *galvanic cell*.

Ordinarily a galvanic cell causes the rapid destruction of the less durable metal. When a brass valve is installed into a steel freshwater pipe, the steel pipe will typically start leaking after just a couple years. Yet steam pipes with brass valves remain sound after a century. How?

The key is that corrosion is a chemical reaction, and so it needs *reactants*. Brass hand valves keep steel pipes in a continuous state of heightened chemical reactivity, yet even after a century or more of this heightened reactivity, steam pipes haven't corroded. This proves that there is nothing for the pipes to react with: there is simply not enough oxygen moving through these systems to corrode the pipes. If there was much oxygen present, the steel pipes would have rotted out decades ago where they contact the brass hand valves.

The galvanic cells are the most vulnerable spots, the canary in the coalmine. And they're not leaking, so we know that the rest of the piping hasn't corroded either.

It shouldn't be surprising that steam pipes prove sound. In most old buildings the wiring and fresh-water piping had to be replaced long ago, and even much of the waste piping has rotted out. Yet original unburied steam pipes virtually never require replacement. Thousands of steam systems continue to operate after a century of service. Such longevity can only be explained by mild service conditions.

That said, conversion does entail extensive pressure testing of the piping, following the same procedures that would be used for new piping.

Fuel Savings from Hydronic Conversion

Three studies have been done on savings from hydronic conversion. While this body of literature is small, the documented results have been in keeping with anecdata from conversions performed in Manhattan loft buildings.

The most apposite study was performed in Minneapolis. Savings for total gas use (including for DHW) ranged from 13% to 39%. After disaggregating DHW, median savings for heating use were probably in the range of 45% to 50%[1].

A local study examined the fuel savings achieved by completely replacing an entire steam system with a hydronic one. Even with the expense of replacing all the radiators and risers, the project paid for itself in just under seven years[2].

The final study was done in upstate New York. The buildings had sophisticated management, but even then the steam systems were so inefficient that hydronic conversion saved from 22% to 50% [3].

Based on these studies and feedback from owners, we estimate that hydronic conversion can be expected to reduce heating fuel use by ~50% in converted loft buildings, given the extremely low efficiency of these buildings' crude and archaic steam systems. Indeed, given their high fuel use, it is difficult to imagine these systems remaining in service as steam systems once new CO_2 regulations come into effect in 2035. Many will have difficulty avoiding fines starting in 2030, when Local Law 97 will set a limit of 4.53 $KgCO_2e/Ft^2$.

[1] Mary Sue Loebenstein *et al*, 1986, "Converting Steam Heated Buildings to Hot Water", *Proceedings of the American Council for an Energy Efficient Economy*, 1986 Summer Study (1), pp. 183–196.

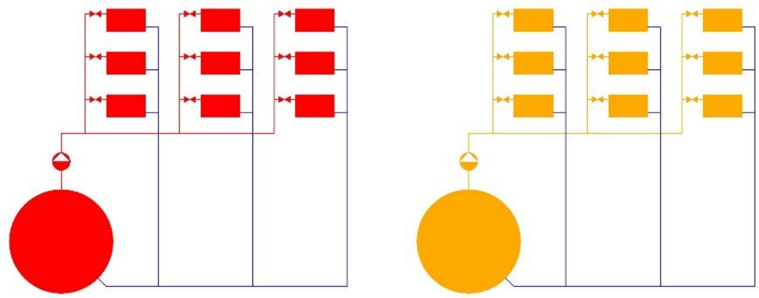
[2] Dan Rieber, September/October 2012, "179 Henry Street: A Case Study in Converting from Two-Pipe Steam to Hydronic Heating", *Home Energy*, pp. 32-36

[3] Ian Shapiro, May 2010, "Water and Energy Use in Steam-Heated Buildings", *ASHRAE Journal*, pp. 14-18

Functional Benefits

Accurate Temperature Control

In a hydronic system, the heating water circulates continuously. Its temperature varies in response to outdoor temperature, so that on mild days the water is barely warm, while on bitterly cold days it can be nearly as hot as steam (diagram at right). This gradual temperature variation eliminates the temperature swings and overheating caused by steam.



Continual operation also enables hydronic systems to comfortably accommodate extremely heterogenous equipment, conditions, and activities within the same building. Steam systems by contrast have great difficulty tailoring their output to different needs in different areas.

Respiratory Health

Steam heat is bad for respiratory health:

> Steam-heated radiators are uniquely bad for air quality because they get hot enough to pyrolyze dust, as shown in the photo on the bottom of Page 84. And because steam heat so frequently overheats buildings, it can encourage people to open windows during the winter, causing indoor humidity levels to drop to unhealthy levels. A healthier alternative would be radiators heated with hot water, since hot water radiators normally don't get as hot as steam radiators and are easy to control with a thermostat on each radiator, which prevents overheating. (Gifford, Henry, *Buildings Don't Lie*, Energy Saving Press LLC, 2017, page 430)

Low humidity is a serious concern in the Covid era, because it increases the transmission of airborne respiratory viruses. A study by the Yale School of Public Health has found a correlation between low humidity and increased transmission of the virus that causes COVID-19.

Flexibility

In a steam system, radiators need to be installed near to risers, using bulky and finicky piping, or hammer and poor heat will result. But hydronic radiators can be located anywhere, using much smaller piping.

In addition, steam systems require that all radiators be of the same type. But hydronic systems can accommodate every type of heater together: cast-iron radiators, inexpensive baseboard radiators, high-design panel radiators. Even radiant floors can be connected.

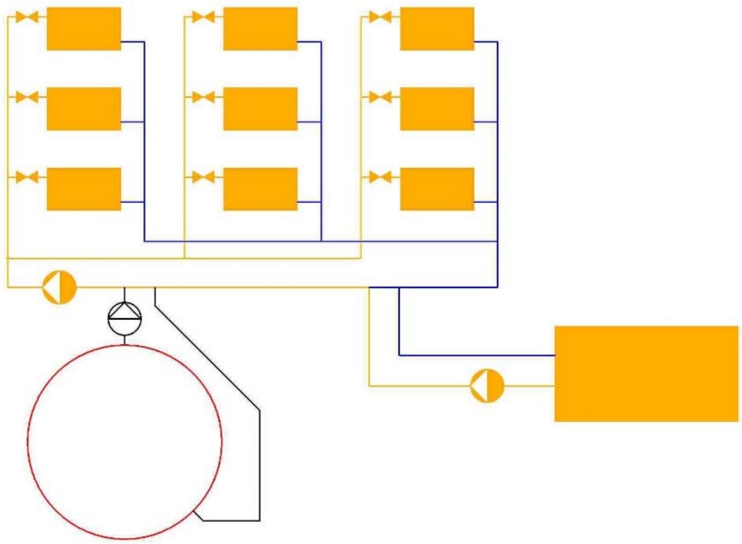
Silent Operation

Conversion eliminates the three sources of noise in steam systems:

- Hammer: This is caused by steam meeting water. With the steam gone, no hammer can occur.
- Expansion noise: because a properly configured hydronic system changes temperature very slowly, the noises caused by rapid thermal expansion are eliminated.
- Venting air: In a steam system, this happens about once an hour. In a hydronic system, it happens only when the system is first filled with water.

Pathway to Electrification

Hydronic systems offer a simplified pathway to the use of heat pumps rather than fossil fuels. Heat pumps cannot efficiently generate the high temperatures needed to make steam, but they are extremely efficient at heating water to temperatures that can be used in hydronic systems.



A very attractive option is to add a relatively small air-to-water heat pump to the converted system, while leaving the original boiler in place (diagram at right). The boiler would operate only during the coldest weather, when very hot water is needed (and when heat pumps are least efficient). During the bulk of the heating season the boiler would stay off, and the full heating load would be carried by the heat pump, operating at its maximal efficiency. This hybrid configuration, called “displacement”, would capture the majority of available energy savings at a fraction of the cost of a full heat pump conversion.

Eventual full electrification might require that the radiators be fan-assisted (this has to be evaluated case-by-case). Fan-assist can be achieved by replacing the existing radiators with fan-coil units, or possibly by retrofitting the radiators with fan-equipped enclosures.

Either configuration eliminates one of the difficulties of heat pumps: running hundreds of feet of refrigerant lines through occupied spaces to every radiator in the building. Compared to re-using old steam pipes, new refrigerant lines have some disadvantages. Leaks are an environmental concern, because refrigerants are potent greenhouse gasses, hundreds to thousands of times more potent than CO_2. Leaks can be created both during and after installation, and can be extremely difficult (or even impossible) to find. Many refrigerants are flammable (although these are banned in NYC). Refrigerant systems usually can’t be expanded, whereas old steam pipes are so large that they can easily accommodate additional radiators. The added piping can run in any length and direction, but refrigerant piping has to follow specific rules. Laying out and filling refrigerant systems is specialized work. Doing it wrong reduces efficiency and comfort. Finally, converted steam pipes are more future-proof: as various refrigerants are phased out in the future, some refrigerant piping might prove unsuitable for re-use.

The hydronic system can also be used for air conditioning, although this is a much larger project. A cooling tower or dry cooler would have to be installed, the radiators replaced by small heat pump/AC units, and (unpressurized) tubing run from the units to drain condensate. That said, this configuration can be attractive, since the alternatives all require one of following: units in the windows or through the exterior walls; units mounted to the building façade; or an extensive network of refrigerant tubing running through the building. The hydronic configuration avoids these requirements, and has been used in new construction for decades. And it can fully electrify the heat (even as the old boiler can be kept in place as a backup).

Work Needed for Hydronic Conversion

Thermostatic Radiator Valves

As part of the conversion, each radiator needs to be equipped with a thermostatic radiator valve (TRV), which acts as a thermostat. TRV's sense room air temperature, and vary the flow of heating water as needed to maintain comfort. They are simple devices that require no electrical wiring.

Because TRV's work independently, tenants control their own heat without affecting anybody else. In addition, TRV's compensate for different radiators, different exposures, and changing weather conditions. As sunlight and wind vary, TRV's in different parts of the building respond as needed to maintain constant temperatures.

TRV's (sometimes called Danfoss valves) work poorly in many steam-systems. But they work perfectly in hydronic systems.

And they are essential to saving fuel. A well-balanced heating-system uses the same principle as a flat "soaker hose": water runs easily through the length of the hose, but meets resistance at the tiny holes that run along it. The result is that the farthest holes get as much water as the nearest ones, because resistance at each hole dwarfs the resistance thru the hose. TRV's do the same thing: by creating high resistance at each radiator, they make irrelevant the resistance in the distribution piping. So each radiator gets comparable flow, even though the length and size of the piping varies radically.

Sometimes converted loft buildings will already have various types of TRV's in place. All can be re-used, there is no need for absolute uniformity. Just so long as similar resistance is being created at every radiator, the system will balance.

Automatic Air-bleeders

In a conversion, most radiators need to be equipped with a small automatic air bleeder. These let air out of the radiators so that the water can fill them. The bleeders are very small, about the size of a cherry (photo at right).

The top of each riser receives a higher capacity bleeder, about the size of a baseball.

Heating Plant

A wide variety of approaches can be taken at the plant. If the plant is a boiler, it can supply steam to a steam-to-water heat exchanger, or the boiler itself can be converted to hydronic. If steam is supplied from a remote plant, a steam-to-water heat exchanger will be installed. If some manner of heat exchanger is in place already, it can generally be re-used: an exchanger that accommodates steam can easily accommodate water.

Pump Set

A circulator pump (or two, for redundancy) circulates the heating water through the entire system. These pumps are much smaller than those in new systems, because large steam pipes offer negligible resistance to flow. So electrical consumption is minimal, and the pumps operate silently.

Pump selection is an important part of design. High head pumps should be selected on the basis of careful matching to the system. The more common flat-curve pumps won't suffice, and will use excessive energy.

Expansion Tanks

Because water expands as it is heated, every hydronic system requires tanks to accommodate the expanded volume of water. Steam pipes are large, so converted systems generally need several 120-gallon expansion tanks (photo at right). While bulky, these tanks can be located pretty much anywhere.

Heat Control

Duty-cycle steam controls (the most common type) cannot be re-used in the converted system. Such controls need to be replaced with a simple outdoor reset hydronic control or with a more sophisticated EMS system. If an EMS is in place already, it can be reused in the converted system.

Replace or Abandon Buried Pipes

As noted, buried pipes cannot re-used, as they have been subject to destructive electrolysis. But in many cases they would become redundant in the converted system, and so can be abandoned without being replaced. Where they must be replaced, the new piping can be much smaller, and can run overhead.

Obviated Components

All air-vents and steam-traps are removed in a conversion. Short runs of basement drip piping are typically also removed.

Testing & Leak Prevention

Leaks are the greatest concern raised by hot-water conversion. Leaks are prevented by testing the system in stages, using pressurized air. After all piping work is complete, the system is pressurized and inspected. Leaks are apparent from the sound of hissing air. During inspection the pipe joints can be sprayed with mild soap suds for extra rigor.

Leaks in original piping are exceedingly rare; most leaks are at hand-valves that had been replaced at some point. Perhaps one in ten to twenty radiators will have such a leak.

Once the leaks are repaired, the system is again pressurized and inspected to ensure the repairs are sound. The sequence is repeated as needed until no leaks remain.

For additional certainty, one more pressure test can be performed, this time with peppermint oil added to the air. If any leaks remain, peppermint aroma will indicate their location.

After all air testing is complete, the system is filled with water, the heating system activated, and the entire system inspected again. With the system hot, a handful of very slow seeping leaks may start. About half will seal themselves. The rest may be too slow even to generate water drops, but generally should be repaired anyway. Again, these will virtually all be in the small radiator piping.

Ideally, every foot of pipe should be visible. If piping is enclosed in box-outs and cabinetry, the enclosures should be opened as much as possible. Full visual inspection is the ideal. If too many pipes are obscured, a peppermint test is required.

The key to preventing leak damage is logistical: during the tests, every space must be accessed, every room entered, every pipe looked at. So long as access is good, damage is easily avoided.

This leak testing procedure is time-consuming and logistically challenging. But what makes it complicated is not the age of the piping, it's that the testing occurs in an occupied building. New piping would have to undergo the exact same procedure, and would entail much more disruptive work.

Feasibility of Work by Building Staff

The majority of work in a hydronic conversion, namely TRV's and air bleeders, is done at the radiators. This work can be done by any staff competent to replace a hand-valve (a common superintendent task). Where building labor is available, costs could be greatly reduced by having staff perform this portion of the work.

Design

The design of hydronic conversions is simple, and was perfected decades ago in Europe. Converted systems are even simpler, as they do not require specialized valves to even out the flow (whereas the smaller piping in new systems makes such valves necessary).

Systems Suitable for Conversion

Maximum System Height

The main factor limiting hydronic conversion is building height. The taller the building, the greater the water pressure in the lowest floors of a hydronic system.

Conservative practice is to limit cast-iron components of unknown rating to 30 PSI. This would restrict conversions to six-story buildings. But in reality, cast iron can easily bear at least 50 PSI of pressure, which allows for a system at least eighty feet high. The converted Greenwich Village building, for example, is nine stories tall.

Cast-iron radiators' true pressure capacity is not known, but could be determined by testing some old cast-iron radiators to destruction. Boiler manufacturers test cast-iron boilers to double their rated capacity, and they don't fail even at the higher pressure. Given cast iron's strength, thorough testing is certain to enable the conversion of taller systems. Even the antique radiator at right was successfully converted to hydronic.

Another approach is to replace any cast-iron radiators on the lowest floors, installing heaters made of copper fin-tube or steel. Ground floors in particular often have only a few old radiators, so this approach can be practical. Such an approach can increase costs greatly, however, and will hopefully prove unnecessary once cast iron's capacity is better understood.

Two-Pipe versus One-Pipe

Two-pipe steam systems are the most amenable to conversion. That said, one-pipe conversions do happen, and can yield good paybacks.

The most straightforward method is to add risers and connect them to the radiators. This is far more intrusive than most hydronic conversions, which generally don't disturb finished surfaces. And the additional expense lengthens payback. That said, one-pipe systems with especially high fuel use can probably achieve reasonable paybacks from hydronic conversion. And as noted previously, one building achieved a seven-year payback despite piping an entirely new hydronic system, without re-using any existing components at all.

In some one-pipe systems, it is practical to reverse the direction of flow through half the risers, turning them into return risers. Each radiator is then connected to a second riser via small piping. No new risers are needed, so no floors have to be drilled. This strategy is especially well-suited to very small buildings, or systems with mixed one- and-two pipe sections. A system does not have to be entirely two-pipe to be a good candidate for conversion.

Hidden Piping

Ideally, all piping is visible for a hydronic conversion, so that everything can be inspected for leaks. That said, inevitably some piping is hidden, such as where risers pass through joist spaces. If much more piping than that is hidden, though, a peppermint test will be needed. If most of the piping is hidden, conversion may not be feasible, unless the enclosing components can be opened to allow for inspection.

Buried Risers

In many apartment buildings the risers are buried in walls. Often they run in the exterior walls, and are therefore insulated, typically with asbestos. While riser leaks are extremely rare, during the testing procedure any leaks that did exist could cause pressurized air to be blown into friable asbestos. This makes reuse of this piping infeasible.

If risers are buried in *interior* walls, however, they are probably uninsulated, and so are good candidates for conversion. Riser leaks are extremely rare, and a peppermint test can be relied on to reveal them.

Radiators With Bottom-Only Connections

Many radiators built before 1920 have sections that connect at the bottom but not at the top, such as the example at right. These radiators won't completely fill with water, because air stays trapped in them. But this probably doesn't matter: because of the basic physics of heat flow, these radiators will likely operate near full output after conversion. A radiator is covered with an insulating air film that impedes heat flow. Vastly more heat can be transferred from the heating water into the radiator than can flow out of the radiator's lower area. This excess heat travels up through the metal and eventually heats the entire radiator. And in any case, it is extremely unlikely that the radiators' full output would ever be needed, as most radiators became vastly oversized when windows were replaced.

Cast-Iron Baseboard

Cast-iron baseboard is perfectly suited to hydronic operation. However, runs longer than about twelve feet tend to develop slow leaks at their internal joints.

Buried Steam Mains

Most buried pipes are return pipes. But in some apartment buildings that were built on grade, typically post-war, the steam mains were buried in dirt and run beneath finished floors. Such piping would have to be replaced and run in sleeves or overhead, probably rendering conversion infeasible. Fortunately, this situation is rare in New York.