Urban Green

February 2019

DEMYSTIFYING STEAM

Urban Green Council's mission is to transform NYC buildings for a sustainable future. We believe the critical issue facing the world today is climate change. Our focus on climate change requires us to improve energy and other resource efficiencies in buildings, creating a more resilient, healthy and affordable city for all New Yorkers and beyond.

DISCLAIMER

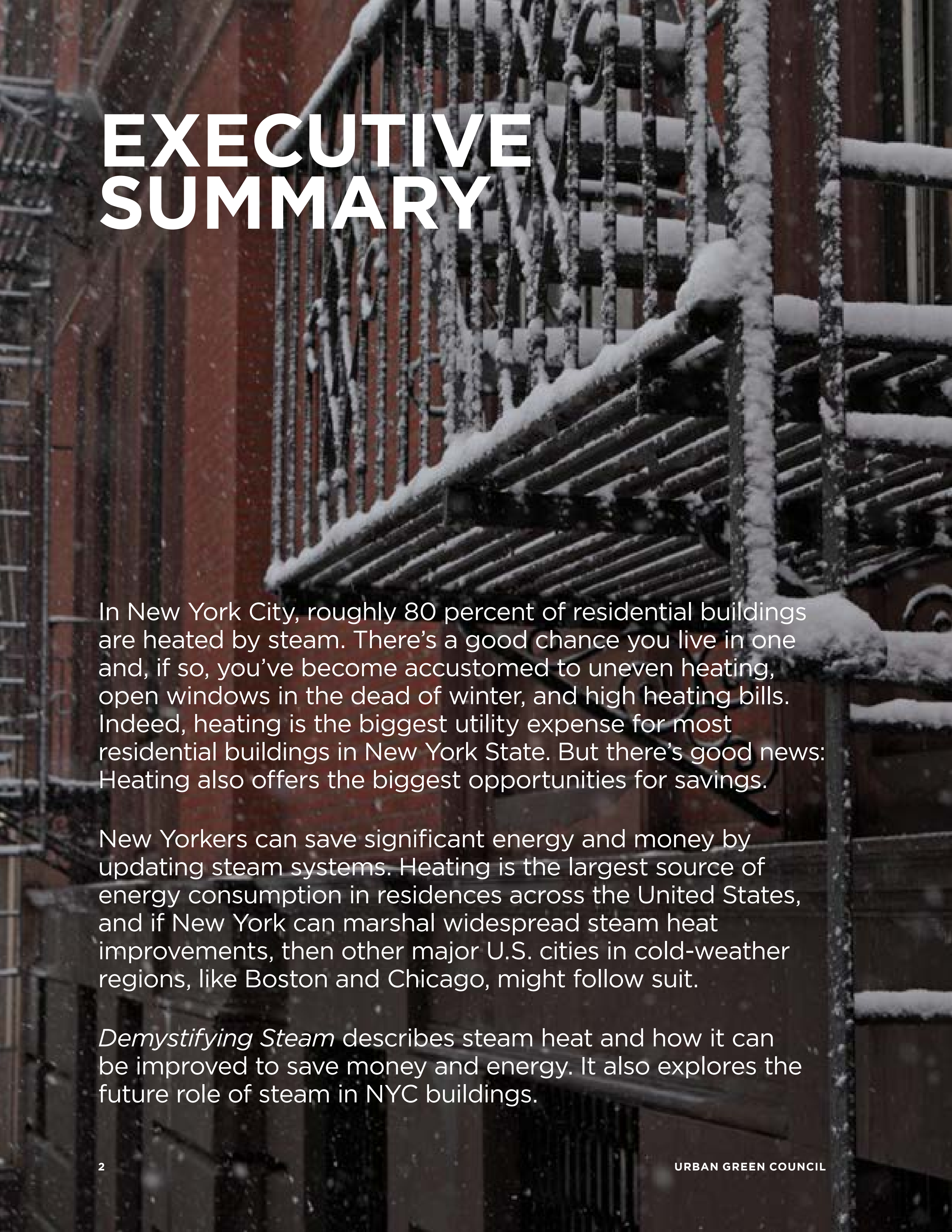
DEMYSTIFYING STEAM

For All New Yorkers

For Building Owners

For Policy Makers

For More Information



EXECUTIVE SUMMARY

In New York City, roughly 80 percent of residential buildings are heated by steam. There's a good chance you live in one and, if so, you've become accustomed to uneven heating, open windows in the dead of winter, and high heating bills. Indeed, heating is the biggest utility expense for most residential buildings in New York State. But there's good news: Heating also offers the biggest opportunities for savings.

New Yorkers can save significant energy and money by updating steam systems. Heating is the largest source of energy consumption in residences across the United States, and if New York can marshal widespread steam heat improvements, then other major U.S. cities in cold-weather regions, like Boston and Chicago, might follow suit.

Demystifying Steam describes steam heat and how it can be improved to save money and energy. It also explores the future role of steam in NYC buildings.

In particular, the *Demystifying Steam* report:

1. Identifies steam system problems affecting building owners, managers and occupants;
2. Details the prevalence of steam systems in New York City and discusses how experts improve common steam systems;
3. Suggests best practices and policies the city and/or state could pursue to capture most or all of the savings from improving steam heat;
4. Analyzes the costs, as well as the potential carbon and fuel savings of improving steam heat in New York City and across the state;

Steam heat revolutionized heating technology. It replaced fireplaces and stoves, offering better indoor air quality, comfort and efficiency. Today, over 100 years later, the steam systems that heat our homes haven't changed much. But what passed for efficiency and comfort in the 20th century is no longer acceptable. Our survey of New York City tenants with steam heat found that nearly 70 percent are chronically overheated in winter. Many tenants open windows for relief, even on the coldest days. But steam systems are so unbalanced that other residents in these same buildings don't receive enough heat.

In other words, we're burning through significant amounts of gas and oil to keep New Yorkers uncomfortable. A 2016 performance analysis showed that fuel consumption in steam heating systems varies widely.[1] Neglect has led to overheating and undiscovered boiler-killing leaks. These systems could be retrofitted to use less fuel. Additionally, converting steam to hydronic heating has yielded as much as 50 percent fuel savings in buildings throughout New York.[2]

With upgrades and more consistent maintenance, it's possible to improve efficiency and comfort. Adding sufficient venting and simple valves can improve distribution and give residents better control over temperature. Controls can also be installed that respond to indoor rather than outdoor temperature.

Oversized boilers are another problem. Without a properly sized boiler—one that provides heat where it needs to and without excess—even a well-maintained system will be inefficient. Boilers can last for more than 30 years, so timely boiler replacement with proper planning is critical. When the boiler is ready to be replaced, properly installing a right-sized boiler can increase system efficiency and reduce fuel costs by 5 percent or more.

For New York City to continue to reduce building emissions, improvements to steam heat must be implemented now. Our research found that retrofitting steam systems in New York City buildings larger than 5,000 square feet would cut that sector's fuel consumption by 19 percent.[3]

The improvements recommended in this report can be made by investing less than a dollar per square foot. If improvements are made at the time of a planned boiler replacement, the reduced cost of a smaller boiler will help offset the cost of distribution upgrades. Afterward, heating and hot water expenses **would drop by roughly 20 percent—with distribution improvements typically responsible for two-thirds of these savings.**

Making steam as efficient as possible over the next 10 years will save building owners and tenants money, avoid cumulative emissions, and improve resident comfort. In the long run, however, more will be needed to meet New York City's 80x50 carbon reduction goals. To achieve 80x50, we must cut 80 percent of 2005 emissions—over 33 million metric tons of carbon in buildings alone—by 2050 (80x50). That's a herculean task that would have the same climate benefits as closing eight coal-fired power plants.[4]

Even if every residential steam system was retrofitted for maximum efficiency, residential steam heat would consume the citywide carbon budget for buildings in 2050, before electricity use or non-residential buildings are considered.[5] The state's greenhouse gas reduction goals of 40 and 80 percent by 2030 and 2050 respectively will require building owners to pursue non-fossil fuel heating technology.

In the long term, to increase tenant comfort and radically reduce New York City's emissions, we need to convert or replace our outdated steam heat systems with modern heating alternatives. In the medium-term, however, fixing steam is a highly cost-effective measure that will buy us time to move away from fossil fuels altogether. But we must act immediately if we wish to mitigate the worst impacts of climate change.

BACKGROUND

The advent of steam heat revolutionized building comfort and safety. Yet as buildings have advanced over the last hundred years, steam systems have changed far less.

The ability to harness heat is central to the success of human civilization. Throughout history, people gathered around fires to cook food, ward off predators, and of course, to keep warm. As human life moved indoors, we designed fireplaces and stoves to capture heat and contain it within the built environment. These early space heating systems were inefficient, and the development of steam heat made comfort more consistent throughout the building while improving safety by isolating fuel burning to the basement.

One of the earliest uses of steam heat was in the 17th century, when it was piped into greenhouses to keep plants warm. That nascent idea was iterated on many times until James Watt, celebrated for his steam engine, used it to heat his study in the winter of 1784-85. He founded his system on a simple thermal cycle: Fire heats water until it boils and becomes steam. The steam travels through distribution pipes, releases heat, and then conveniently condenses back into water. Gravity brings that water back to the boiler and the process repeats. This system spread and developed rapidly; it reached American homes by 1855, when steam heat was installed in President Pierce's White House.[6]

The history of steam heat offers clues as to how we can improve these systems today. In the early days of the 20th century, there was a widely-held fear of stagnant air, so people kept their windows open throughout the year. To avoid complaints, builders recommended boilers and radiators that were large enough to heat buildings on the coldest days of the year, with the windows open.

After World War I, the dominant fuel source for central heating changed several times, from coal to oil to natural gas, which now fuels 64 percent of NYC steam systems. Replacement equipment was sized unsystematically and included a generous safety factor to ensure replacement boilers were not too small to heat the necessary space.[7]

Over the years, buildings were retrofitted with double-pane windows that retain heat more effectively than older single-pane models. Insulation and air sealing are now a part of the building energy code and included in some retrofits. But most steam systems in New York City were not modified to account for these changes. People still open their windows in the winter, not out of fear of stagnant air, but because their apartments are overheated by oversized steam systems.

Not surprisingly, steam heat is no longer viewed as the optimal solution. It's uncommon in new construction, however, the technology persists in existing buildings. The result is poorly maintained and inappropriately sized systems that waste energy, release excess greenhouse gas emissions and overheat some rooms while leaving others cold.

FIGURE 1

Steam Systems Heat Most of NYC

Over 75 percent of residential area is steam heated. It covers 1.8 billion SF of multifamily, almost 700 million SF of commercial and over 90 million SF of industrial building area. See Appendix Table 2 for size details.

SOLUTIONS FOR YOUR BUILDING

Heating is the single largest energy end use in New York City buildings, and simple improvements could save owners close to 20 percent on annual fuel bills.

Heating is a significant operational expense for any building owner. The typical large multifamily building owner in NYC spends $0.60 per square foot annually on heating and hot water. And that's only if the building uses the cheapest fuel—natural gas. If a building uses fuel oil, then the cost can jump to $1.30 per square foot.

Fuel oil is more expensive than natural gas. But regardless of the energy source, heating is one of the largest utility costs for a typical multifamily building owner.

And what are owners paying for? Unfortunately, not tenant comfort. Our tenant survey found that almost all respondents living in a steam-heated building had complaints about loud noises and wild temperature swings.[8] The good news is that these problems can be solved cost-effectively in many cases.

The key to cutting costs and complaints is to send steam to the farthest points of the heating system, while preventing overheating in apartments that are already warm. This evening-out of heat distribution is called *balancing*.

How Steam Heating Works

Steam heat can be divided into two main components: the boiler and the distribution network of radiators. Fuel is burned in a boiler that heats up water until it turns into steam. As the water turns into steam, its expansion causes an increase in pressure. The pressure forces steam out of the boiler and up into the pipes that connect the boiler to the radiators. Once the steam gives up its heat in the radiators, it condenses back into water and drains down into the boiler to repeat the process.

The simplicity of these systems has made them durable. But their durability has locked into place technical limitations of a century ago. Today, our goal is to provide just enough heat while keeping windows closed. That means we must fix leaks, improve maintenance and carefully upgrade steam heat systems.

There are solvable problems with these existing steam systems and we've highlighted the best solutions and upgrades below. Upgrades to the distribution system will cut fuel use and tenant complaints the most. These changes typically cost less than $1 per square foot and can be made even more cost-effective if completed alongside a boiler replacement.

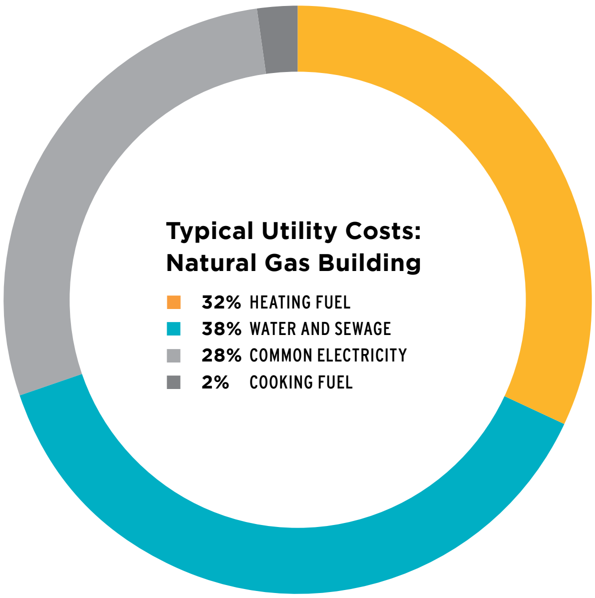
Boilers

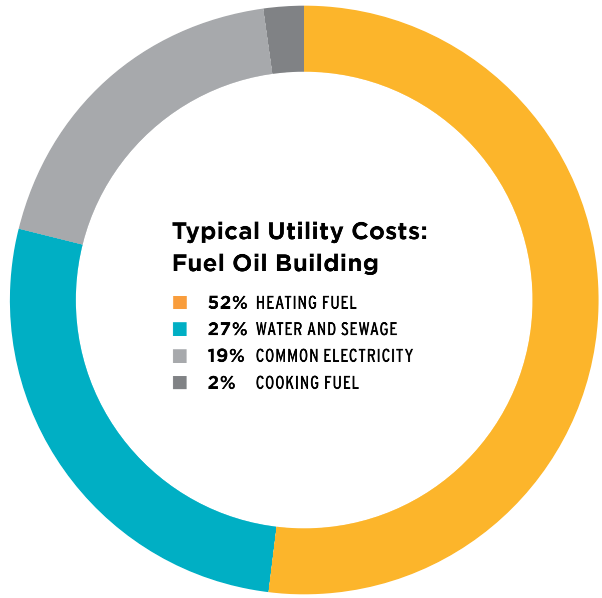
Steam boilers can last 30 years, so implementing best practices at the time of replacement is critical. The right replacement can increase system efficiency, improve occupant comfort and reduce fuel costs by 5 percent or more. The energy-efficient choice may be the most cost-effective, as smaller boilers tend to be less expensive.

FIGURE 2

Fuel Dominates Utility Costs

Fuel oil is more expensive than natural gas. But regardless of the energy source, heating is one of the largest utility costs for typical multifamily building owners.





PLAN BOILER REPLACEMENT

As previously mentioned, many boilers are bigger than necessary. A boiler that is too big for its distribution system will quickly fill the radiators with steam and then shut off. When the system calls for more steam shortly thereafter, the boiler fires back up. This frequent on-and-off cycling wastes energy and makes it difficult to maintain the stable pressure needed for efficient operation.

The original coal-consuming steam boilers are long gone, but the problem persists because new equipment has historically been sized based on the existing boiler upon replacement.

Instead, replacement boilers should be sized based on the existing *distribution* system (Figure 3, Number 1). Building owners should make sure that their engineer or contractor uses one of the following sizing methodologies when replacing steam boilers. Either method will be a major improvement over making a like-for-like replacement.

- The best practice for this is the *cold-start method*. Outlined in more detail in the Appendix, the cold-start method uses the existing boiler to directly measure a building's heating load.

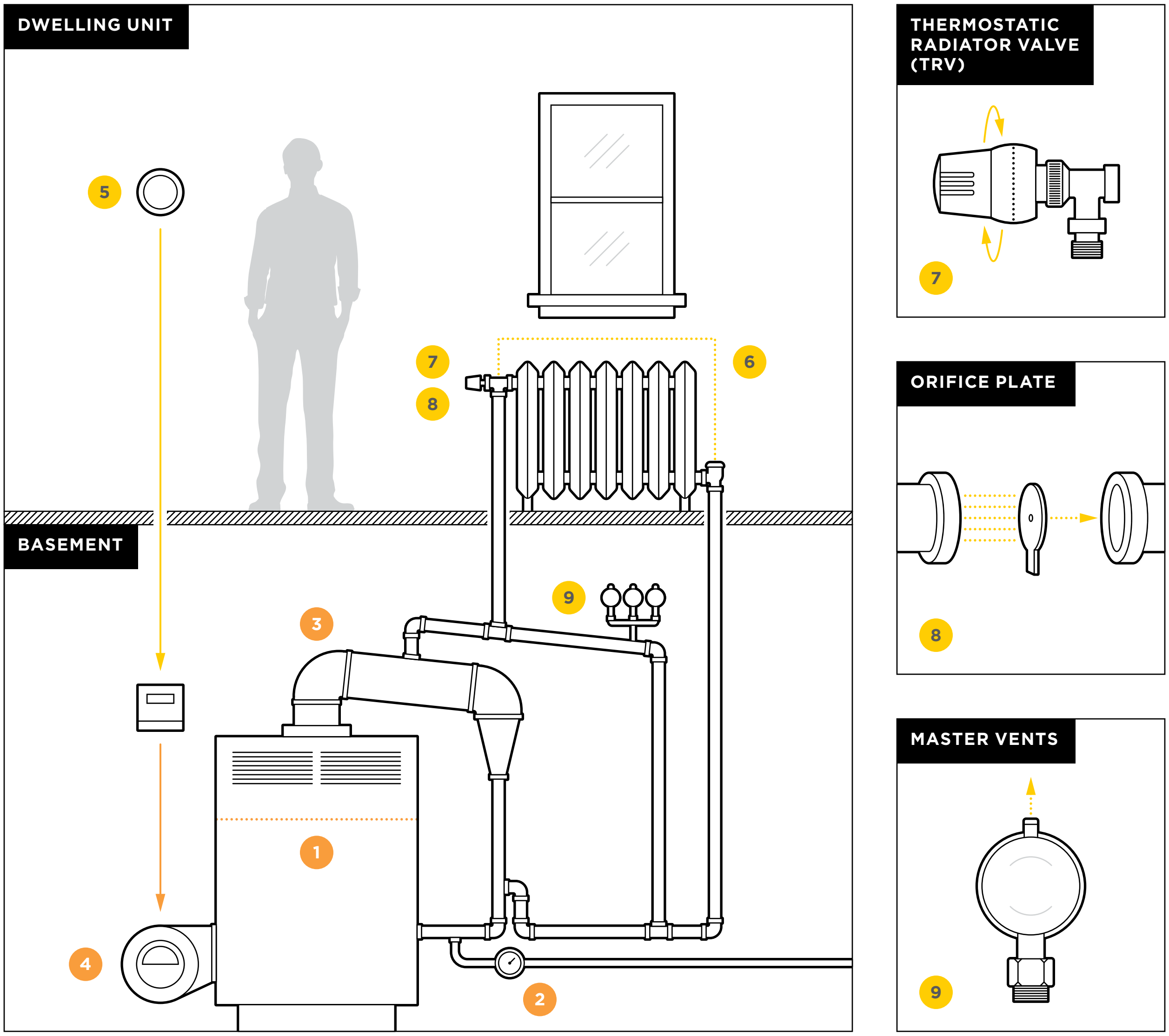
- An alternative method is Equivalent Direct Radiation (EDR), which takes into account the number and type of radiators in the building.

INSTALL MODULATING BURNERS

Even properly sized boilers can run inefficiently without controlling how fuel is burned. One of the most crucial aspects of boiler efficiency is the modulation of its burners, the components that actually produce the flame. Many systems have simple burners that only function in two modes, on and off. Modulating burners can allow for a range of levels of steam production. Burner modulation is similar to turning the kitchen stove flame higher to boil pasta, or lower to gently warm soup. Modulating burners reduce on- and-off cycling and optimize fuel

FIGURE 3

Targeted Improvements to Steam Heat Systems



BOILER IMPROVEMENTS

1. **Right-sizing boilers** at the time of replacement reduces equipment costs and helps conserve fuel.
2. **Dedicated water meters** to measure new makeup water flowing into the boiler help operators detect leaks and save water.
3. **Steam outlets and headers** with proper sizing and configuration are critical to reducing noise and fuel waste.
4. **Modulating burners** vary heat output and allow for a range of levels of steam production to reduce boiler on-off cycling.

DISTRIBUTION IMPROVEMENTS

5. **Indoor thermostatic sensors and controls** cut fuel waste and minimize overheating when implemented with other improvements.
6. **Radiant heat barriers** against colder exterior walls reduce heat loss and reflect it back into the room.
7. **Thermostatic radiator valves (TRVs)** regulate how much steam enters the radiator based on room temperature and give occupants some control.
8. **Orifice plates** constrict the flow of steam into the radiator to reduce overheating.
9. **Master vents** ensure that air escapes the system at the ends of the mains and the top of the risers.

efficiency (Figure 3, Number 4). Code requires modulating burners on large boilers, but the technology is available for smaller burners in low-rise buildings as well.

INSTALL THE OUTLET AND HEADER CORRECTLY

Steam exits the boiler outlet and into the header piping above. The quality of this steam is crucial to improving overall system efficiency. If the steam is too wet (meaning it contains water droplets), it leads to noisy pipes, spitting air vents and wasted fuel. To make dry steam (meaning it contains almost no liquid water), a boiler must be installed and maintained correctly. In particular, the outlet and header are crucial to making dry steam. Both should be installed according to the manufacturer's specifications and the energy code (Figure 3, Number 3).[9]

MEASURE WATER USE TO DETECT LEAKS

A dedicated water meter installed in the makeup feed line, which supplies water to the boiler, will allow the building manager to detect leaks so they can be fixed quickly (Figure 3, Number 2). Water leaks can cause a boiler to wear out quickly because new, fresh water must be added to replace any water that leaks out, and fresh water contains so much oxygen that it's highly corrosive to boilers. Water meters are especially important in buildings with buried heating system pipes, because these pipes frequently corrode and leak, and excessive water waste typically goes undetected.

Distribution Systems

The distribution system is made up of the pipes that carry steam and condensate around the building, the radiators, and all the valves and vents in between. **Improving this system can cut fuel use by at least twice as much as a right-sized boiler replacement.** Upgrades can be made when a tenant moves out or if there's a heating problem that needs to be addressed immediately. Both situations present opportunities to overcome the tenant access issues owners face when repairing distribution systems. Ideally, these improvements are made throughout the building to prevent imbalances.

Individual fixes will yield some savings, but the most benefits are realized when implemented together as a comprehensive improvement. A complete upgrade that includes the measures below will yield *significant* savings—potential fuel use reductions range from 12 to 15 percent. These improvements pay for themselves in lower fuel and maintenance costs in under a decade.

PREVENT TRAPPED AIR WITH MASTER VENTS

Steam and air fill the pipes and radiators at alternating times: Steam fills the system when the boiler's on, and air returns when the system is off. This cycle is not unlike breathing. When the boiler turns on, the steam's mounting pressure forces the air to exhale out through the system's vents. But if a vent is clogged, too small or not present, the air can't leave. This trapped air blocks the passage of steam, resulting in uneven heating throughout the building.

Ample venting can prevent air from being trapped. Large air vents, called master vents, should be installed at the ends of mains, large horizontal pipes, and tops of risers, vertical pipes branching off a main (Figure 3, Number 9). Without master vents, the system can't breathe properly; the rooms closest to the boiler get overheated, while the farthest rooms aren't warm enough. Proper venting means the system can run at low pressure, distributing steam quickly and evenly and reducing wasted heat from boiler short cycling.

INSTALL INDOOR HEAT CONTROL

Steam systems generally turn on and off based on *outdoor* air temperatures instead of *indoor* temperatures. If a building has reduced its heating demand by upgrading its windows or sealing air leaks, the boiler won't detect that it's overheating the space. Multi-sensor thermostatic heat controls are tied to a network of sensors that measure the temperature inside apartments; installing these controls makes it possible for the heat to turn off once the median temperature of the sampled apartments exceeds a certain point (Figure 3, Number 5).

Multi-sensor controls will yield the most benefits when implemented with other improvements, like installing master vents. When the system is distributing heat evenly, advanced heating controls will cut fuel waste and minimize overheating. However, if the system is unbalanced and some apartments receive much more heat than others, advanced heating controls can't reduce the imbalance.

REFLECT HEAT WITH A BARRIER

When the heat is on, the large temperature difference between the radiator and the outside of the building causes heat to flow out through the walls. A radiant barrier, a simple piece of rigid or bubble insulation wrapped in a layer of metal foil, can be placed behind the radiator to stop some of this heat flow (Figure 3, Number 6). The foil's reflective surface bounces heat back into the room.

IMPROVE RADIATOR PERFORMANCE

Improving the controls on individual radiators can significantly increase energy efficiency. However, to choose the best control device for your building, it is important to understand the two types of steam distribution systems: one-pipe or two-pipe steam.

Both one-pipe and two-pipe systems use a boiler to burn fuel and produce steam, but they handle condensate differently. One-pipe systems carry away condensate down through the same pipes that send steam to the radiator. Two-pipe systems send steam up with one set of pipes and drain away condensed water with another set of pipes.

In both types of systems, the key to controlling radiators is to limit the amount of steam that enters them.

Thermostatic Radiator Valves for One-pipe Systems

One-pipe systems are usually found in smaller, older buildings, and heat half of New York's residential floor area. Although simpler in design than two-pipe systems, they are much more difficult to control because the radiator valve must remain wide open both for steam to enter and water to exit. If a one-pipe radiator valve is partially closed, water hammer (loud banging that results from water meeting steam) often occurs. That means that these radiators have to be either on or off—there is no in between.

The best option for one-pipe systems is to install thermostatic radiator valves (TRVs) on radiators (Figure 3, Number 7).[10] These valves are usually open to let air out. When steam flows into a radiator with a TRV installed, as the room warms, the valve will respond to the increase in temperature and close. This traps air in the radiator and prevents additional steam from entering.

Orifice Plates and TRVs for Two-pipe Systems

Two-pipe steam systems are mostly found in commercial or large residential buildings (Figure 1). They are quieter, easier to control than one-pipe systems and present more opportunities for savings because they allow adjustment to radiator steam supply.

A simple way to reduce a two-pipe radiator's steam supply is with an orifice plate, a small metal disc with a hole in the center (Figure 3, Number 8). When installed in the radiator valve, it only allows as much steam to enter the radiator as the radiator can condense.

Another benefit of installing orifice plates is that they eliminate the need for almost all steam traps. These devices, located between the radiator and condensate return pipe, stop steam from entering the return. But steam traps notoriously fail within 5 years and are a hassle to replace, so eliminating them reduces maintenance costs.

TRVs, discussed above, can also be used in two-pipe systems. In this application, the TRVs directly regulate the supply of steam coming into the radiator. TRVs should always be installed in overheated apartments since they will automatically stop the steam from entering the radiator once the temperature gets too hot.

RADIATOR COVERS

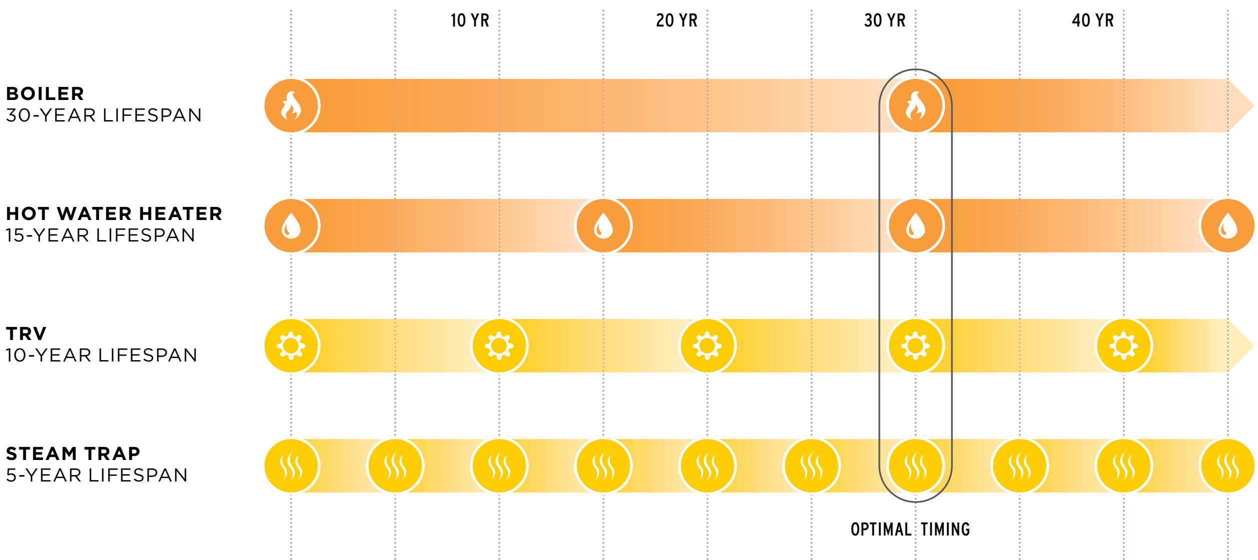
Thermostatic radiator enclosures (TREs), also known as 'cozies', are simply insulated enclosures that cover existing radiators. The enclosure keeps heat inside the radiator until it is needed in the room. When the room gets too cold, a small fan inside the cozy quickly blows heat into the space. The cozy effectively becomes an on/off switch for each radiator. It also communicates room temperatures back to the boiler, optimizing when it burns fuel. These systems have already been installed in some NYC buildings with encouraging results.

NYSERDA published a study in May 2018 that detailed the fuel savings in seven buildings that made the distribution upgrades outlined

FIGURE 4

Replacement Planning is Critical

Equipment lifetimes vary and investment opportunities for the most expensive elements are limited. Planned comprehensive replacements can reduce costs and have the biggest savings.



in this report and installed cozies.[11] They saw energy savings of at least 14 percent from space heating, and room temperatures also dropped by a few degrees while staying comfortable. The buildings that saw smaller savings had steam systems that were already operating efficiently, so cozies may be able save fuel even after traditional steam improvements have been made.

Cozies require comprehensive upgrades, like master venting and trap replacement, but offer an additional improvement to both comfort and efficiency.

CONVERTING TWO-PIPE STEAM TO HYDRONIC

In certain cases, steam systems can be converted to carry hot water instead of steam. Some of these conversions have achieved fuel savings of 40 to 50 percent.[12] Costs for this work can vary widely by building depending on the accessibility of the piping and whether the steam radiators can accommodate hot water. Hydronic conversion is an excellent option to consider at the time of boiler replacement if all of the existing distribution equipment can be reused.

Cost Savings and Case Studies

The most cost-effective way to balance a steam system is by making improvements to the steam distribution system in conjunction with boiler replacements. When done together, the simple payback period for the combined sets of improvements on residential buildings is eight years or less. Not only is this the most economical approach, but experts say it is the most effective way to ensure the steam systems perform optimally, reduce fuel waste and increase tenant comfort.

Simple paybacks depend on many factors, including fuel prices and the building's distribution system type.[13] As discussed earlier in this section, on average, one-pipe systems waste more fuel, and two-pipe systems are more amenable to improvement.

A wider variety of building case studies is presented in the report's appendix.

The four retrofit examples in Figure 5 are all medium-sized (50,000 square foot) residential buildings that use one boiler for both space heating and supplying domestic hot water.

FIGURE 5

Combining Improvements Cuts Costs

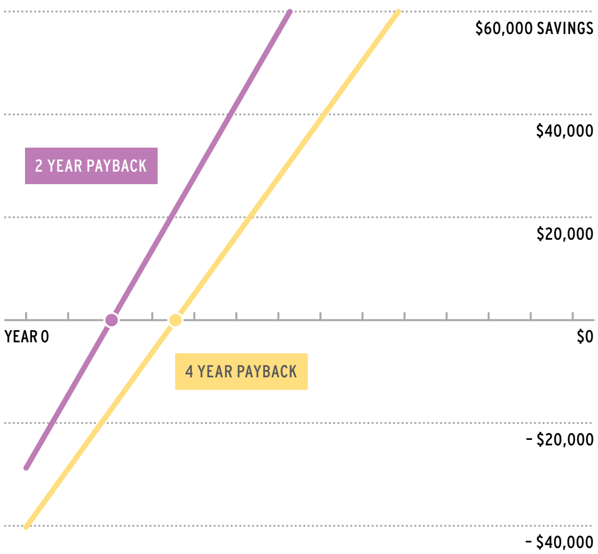
Comprehensive improvements to both the boiler and the distribution system are most cost effective and yield the most energy savings when implemented together at time of natural boiler replacement.

See Appendix, pages 26 to 28 for complete tables of projected cost savings for other building types.

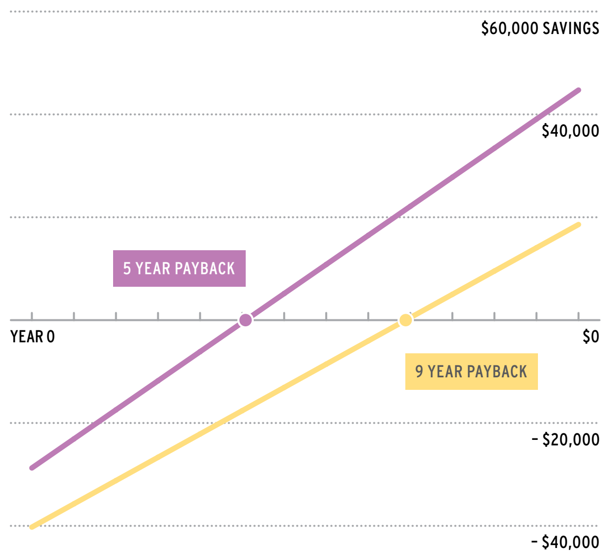
Cost Payback Case Study: 50,000 SF Residential Steam-heated Building

DISTRIBUTION IMPROVEMENT PACKAGE ONLY
COMBINED DISTRIBUTION AND BOILER IMPROVEMENT PACKAGES

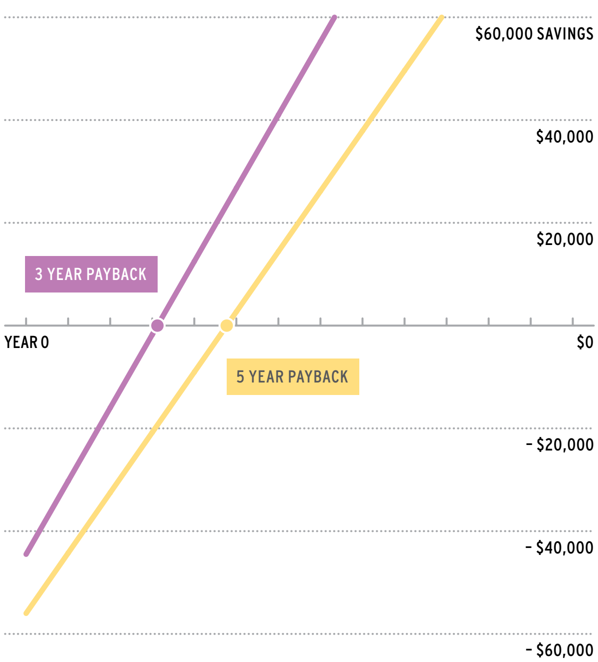
ONE-PIPE STEAM, FUEL OIL



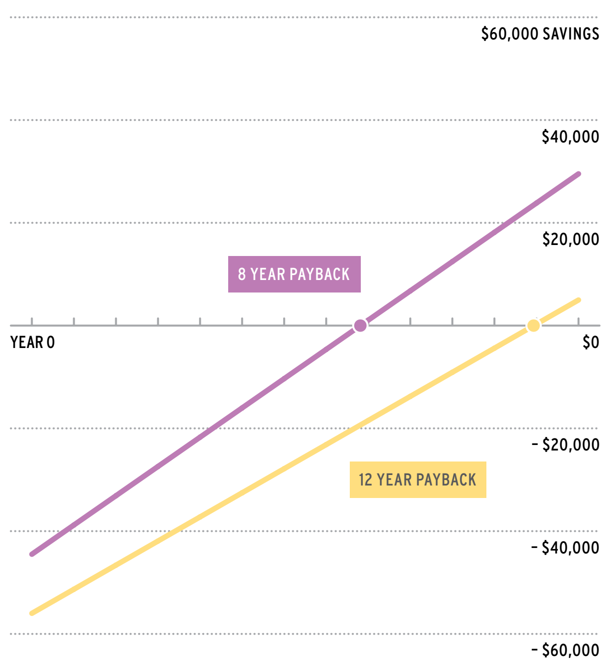
ONE-PIPE STEAM, NATURAL GAS



TWO-PIPE STEAM, FUEL OIL



TWO-PIPE STEAM, NATURAL GAS



The key differences between the examples are their distribution type and fuel source. Two cases have one-pipe steam distribution and show the difference between using number 2 fuel oil and natural gas. The other two cases have two-pipe steam distribution and show the difference between using number 2 fuel oil and natural gas.

Because oil is more expensive than gas, the buildings that use oil have shorter payback periods than the gas buildings. Fuel oil prices are expected to rise faster than natural gas prices over the next five years.[14] Two-pipe steam upgrades are more expensive than one-pipe steam upgrades but they are more responsive to the changes.

The most common configuration for medium residential buildings in New York City is one-pipe steam distribution with natural gas. In a 50,000 square foot residential building that uses natural gas and one-pipe steam, the distribution improvements alone will pay for themselves in **eight to nine years**. If the distribution system improvements are implemented at the time of boiler replacement, then this combined retrofit will pay for itself in just **five years**.

POLICY SOLUTIONS

The following recommendations for policy-makers focus on maximizing impact and logistical ease while making improvements more cost-effective.

Previous sections of this report describe and analyze a set of boiler and steam distribution improvements that enhance the efficiency and functionality of steam heat systems. Our research demonstrates that, if implemented in all existing buildings larger than 5,000 square feet, these improvements have the potential to produce nearly a 6 percent drop in fossil fuel consumption in buildings citywide as well as significant reductions in statewide greenhouse gas emissions.[15] There are several policies that the city and/or state can pursue in order to capture most or all of these savings.

Update Energy Code to Require Efficient Boiler Replacements

In the next iteration of the New York State and/or New York City energy codes, require that replacement boilers be properly sized and designed to function more efficiently.

The next code revision should require that engineers replacing boilers be trained on how to size a boiler based on a building's distribution system (see Appendix for draft code language).

In addition, *now* is the time to institute these requirements. The Intergovernmental Panel on Climate Change (IPCC) Special Report, released in October 2018, highlighted the urgent need to stop the accumulation of carbon in the atmosphere. Boilers can last 30 years or more, so between now and 2050 most of the boilers in the state will be replaced only once.[16] **Because boilers remain in operation so long, it is imperative that inefficient installations be prevented.**

The proposed code requirements are intended to work with, not against, normal capital cycles and equipment replacement.

Promote Joint Boiler and Distribution Upgrades

Encourage upgrades to steam distribution systems at the time of boiler replacements as a best practice. Update the Energy Law to allow the possibility of requiring distribution upgrades in a future NYS code cycle.

If all buildings larger than 5,000 square feet were to pursue the distribution system upgrades in addition to boiler replacements, citywide building-based emissions could be reduced by over 7 percent.

Upgrades to steam distribution systems can have fairly long payback periods—around ten years for some building types. But when combined with boiler replacements, the savings gained from downsizing the boiler cut the payback periods in half for many of these building types.

The NYS Energy Law currently prohibits energy codes from requiring upgrades to unaltered building systems. That means that code requirements for a boiler replacement cannot trigger mandatory distribution system upgrades. Given the benefits of simultaneous boiler and distribution work, the state may want to consider amending the NYS Energy Law to allow requirements to address unaltered systems if they meet the state's cost effectiveness parameters. Then, if deemed appropriate, a future code cycle could require the distribution system upgrades (page 9) at the time of boiler replacement.

For now, steam distribution system upgrades at the time of boiler replacement should be promoted by:

EDUCATION AND OUTREACH

For steam distribution improvements to be effective, a trained workforce is essential. New York City and State should ensure that training programs are available and widely promoted; that they reach consultants, mechanical contractors and building operators; and are possibly subsidized to reach more people.

In NYC, in addition to working with the industry associations (REBNY, BOMA, RSA, Council of Coops and Condos, etc.), the city and state should partner with programs such as NYC's Carbon Challenge and the Retrofit Accelerator.

GOVERNMENT LEADING BY EXAMPLE

Government often kick-starts new practices, and New York State is leading the way on energy efficiency. To meet the state's goal of reducing greenhouse gases 40 percent by 2030, the state's *New Efficiency: New York* report calls for a comprehensive strategy to support and enable New York to meet an ambitious new energy efficiency target of 185 TBtus of end-use energy savings below the 2025 forecast.

One City: Built to Last is a ten-year plan for NYC to cut emissions from public buildings by 30 percent by 2025. Programs like this have several benefits: they help to familiarize the industry with new technology, they broaden the cohort of trained and experienced providers, and since government portfolios can be quite large, they can have a real impact. Portfolios that should be targeted include: New York State buildings, New York City buildings, the New York City Housing Authority, and the university systems. Together, the city portfolio (NYC, NYCHA, and CUNY) constitutes almost 500 million square feet of space, which is larger than most American cities!

DATA COLLECTION AND TRANSPARENCY

These steam improvement strategies will only gain widespread acceptance if their costs and impacts are clearly documented and promoted. The city and/or state should collect uniform data across all relevant programs and bring them together into one data set. The data collected should include items implemented, costs incurred, and energy/cost/emissions outcomes. The data system should be well coordinated with the city's LL84 and LL87 data forms.

Ideally, the data would be made available to the public (with buildings anonymized if necessary) to benefit the widest possible set of potential researchers. If a project receives financial incentives, then more retrofit and observed savings information should be made available online and through case studies.

Future-proof New Buildings

Evaluate regulatory strategies to prohibit steam distribution systems in new buildings.

It's time to stop installing steam heat systems in new buildings. Traditional steam systems use more water and fuel than hydronic systems. But to be legally feasible, there are likely regulatory challenges to overcome.

Steam is finicky, difficult to maintain and operates inefficiently over the long haul, leading collectively to significant wasted energy. In an old-world twist, 28 newly constructed properties, totaling over 7.5M SF of building area, installed some form of steam heat between 2000 and 2010.[17]

In addition, an equally important reason to stop installing steam systems is that they cannot easily convert to electric heating. A new hydronic system that is serviced by a gas boiler can be transformed to an all-electric system by switching the boiler out for a heat pump (see next section); the distribution system would not need to change. However, the same would not be possible in a building equipped with steam heat, because heat pumps cannot concentrate enough heat to produce steam.

City and state policymakers should assess the feasibility—legal and otherwise—of strategies to prohibit new steam installations, including potential requirements in future state and city energy codes that limit new steam systems.

THE FUTURE OF STEAM

Given its prevalence, upgrading steam heat must be a part of any plan to cut carbon in NYC. But even at its best, emissions from steam could thwart long-term emission goals.

Steam boilers provide heat and hot water to over 75,000 buildings larger than 5,000 square feet citywide, so they are the most common system in NYC. Within multifamily buildings, steam is even more ubiquitous and is responsible for 74 percent of that sector's carbon emissions.

The improvements laid out in pages 6 to 13 of this report have the potential to reduce fuel use by 20 percent or more. Boiler improvements make up one-third of these savings and steam balancing and distribution improvements make up the other two-thirds.

But those measures will not be enough to ensure NYC buildings cut their overall emissions 80 percent by the year 2050. There is currently no clear and cost-effective solution to completely cut fuel use in NYC buildings, so we recommend that buildings improve steam systems as much as possible over the next decade. This section will take a deeper look into why steam improvements make sense now.

Other steps need to be taken for NYC to hit its 80x50 commitment. We also describe several new forms of technology that could help bridge that gap and argue that improving steam is not just about emissions reductions and savings—it's about improving overall quality of life.

Steam's Carbon Cost

Taking a look at the realities of steam heating systems today will help us determine how to invest in these systems for the short-term and prepare us to eventually replace them long-term. Public information on all of New York City's one million buildings is incomplete but growing in volume and accuracy. This report used a combination of three data sources to estimate the prevalence and fuel use of steam heat in NYC.[18]

We ran a series of cost/benefit analyses of individual steam improvements on the citywide building set. The result is a good estimate of how many steam systems are used in the city and how much they can be improved with conventional measures.

Table 1 shows that nearly 2.5 million metric tons of carbon would be cut from citywide annual emissions if every steam building larger than 5,000 SF upgraded their system from boiler to radiator. But those buildings would still emit over 6.7 million metric tons of carbon annually just from burning gas on-site to heat and provide hot water to their occupants.

Assuming that buildings must cut emissions by 80 percent from 2005 levels, the entire carbon budget for all buildings citywide in 2050 will be 8.5 million metric tons. That means steam systems in medium and large buildings would consume almost all of our carbon budget for buildings. That would leave little room for other emissions sources like electricity, which makes up 40 percent of NYC building emissions today.

FIGURE 6

Energy Flows in Multifamily Buildings

Most site energy use in multifamily buildings comes from burning natural gas. Nearly all heat and hot water is produced using fossil fuels. Steam boilers use 62 percent of site energy in multifamily buildings.

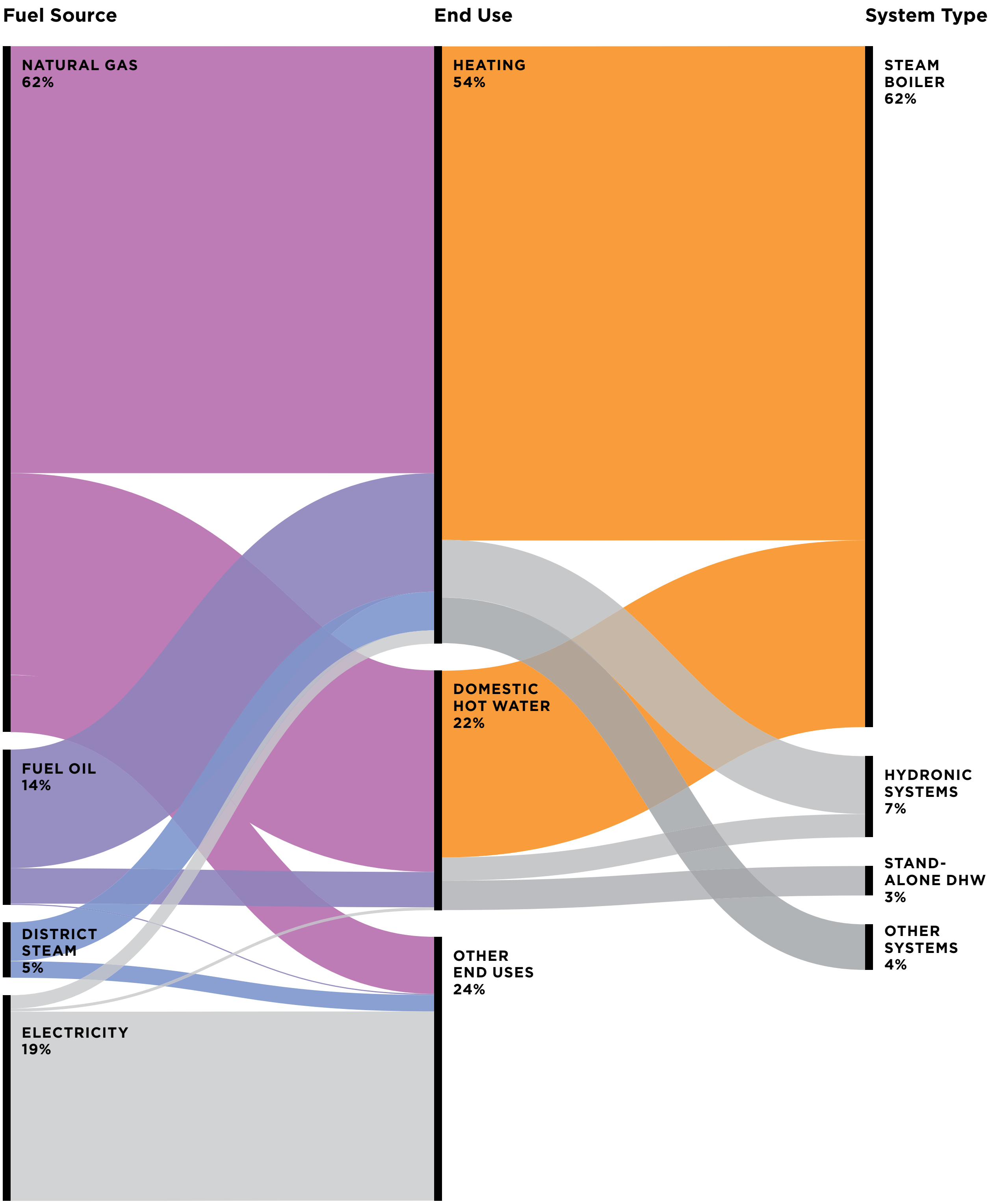


TABLE 1

Projected Citywide Carbon Savings from Improving Steam Heat

Steam Heat Fuel GHG Emissions for Buildings Larger than 5,000 SF
(METRIC TONS OF CO_2E)

	Existing (2015)	Improved (2030)	Carbon Reduction
Residential	7,353,500	5,471,000	1,882,500
Commercial/Public	1,651,000	1,133,400	517,600
Industrial	190,300	130,000	60,300
Total	9,194,800	6,734,400	2,460,400

Improving steam heat is a needed and immediate way to cut carbon, but upgrades alone cannot cut 80 percent of these emissions.

And there is plenty of steam in smaller buildings too. If we assume that just one quarter of very small buildings[19] use steam, then steam heat would be responsible for 8.6 million metric tons annually in 2050. The entire building carbon budget would go toward steam heat.

New Directions in Heating Systems

Beyond 2030, building heating systems will need more than incremental improvements.

As steam systems age out, they should be replaced by hydronic systems or by electric-powered heat pumps. Heat pumps are effectively air-conditioning units that work in two directions. In the winter, they extract heat from the air outside and bring it inside. Much less energy is needed for moving heat than converting fuel to heat. Converting building heat and hot water from fossil fuels to electricity in this way is referred to as electrification.

Heat pump uptake is not yet common in NYC's large building stock. Small capacity heat pumps are already widespread in Asia, even in individual high-rise units. We see this same trend in North America—but mostly in single-family homes and new construction—and there is an increasing effort to optimize them for cold weather. Right now, the only option for NYC is to use this small capacity equipment in multifamily buildings. But most heating and hot water in NYC apartments comes from large central systems (boilers producing steam heat, for example). Heat pumps can gather enough heat to produce hot water but not steam, so converting steam systems to run hot water would be an excellent first step towards electrification.

Another reason to invest in steam now is that, before buildings fully electrify, we may see the development of hybrid heating systems that continue to use steam to supplement heat pumps. In a hybrid system, heat pumps might be able to serve a building's entire heating load during shoulder seasons, with steam providing additional heat in colder months. Gas prices will rise, and heat pumps will improve and expand. In a decade, fully electrifying these buildings may become cost effective and common.

Beyond Cost

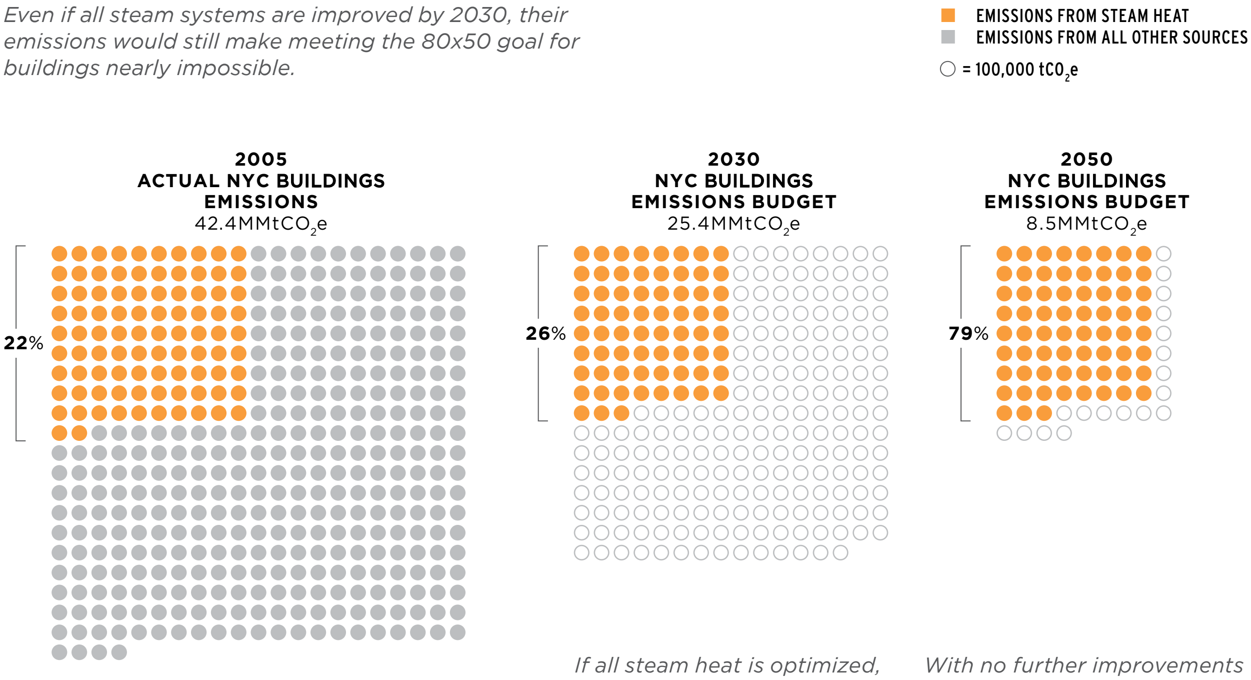
Cost, carbon and fuel savings potential are all important benefits of improving steam heat. But these metrics leave out the qualitative benefits for owners and tenants, including reduced noise from steam pipes, evenly distributed heat, increased comfort, better air quality, improved control over room temperatures and reduced service calls and complaints.

The city recently increased the minimum temperatures needed during the heating season, and that policy change was welcomed warmly by tenants but fought by building owners. It may be that changing temperature

FIGURE 7

Fixing Steam Will Not Be Enough

Even if all steam systems are improved by 2030, their emissions would still make meeting the 80x50 goal for buildings nearly impossible.



If all steam heat is optimized, 2030 emissions fall in keeping with the overall city budget.

With no further improvements available, steam emissions dominate the 2050 budget.

setpoints is not the most effective way to improve tenant comfort. If steam systems run properly, they get steam to every radiator in the building, and tenants get more consistent heat without being overheated.

To estimate the operational and productivity value of these improvements, Urban Green Council surveyed 70 New York City tenants and asked them how they feel about their steam heat systems.

Ninety percent of survey participants had at least one problem with steam heat. Over two-thirds of survey participants had more than one problem. The most common complaints were (1) a lack of control over the room temperature, (2) having too much heat, and (3) systems making too much noise. The most common coping mechanism cited was opening windows.

These results can help building owners determine which improvements to prioritize, but they also clearly demonstrate that there is a high demand for steam improvements among NYC tenants. The time to make these changes is now.

The year 2030 will be an important milestone. Any major equipment—a boiler for example—installed after that year may still be in operation in 2050. We should invest in steam heat improvements—like smaller and more efficient boilers—now.

The state's greenhouse gas reduction goals of 40 and 80 percent by 2030 and 2050 respectively will require building owners to pursue non-fossil fuel heating technology. Each building will need a plan for weaning their systems off of fossil fuels. The best path for some will be to convert their steam heat to hydronic heat systems. Others may upgrade their steam heat and wait for an economically attractive heat pump solution. No building should stand on the sidelines, wasting fuel and money over the next decade.

Avoided carbon emissions today are more valuable than future promises to save carbon. That is exactly what NYC can achieve by making these steam heat upgrades now. Those upgrades will save money and make New Yorkers more comfortable—it's time to push the accelerator on steam heat retrofits.

APPENDIX

Analysis Methodology and Assumptions

AREA

The total building areas are calculated from 2017 Pluto data and the proportion of one-pipe and two-pipe steam systems found in LL87 audits. Building square footage was broken down by size (square footage), type (residential, commercial), height (seven stories or greater, less than seven stories), and distribution type (one-pipe, two-pipe, or other). Due to limited data for small buildings, small and medium-sized buildings both use the proportion of steam systems from audits of buildings under 100K SF. There is proportionally more one-pipe steam estimated in small residential buildings than in medium residential buildings because one-pipe steam is more common in shorter buildings, and buildings between 5,000 and 25,000 square feet are mostly under seven stories.

FUEL EUI

Pre-retrofit site fuel EUIs for medium and large building are area weighted mean values from cleaned 2016 LL84 data. RECs data for New York State likely underestimates the fuel usage for small buildings so the pre-retrofit site fuel EUIs for medium-sized buildings were also applied to the small-sized building stock.

Post-retrofit site fuel EUIs estimate individual building fuel use after both the boiler

TABLE 2

Total Building Floor Area by Heating System Type and Building Size (MILLIONS OF SF)

		Small (5K–25K SF)	Medium (25K–100K SF)	Large (100K+ SF)
Residential	One-pipe Steam	391	507	268
	Two-pipe Steam	35	94	537
	Other	46	108	338
Commercial/Public	One-pipe Steam	8	25	48
	Two-pipe Steam	48	78	477
	Other	82	121	399
Industrial	One-pipe Steam	6	7	7
	Two-pipe Steam	21	26	27
	Other	32	40	40

replacement and the distribution improvement retrofit packages have been followed. Savings are based on Steven Winter Associate field research and demonstrated experience.

Citywide fuel use in buildings larger than 5,000 SF would drop 19 percent if all steam heat improvements were implemented. Small and medium buildings make up most of this analysis since steam heat is more common in those buildings. Buildings larger than 100,000 SF are more evenly split between two-pipe, hydronic and other heating systems. Our analysis did not implement any improvements on non-steam heating systems, so large areas of commercial and residential buildings did not see any fuel savings.

TABLE 3

Baseline Fuel Use and Estimated Savings from Boiler and Distribution Improvements

		Pre-Retrofit Fuel EUI (KBTU/SF)			Post-Retrofit Fuel Savings		
		Small (5K–25K SF)	**Medium** (25K–100K SF)	**Large** (100K+ SF)	**Small** (5K–25K SF)	**Medium** (25K–100K SF)	**Large** (100K+ SF)
BOILER REPLACEMENT PACKAGE							
Residential	One-pipe Steam	73	73	66	-9%	-5%	-5%
	Two-pipe Steam	66	66	61	-9%	-5%	-5%
Commercial/Public	One-pipe Steam	43	43	30	-9%	-5%	-5%
	Two-pipe Steam	40	40	42	-9%	-5%	-5%
Industrial	One-pipe Steam	35	35	33	-9%	-5%	-5%
	Two-pipe Steam	35	35	33	-9%	-5%	-5%
DISTRIBUTION IMPROVEMENT PACKAGE							
Residential	One-pipe Steam	73	73	66	-13%	-13%	-13%
	Two-pipe Steam	66	66	61	-14%	-14%	-14%
Commercial/Public	One-pipe Steam	43	43	30	-18%	-18%	-18%
	Two-pipe Steam	40	40	42	-20%	-20%	-20%
Industrial	One-pipe Steam	35	35	33	-18%	-18%	-18%
	Two-pipe Steam	35	35	33	-20%	-20%	-20%
BOTH PACKAGES							
Residential	One-pipe Steam	73	73	66	-20%	-17%	-17%
	Two-pipe Steam	66	66	61	-22%	-19%	-19%
Commercial/Public	One-pipe Steam	43	43	30	-25%	-22%	-22%
	Two-pipe Steam	40	40	42	-27%	-24%	-24%
Industrial	One-pipe Steam	35	35	33	-25%	-22%	-22%
	Two-pipe Steam	35	35	33	-27%	-24%	-24%

HEAT EUI

Based on LL84 & LL87 data heat use is estimated to be 72 percent of pre-retrofit site fuel use in residential buildings. Heat EUIs were used to separate out space heating energy savings from DHW energy use. Heat EUIs were applied to the 20 percent of residential floor area with a DHW system separate from the base-building steam boiler. DHW loads in commercial buildings were assumed to be negligible.

TENANT SURVEY

Urban Green Council surveyed 70 New York City residents to find out how they feel about their steam heating systems. The survey aimed to move beyond evaluating just cost and carbon and estimate the operational and productivity value of improving steam heat systems. The results validated a common understanding—tenants are dissatisfied with their steam heat systems.

TABLE 5

Steam Heat Tenant Satisfaction Survey

Survey Response Percent Frequency
(FROM OVER 70 NYC TENANTS WITH STEAM HEAT)

What problems have you had with steam heat?	I want more control over the temperature in my apartment	81%
	Too much heat	73%
	Noises interrupt my sleep	48%
	Not enough heat	31%
	I have no problems	10%
How do you resolve these problems?	I open my windows to cool my apartment	63%
	I complain to my building super or manager	38%
	I turn all the knobs and valves until something changes	37%
	I suffer in silence	23%
	I use an appliance to heat my apartment	17%

Draft Code Language for Boiler Replacements, to Amend ASHRAE 90.1 2016.

Note that similar language would need to be incorporated into the commercial and the residential provisions of the IECC.

Add to 3.2 Definitions

cold-start method: A method for sizing replacement steam boilers by observing the ability of the existing boiler to make steam pressure from a cold start while held to part-fire.

equivalent direct radiation (EDR) method: A method for sizing replacement steam boilers by determining the heat output of every terminal unit in the building and then multiplying their combined output by a piping and pickup factor.

Add to 6.1.1.3.1

New HVACR equipment as a direct replacement of existing HVACR equipment shall comply with the following sections as applicable for the equipment being replaced:
... t. 6.5.12 "Boiler Replacement"

Amend 6.4.2.1 Load Calculation ...

Exception: Replacement boilers shall be sized according to 6.5.12.1.

Amend 6.5.4.1 Boiler Turndown

Boiler systems with design input of at least 700,000 Btu/h shall comply with the turndown ratio specified in Table 6.5.4.1 or Table 6.5.4.2, as applicable.

The *system* turndown requirement shall be met through the use of ~~multiple single-input boilers,~~ one or more modulating *boilers*~~, or a combination of single-input and modulating boilers.~~

All *boilers* shall meet the minimum *efficiency* requirements in Table 6.8.1-6.

Amend Table 6.5.4.1 ...

Hot Water Boiler System Design Input, Btu/h

Hot Water *Boiler System* Design Input, *Btu/h*	Minimum Turndown Ratio
< 500,000	N/A
500,000 ≤ 2,000,000	2 to 1
2,000,000 ≤ 5,000,000	4 to 1
> 5,000,000	5 to 1

Add Table 6.5.4.2

Steam *Boiler System* Design Input, *Btu/h*	Minimum Turndown Ratio	
	Gas fired	Oil Fired
< 700,000	N/A	N/A
700,000 ≤ 2,800,000	1.7 to 1	1.7 to 1
2,800,000 ≤ 4,800,000	3 to 1	4 to 1
4,800,000 ≤ 7,500,000	4.5 to 1	4.5 to 1
7,500,000 ≤ 49,000,000	6 to 1	6 to 1
> 49,000,000	10 to 1	10 to 1

Add sections:

6.5.12 Boiler Replacement
Replacement boilers shall comply with the following requirements:

6.5.12.1 Replacement Boiler Sizing
Replacement boilers shall be sized according to the following methods.

6.5.12.1.1 Steam Boilers
Replacement steam boilers for systems with passive heaters shall be sized according to the equivalent direct radiation (EDR) method or by observing the ability of the existing boiler to make steam pressure from a cold start while held to part-fire (the "cold-start method", see Appendix NNN). EDR method shall be based on the combined output of the heaters, with a piping and pickup factor (P&P) of up to 2 applied for Scotch marine steel boilers. For cast iron boilers a factor of 2.5 may be applied, to allow for derating. If a higher factor is used, the construction documents shall include an explanation of the higher factor. If the EDR method is used, the construction documents shall include the dimensions, locations, and outputs of the surveyed heaters, and the calculation of their total output.

6.5.12.1.2 Hot Water Boilers
Replacement hot water boilers shall be sized in accordance with ANSI/ ASHRAE/ ACCA Standard 183 or on the basis of weather-normalized historic fuel use.

6.5.12.2 Sizing Steam Boiler Outlet
Boiler steam outlet(s) on Scotch marine steel boilers shall have a minimum of 1.67 in. net free open area per 100,000 Btu/h of gross boiler output. To meet this

requirement, more than one steam outlet may be installed.

6.5.12.3 Steam Boiler Header Configuration

Piping at header shall be well-pitched and include a separation point at which steam entering the system makes a turn of at least 90 degrees, while entrained droplets continue in an uninterrupted straight line for at least 12 in. past the separation point, then flow by gravity out of the steam piping.

6.5.12.5 Parallel-positioning Combustion Controls

Steam boilers with a design input of at least 4,200,000 Btu/h shall be provided with parallel-positioning combustion controls.

6.5.12.6 Variable-speed controls

Burner blower motors 5 hp and larger shall include variable-speed controls.

6.5.12.7 Forced Draft

Replacement boilers with a design input of at least 700,000 Btu/h shall have forced draft burners.

6.5.12.7 Water Meters

Makeup water lines to any boiler with design input of at least 2,800,000 Btu/h shall include a water sub-meter in accordance with NYC Plumbing Code Section 608.16.2.

Add Appendix NNN to ***ASHRAE 90.1 2016***
(Exact location TBD)

Appendix NNN: Acceptable Methods for Sizing Replacement Steam Boilers for Systems with Passive Heaters

Equivalent Direct Radiation (EDR) method:

Boiler size shall be based on the combined output of the heaters, with a piping and pickup factor (P&P) of up to 2 applied for Scotch marine steel boilers. For cast iron boilers a factor of 2.5 may be applied, to allow for derating. If a higher factor is used, the boiler filing shall include the reason for the higher factor. The filing shall include the dimensions, locations, and outputs of the surveyed heaters, and the calculation of their total output.

Cold-Start Method:

This sizing method may be used for steam systems with passive (non-fan-assisted) heaters and no more than two boilers.

With the system cold (off for at least three hours), adjust the burner to no more than roughly 50 percent fire, then fire the boiler continuously. If the boiler makes 2 lb/in.^{2} of pressure within 45 minutes, then the firing rate at which the cold-start test was performed should be the maximum firing rate of the new boiler.

If the boiler does not make 2 lb/in.^{2} of pressure, then adjust the burner to halfway between low-fire and high-fire and repeat the test with the system cold. Repeat the test as necessary, each time with the system cold. The lowest firing rate at which the existing boiler makes pressure should be the maximum firing rate of the new boiler. If the firing rate falls between readily available boiler sizes, install the next size up.

Confirm the successful test firing rate as follows:

- For natural gas: clock the gas meter.
- For pressure-atomized oil: measure the pressure to the oil nozzle and confirm the nozzle size.
- For air-atomized oil: record the position of the metering device and confirm the nozzle size.

If the heating system is two-pipe with more than 1 ounce/in.^{2} of pressure in the returns, continue to run the boiler for an additional hour to ensure that it holds pressure.

Ensure that any zone valves (including modulating valves) are fully open for the entire test.

If the heaters have thermostatic valves, perform the test when outdoor temperature does not exceed 45°F (including during the cool-off period).

Amendment to Chapter 1: Administrative Section of the NYC ECC:

Add section:

105.1 Approved Agency. Replacement of boilers with a design input of at least 350,000 Btu/h, including all installation work as required in Section 6.5.12, shall be performed by an approved replacement-boiler installation agency.

Amendment to 1 RCNY Section 101-07
CHAPTER 100
Subchapter A Administration
Section 101-07 Approved Agencies

Add definitions:

(2) Approved replacement-boiler installation agency. An agency employing one or more qualified replacement-boiler installers.

(10) Qualified replacement-boiler installer. A replacement-boiler installer, who has received a qualifying certificate proving that he or she has taken an approved course and has passed the required test for the proper installation of replacement- boilers, has kept up with any required continuing education requirements and has [NN years as required by DOB] experience installing replacement-boilers.

Sample Retrofit Case Studies

TABLE 6A

Projected Cost Savings: Distribution Improvements Package

		Total Capital Costs (DOLLARS)	Annual Cost Savings per SF (DOLLARS/SF)	Simple Payback (YEARS)
CASE STUDY A: RESIDENTIAL ONE-PIPE STEAM				
Small 5K SF	Natural Gas	$ 6,000	$ 0.13	10
	Fuel Oil no. 2	$ 6,000	$ 0.23	6
Medium 50K SF	Natural Gas	$ 40,250	$ 0.09	9
	Fuel Oil no. 2	$ 40,250	$ 0.23	4
Large 200K SF	Natural Gas	$ 96,000	$ 0.08	6
	Fuel Oil no. 2	$ 96,000	$ 0.20	3
CASE STUDY B: RESIDENTIAL TWO-PIPE STEAM				
Small 5K SF	Natural Gas	$ 6,000	$ 0.16	8
	Fuel Oil no. 2	$ 6,000	$ 0.40	3
Medium 50K SF	Natural Gas	$ 56,000	$ 0.09	12
	Fuel Oil no. 2	$ 56,000	$ 0.23	5
Large 200K SF	Natural Gas	$ 152,000	$ 0.09	9
	Fuel Oil no. 2	$ 152,000	$ 0.22	4
CASE STUDY C: COMMERCIAL TWO-PIPE STEAM				
Small 20K SF	Natural Gas	$ 9,750	$ 0.02	7
Medium 90K SF	Natural Gas	$ 97,500	$ 0.08	14
Large 250K SF	Natural Gas	$ 186,000	$ 0.08	9
	Fuel Oil no. 2	$ 186,000	$ 0.10	8
	District Steam	$ 186,000	$ 0.26	3

Commercial and residential (multifamily buildings larger than 25k SF) natural gas costs estimated at $0.00982 per KBTU. Small residential natural gas estimated at $0.01365 per KBTU. Commercial fuel oil cost estimated at $0.01145 per KBTU. Residential fuel oil cost estimated at $0.02458 per KBTU.

Referenced from: https://www.nyserda.ny.gov/Researchers-and-Policymakers/Energy-Prices/Natural-Gas

TABLE 6B

Projected Cost Savings: Boiler Replacement Package

		Total Capital Costs* (DOLLARS)		Annual Cost Savings per SF (DOLLARS/SF)	Simple Payback (YEARS)
CASE STUDY A: RESIDENTIAL ONE-PIPE STEAM					
Small 5K SF	Natural Gas	$ -5,750		$ 0.09	0
	Fuel Oil no. 2	$ -5,750		$ 0.15	0
Medium 50K SF	Natural Gas	$ -12,000	±500	$ 0.04	0
	Fuel Oil no. 2	$ -12,000	±500	$ 0.09	0
Large 200K SF	Natural Gas	$ -39,250	±4,000	$ 0.02	0
	Fuel Oil no. 2	$ -39,250	±4,000	$ 0.06	0
CASE STUDY B: RESIDENTIAL TWO-PIPE STEAM					
Small 5K SF	Natural Gas	$ -5,750		$ 0.12	0
	Fuel Oil no. 2	$ -5,750		$ 0.30	0
Medium 50K SF	Natural Gas	$ -12,000	±500	$ 0.03	0
	Fuel Oil no. 2	$ -12,000	±500	$ 0.08	0
Large 200K SF	Natural Gas	$ -39,250	±4,000	$ 0.03	0
	Fuel Oil no. 2	$ -39,250	±4,000	$ 0.08	0
CASE STUDY C: COMMERCIAL TWO-PIPE STEAM					
Small 20K SF	Natural Gas	$ 500		$ 0.01	0
Medium 90K SF	Natural Gas	$ -12,000	±500	$ 0.02	0
Large 250K SF	Natural Gas	$ -39,250	±4,000	$ 0.02	0
	Fuel Oil no. 2	$ -39,250	±4,000	$ 0.02	0
	District Steam	$ -39,250	±4,000	$ 0.07	0

** Most cases result in savings from smaller boiler rather than like-for-like replacement*

TABLE 6C

Projected Cost Savings: Both Distribution and Boiler Replacement Packages

		Total Capital Costs (DOLLARS)		Annual Cost Savings per SF (DOLLARS/SF)	Simple Payback (YEARS)
CASE STUDY A: RESIDENTIAL ONE-PIPE STEAM					
Small 5K SF	Natural Gas	$ 0		$ 0.18	0
	Fuel Oil no. 2	$ 0		$ 0.32	0
Medium 50K SF	Natural Gas	$ 28,250	±500	$ 0.11	5
	Fuel Oil no. 2	$ 28,250	±500	$ 0.28	2
Large 200K SF	Natural Gas	$ 56,800	±4,000	$ 0.10	3
	Fuel Oil no. 2	$ 56,800	±4,000	$ 0.26	1
CASE STUDY B: RESIDENTIAL TWO-PIPE STEAM					
Small 5K SF	Natural Gas	$ 0		$ 0.21	0
	Fuel Oil no. 2	$ 0		$ 0.52	0
Medium 50K SF	Natural Gas	$ 44,000	±500	$ 0.11	8
	Fuel Oil no. 2	$ 44,000	±500	$ 0.28	3
Large 200K SF	Natural Gas	$ 112,800	±4,000	$ 0.11	5
	Fuel Oil no. 2	$ 112,800	±4,000	$ 0.28	2
CASE STUDY C: COMMERCIAL TWO-PIPE STEAM					
Small 20K SF	Natural Gas	$ 3,975		$ 0.02	2
Medium 90K SF	Natural Gas	$ 85,800	±500	$ 0.10	10
Large 250K SF	Natural Gas	$ 146,800	±4,000	$ 0.10	6
	Fuel Oil no. 2	$ 146,800	±4,000	$ 0.11	5
	District Steam	$ 146,800	±4,000	$ 0.32	2

NOTES

1. *New York City's Energy and Water Use 2013 Report*. Figure 8 shows distributions of fuel energy use intensities (FEUI) by heating system. Steam systems have a wide variance in their FEUIS. Outliers use 2 or 3 times the median FEUI. http://www.nyc.gov/html/gbee/downloads/pdf/nyc_energy_water_use_2013_report_final.pdf

2. Hydronic heating systems circulate hot water from a boiler through closed loops of piping to radiators and radiant floors to warm the building. Converting steam to hydronic systems has been shown to save fuel but is costly.

   Rieber, Dan. (2012, September). *179 Henry Street - A Case Study in Converting from Two-Pipe Steam to Hydronic Heating*. Retrieved from http://www.ratheassociates.com/docs/HenryStreet_CaseStudy.pdf

   Shapiro, Ian. (2010). Water and Energy Use in Steam-Heated Buildings. *ASHRAE Journal*, 14-18.

3. Details on calculation can be found in the report appendix. Overall fuel saving proportion is slightly lower than the typical savings in a single building because large buildings (with higher fuel use but lower fuel intensities) tend to have other types of heating systems.

4. In 2005, buildings emitted 42M tons of carbon from direct energy use. Buildings would need to cut 33.6M tons of carbon to meet the 80x50 goal. Carbon to coal plant comparison is based on data from EPA Greenhouse Gas Equivalencies Calculator.

   Inventory of New York City Greenhouse Gas Emissions in 2016: https://www1.nyc.gov/assets/sustainability/downloads/pdf/publications/GHG%20Inventory%20Report%20Emission%20Year%202016.pdf

5. Steam heat in residential buildings would still emit 8.5 million metric tons of carbon. Calculation assumes no new steam heat installations, one-quarter of single-family homes use steam heat, retrofits reduce all residential steam system fuel use by 20 percent and all these systems use natural gas.

6. Bernan, Walter. (1845). *On the History and Art of Warming and Ventilating Rooms and Buildings* (Vol. 2). Republished by Forgotten Books in 2015.

7. Holohan, Dan. (2010). *Greening Steam: How to Bring 19th-Century Heating Systems into the 21st Century.* Chapter 2: Greening the Load.

8. Seventy residents who live in NYC buildings with steam heat were surveyed by Urban Green to determine the issues tenants experience with these systems.

9. A boiler's steam outlet is also critical to making dry steam. Stock outlets on large steel boilers (over 100 HP) are often too small and cause steam to flow too quickly out of the boiler. When these boilers run at full fire, wet steam carries so much water out of them that they have to shut down. For a more detailed explanation of boiler outlets and headers, refer to Figures 12 and 14 in *Clanging Pipes and Open Windows: Upgrading NYC Steam Systems for the 21st Century* (Energy Efficiency for All, 2015).

10. Holohan, Dan. (2010). *Greening Steam: How to Bring 19th-Century Heating Systems into the 21st Century.*

11. NYSERDA and Energy & Resource Solutions (2018, May). *A Focused Demonstration Project: The "Cozy" by Radiator Labs* (Rep. No. 18-12). Retrieved from https://www.radiatorlabs.com/wp-content/uploads/2018/10/Radiator-Labs.Cozy_.NYSERDA-Report.2018.pdf

12. Shapiro, Ian. (2010). Water and Energy Use in Steam-Heated Buildings. *ASHRAE Journal*, 14-18. https://www.taitem.com/wp-content/uploads/SteamBoilerReplacements.pdf

13. The hypothetical retrofit case studies in this report are based on the most up-to-date fuel prices from NYSERDA and the U.S. Energy Information Administration (EIA) for residential and commercial buildings, separately.

14. Based on EIA projections in the Annual Energy Outlook 2018: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2018&cases=ref2018&sourcekey=0

15. The threshold of 5,000 square feet was set primarily for logistical reasons. In New York City, such buildings represent over 10 percent of NYC's one million buildings, but they account for approximately 72 percent of the square footage, so preferentially addressing these buildings represents an excellent bang for the buck.

16. The boiler life expectancy is based on ASHRAE's Equipment Life Expectancy Chart. Based on LL87 audit data, the average age of boilers in large buildings is 26 years, so owners of audited buildings may replace their equipment slightly before it fails. But there are many buildings that keep boilers running beyond 30 years by patching leaks and replacing parts—this presents a barrier to boiler replacement efficiency gains.

17. Based on large buildings that submitted reliable audit data under Local Law 87. Citywide rates of steam installation may be different.

18. This report used property data from the Department of Finance, energy use data from building benchmarking (building owners are now required to publish how much energy they use annually) and system data from building audits. Building areas were broken down by size (square footage), type (residential, commercial), height (7 stories or greater, or fewer than 7 stories), and distribution type (one-pipe, two-pipe). Due to limited data for small buildings, for small and medium-sized buildings we used the proportion of steam systems from Local Law 87 audits of buildings under 100,000 square feet.

19. This report considers buildings under 5,000 SF to be very small. This building size is comprised mainly of one to four-family homes. The EIA 2015 Residential Energy Consumption Survey (RECS) estimated that 28 percent of homes in the Northeast use steam, so our estimate is conservative.

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