NYCHA CLIMATE MITIGATION ROADMAP

Meeting Local Law 97 through Energy Efficiency and Beneficial Electrification

NEW YORK CITY HOUSING AUTHORITY

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INTRODUCTION

Local Law 97 of 2019 (LL97) directs NYCHA to "make efforts to reduce greenhouse gas emissions by 40% by the year 2030 and 80% by the year 2050, relative to such emissions for calendar year 2005."[1] Achieving the 2050 goal will ultimately require NYCHA to meet the majority of its buildings' energy needs through a combination of low- or no-carbon sources and significant reductions in resident consumption. One pathway to 80x50 generally agreed upon by industry experts as the most economically and technically promising of various options is electrification, the replacement of fossil-fuel energy use with low-carbon electricity.

Because energy consumption at NYCHA buildings is largely driven by the provision of heat and hot water, providing them from no-carbon sources would eliminate 70-75% of greenhouse gas (GHG) emissions from NYCHA operations.[2] NYCHA has already begun to adopt beneficial electrification of heat and hot water. In December 2019, NYCHA released its first solicitations for beneficial electrification of its heating systems at 11 developments. This solicitation requires projects to meet or exceed the LL97 2024 performance requirement and describe pathways for further reductions to meet 2050 requirements. The contracts are scheduled to be awarded in the fall of 2020 with construction completions in 2022 and 2023.

Addressing in-apartment energy use presents significant opportunities to improve resident quality of life through elimination of gas outages, provision of cooling, and reduction of the total cost of rent and utilities, while simultaneously reducing NYCHA's electrification costs. Electric submeters and billing for consumption in individual apartments is a proven strategy in reducing energy consumption,[3, 4] but the possible costs and benefits for residents must be identified and addressed before implementation.

Time is of the Essence

NYCHA is the largest residential landlord in the city, with more than 2,410 residential buildings in its portfolio.[5] More than 70% of those buildings are 50 years old or older. Electrifying this portfolio will be a significant undertaking. Even at a hypothetical pace of 100 buildings per year, it would take NYCHA 30 years to address the needs of all its buildings.

Given these facts, it is essential that NYCHA move aggressively to address this issue and resist the temptation to wait for some future "silver bullet" technology that may or may not materialize. Existing technology is more than adequate to make substantial progress towards the necessary GHG reductions.

Generally, near-term actions to reduce emissions are less costly and far more valuable than actions taken later. Early actions reduce the rate of increase in GHG emissions and help keep the increase in average global temperatures to below the 1.5°C threshold, above which climate consequences are projected to be more dire.[6] Delayed action will require more extreme, and likely more costly, actions to achieve the same reductions by 2050.

Meeting the GHG Limits of Local Law 97

LL97, one of 11 laws included in the Climate Mobilization Act, requires that NYC buildings larger than 25,000 square feet achieve specific GHG emissions limits. Steadily-decreasing GHG targets are intended to provide building owners with the time and the incentive to achieve the 2050 goals.

LL97 sets requirements for NYCHA that differ from those for private buildings. The LL97 reduction targets for NYCHA are portfolio-wide, rather than building-specific. NYCHA is required to reduce emissions by 40% by 2030 and by 80% by 2050 relative to a 2005 baseline. The requirement applies to all buildings owned or operated by NYCHA regardless of size. For private buildings, LL97 imposes financial penalties starting 2024. Buildings owned or operated by NYCHA or private buildings on NYCHA land are subject to NYC Department of Building (DOB) enforcement, but are exempt from financial penalties. In the event that NYCHA fails to achieve the goals, the Mayor's Office of Sustainability is authorized to recommend remedial actions.

Excerpt from Local Law 97

Reduction of emissions by the New York city housing authority. The New York city housing authority shall make efforts to reduce greenhouse gas emissions by 40% by the year 2030 and 80% by the year 2050, relative to such emissions for calendar year 2005, for the portfolio of buildings owned or operated by the New York city housing authority. If the office determines that such emissions reduction is not feasible despite the best efforts of city government operations, such office shall report such findings and make recommendations with respect to policies, programs and actions that may be undertaken to achieve such reductions.

— Local Law 97, Item 3, subdivision b of section 24-803 of the Administrative Code of the City of New York

Reducing energy consumption to meet the GHG ceilings of LL97 for existing buildings will require much deeper reductions than the 10-20% reductions that typical energy-efficiency measures are able to deliver. The options to reduce GHG emissions generally start with relatively low-cost measures, such as upgrading lighting to LEDs, and end with major capital investments that replace one or more major building systems. Preliminary analysis has shown that achieving the deep reductions necessary will require removal of fossil-fuel burning systems from buildings while the State simultaneously moves towards a low-emissions electric grid.[7, 8]

New York State's Clean Energy Standard established a commitment to generate 70% of New York's electricity renewably by 2030 and achieve 100% clean energy by 2040 as part of an effort to reduce GHG emissions by 40%.[9] This requirement, coupled with commitments by cities and municipalities to increase renewable energy and aided by advances in electric heating technology, now makes electricity a viable option for affordably providing heating and cooling in residential buildings within the State.[10]

What is Beneficial Electrification?

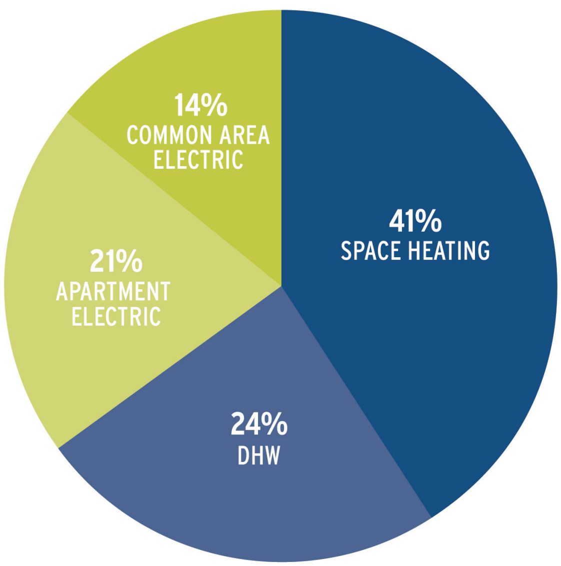
Beneficial electrification[11] is the replacement of fossil fuels with electricity that is affordable and has low or no GHG emissions. It is generally viewed as the most cost-effective path towards large-scale GHG reductions that is possible with existing and likely future technology.[12, 13] A recent study by the National Renewable Energy Laboratory (NREL) found that electrification without a low-carbon electric grid could reduce emissions by roughly 40%.[14] The study went on to show that the combination of electrification and power sector decarbonization would reduce nationwide emissions 74% below 2005 levels.

A recent report by the New York State Energy Research and Development Authority (NYSERDA) states that electric heat pumps could economically serve half of the statewide heating needs for small residential sites, which is equivalent to 23% of all heating load in NYS, and was the most cost-effective approach to reducing energy use and emissions.[15] As heat pump technologies continue to improve and the grid becomes increasingly greener, the number of residential and commercial sites that can benefit from heat pumps will steadily increase. NYCHA's ultimate success in meeting 80x50 thus depends not only on electrification, but also on New York State's progress towards increased electric generation from non-fossil-fuel sources, as outlined in the Clean Energy Standard and the recently-passed Climate Leadership and Community Protection Act (CLCPA).

Electrification of Heat and Hot Water

As is typical in multifamily buildings, two thirds of NYCHA's energy consumption is devoted to providing heat and domestic hot water (DHW). Although NYCHA's portfolio includes a variety of heating systems and equipment, the largest share of the portfolio is served by campus-scale steam heating systems that must run year-round in order to make DHW.

NYCHA cannot meet the GHG reduction requirements of LL97 by continuing to employ steam heating and DHW systems. The options to radically reduce energy consumption and GHG emissions include conversion to building-scale hydronic (heating hot water distribution) and conversion to heat pumps.



Space heating and hot water making account for 65% of energy use.

Heating boilers must run all year to make hot water (DHW).

In-apartment use is paid for by NYCHA but outside NYCHA's direct control.

Figure 1. How energy is used in NYCHA developments

Why Must Apartment Energy Use Be Reduced in Tandem with Electrification?

Capital-intensive projects to electrify building systems will take years to complete, and alone may be insufficient to achieve LL97 2030 goals. To achieve a large net reduction in GHGs, beneficial electrification at a particular building is best preceded by actions that increase energy-efficiency and the ability of NYCHA and its residents to track and control how energy is used.[16] Reducing in-apartment energy use will increase the likelihood of achieving the GHG reduction targets.

Beneficial electrification may increase electric loads and require upgrading some of the existing electrical infrastructure; however, reducing in-apartment electric use will free up capacity in the building's electric infrastructure, and may help postpone, perhaps indefinitely, the need for costly electrical infrastructure upgrades (see Appendix A).

Reducing energy use within apartments will directly reduce emissions. Electrification will further reduce direct fossil fuel use and emissions and create opportunities for further indirect reductions as the carbon intensity of the electrical grid declines.

PART 1

CONSERVATION AND ELECTRIFICATION OF HEAT AND HOT WATER PROVISION

Steam Heat is a 19th-Century Technology Incompatible with 21st-Century Needs

Whether in terms of floor area or by greenhouse gas emissions, the dominant heating system type at NYCHA is two-pipe campus steam with a central boiler plant.

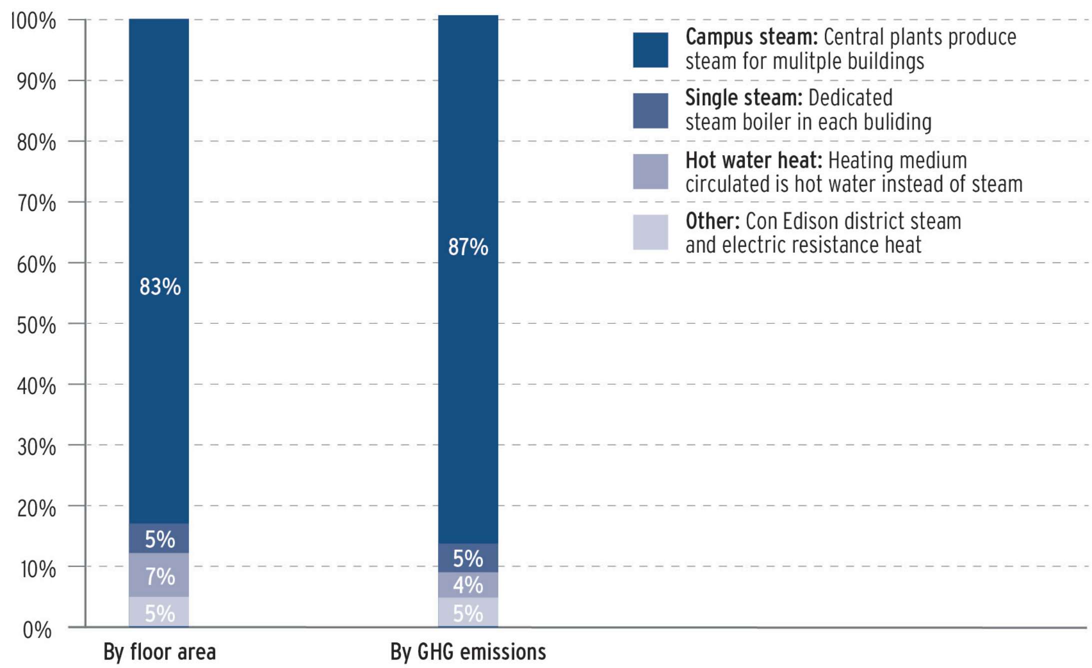


Figure 2. Campus steam heat produces 87% of NYCHA's heating and hot water-related GHG emissions. (Analysis by Steven Winter Associates)

Even Under Ideal Conditions, Campus Steam Heat Wastes Energy

Steam boilers are among the least-efficient heating technologies. The best steam boilers are about 80% efficient, meaning that under ideal conditions 80% of the energy input as fuel is turned into useful heat. In comparison, the best hydronic boilers approach 95% efficiency and heat pumps are three times more efficient[17] than the best hydronic boilers.[18, 19]

The efficiency of steam boilers drops significantly during real-world operations. Because of the need for steam boiler water treatment, thousands of gallons of hot boiler water must be discharged ("blown down") every day; the energy in this water literally goes down the drain and significantly reduces efficiency. Campus systems, in which boiler plants in one building produce steam for other buildings, must contend with distribution losses—energy escaping into the air and ground instead of being used in buildings. Over the course of a year, when these and other operational losses are considered, only about a third of a campus steam system's input energy is converted to useful heat (Figure 3).

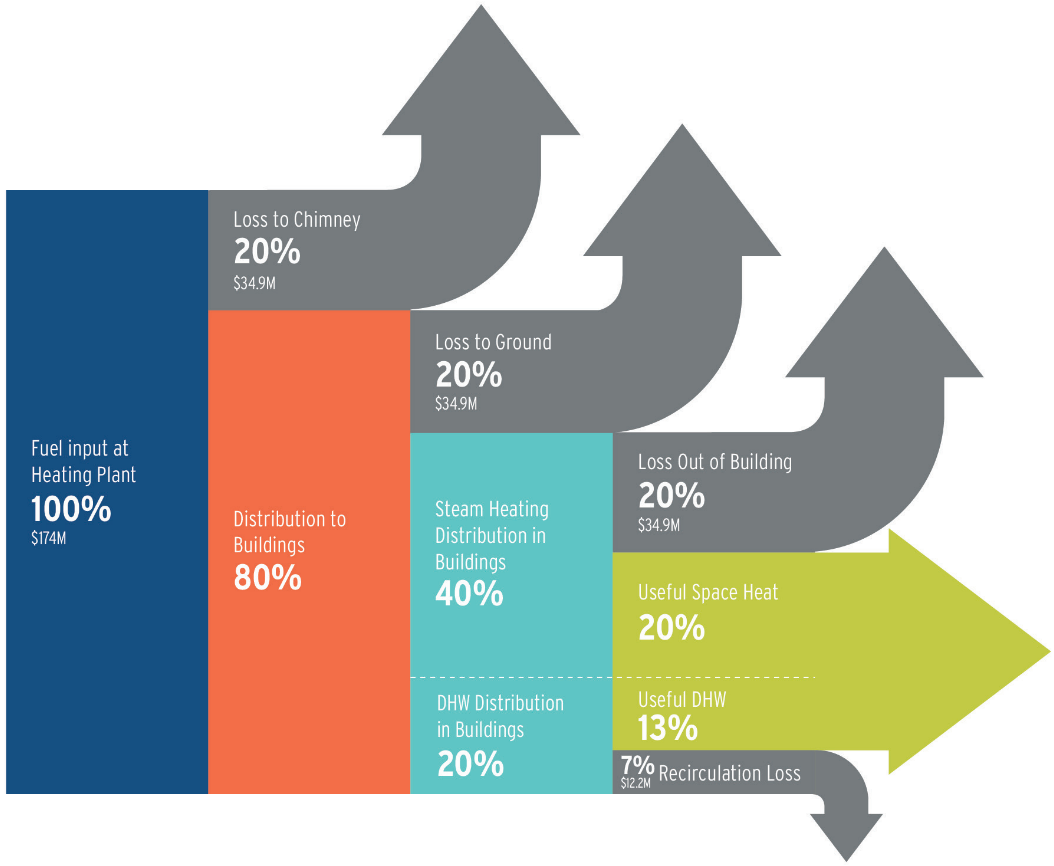


Figure 3. Campus steam systems lose 2/3 of input energy (Prepared by Steven Winter Associates for NYCHA)

Campus Steam Heat is Nearly Impossible to Keep Running in Top Condition

A campus steam heating system comprises miles of pipe, thousands of pipe joints, complicated controls, numerous moving parts, high temperatures and corrosive materials. It requires almost constant monitoring and care, yet many of its elements are buried or otherwise difficult to access. Pervasive leaks in buried distribution pipes are prohibitively expensive to locate and repair.

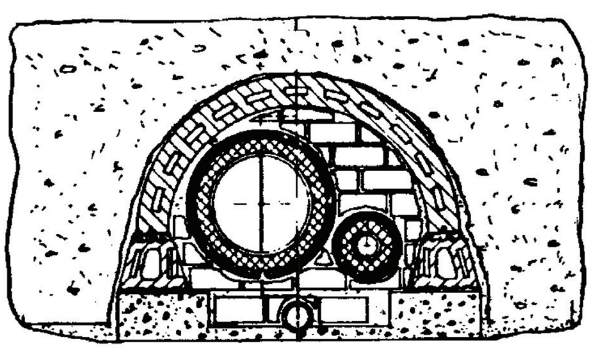


Figure 4. Typical NYCHA buried steam pipe conduit. Steam and condensate leaks are difficult to locate and repair.

Even a small amount of neglect, deferred maintenance or incorrect operation inevitably leads to failures throughout the system. Failed steam traps, to cite just one example, lead to severe heat imbalance, resident discomfort, damaged vacuum pumps and water hammer. A failed condensate pump motor seal can lead to wasted heat, water damage in tank rooms, excessive boiler makeup water, and boiler tube replacement.

These problems extend to the underground steam distribution lines, which have not been fully replaced since their original installation and are at or near the end of their useful life. Developments that continue to use campus steam for the foreseeable future—those that have recently replaced boiler plants, for example—will require replacement (rather than repair) of underground distribution lines to keep the system in efficient working order. If NYCHA were to replace additional campus steam boiler plants and underground distribution between now and 2050, NYCHA would be committed to expending significant future resources on systems that will not meet 80x50.

Exacerbating the situation is the fact that, industry-wide, the number of heating and mechanical professionals who know how to operate or repair these systems to their original design intent is very small and decreases every year. Proper steam system operation is challenging at the best of times. As the knowledge base dwindles, steam system operation and repair will become more and more difficult and expensive.

Steam Heat Results in Overheated Apartments

Avoiding overheating is exceedingly difficult in steam heating systems because different apartments need different amounts of heat but the steam system has only one "speed." North-facing apartments receive less solar heat than south-facing apartments. Wind direction and intensity can also affect the heating needs of apartments at different times. Apartments located on different floors are affected differently by steam distribution problems. Some apartments experience more air leakage and drafts than others. Finally, different people may simply have different ambient temperature preferences. Heating professionals observe that in steam buildings the rule of thumb is to "turn up" the heat until the last tenant stops complaining of cold, and those who are overheated will use their "double-hung zone valves"–open their windows–to control the temperature.

Providing consistently comfortable heat in every apartment without under- or overheating would require control over the amount of steam provided to each room in each apartment. Because steam is a gas, its movement is more difficult to control than a liquid's (like hot water). It is possible to somewhat regulate the amount of steam that goes into each radiator, but in practice it is rarely achieved. Because it is difficult to control the amount of heat delivered through a steam system, the temperature in a given apartment will fluctuate significantly over the course of a day. Variable-vacuum steam systems, such as NYCHA's, theoretically can vary the temperature of steam and thus vary the output of the radiators, but even systems in a perfect state of repair are rarely, if ever, successfully operated in this way. Add to this the effects of solar heat and wind, and it becomes exceptionally difficult to "balance" a steam heating system.

At NYCHA, the problem of pervasive overheating has been thoroughly documented. For example, NYCHA's Performance Tracking and Analytics Department (PTAD) analyzed apartment temperature sensor data from October 2017 – January 2018 at 11 developments. The data showed that there was an overwhelming amount of overheating. During the day, only about 37% of daily apartment temperature averages met the study's target range of 68°F-74°F. More than half (59%) exceeded 75°F, and more than 14% exceeded 80°F. At night, 92% exceeded the upper limit of the target temperature range of 62-69°F.

Options for Conservation and Beneficial Electrification of Heat and Hot Water

A practical strategy to meet the requirements of LL97 will include both short- and long-term options, including enhancements to existing campus steam systems that will continue in service as well as major capital projects to adopt new technology. This section examines four key elements. Appendix E presents in detail the GHG implications for various strategies and Appendix F examines the feasibility of DHW electrification.

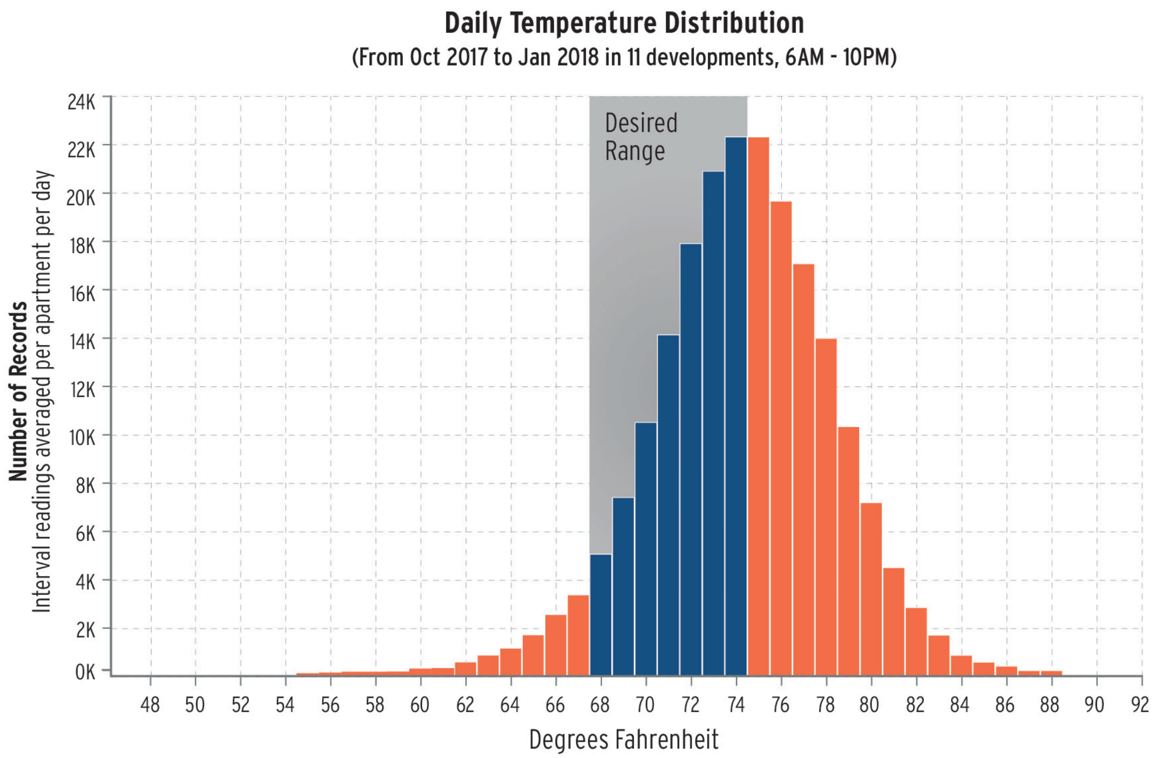
Steam System Optimization

Any steam system that continues to operate during the transition to electrification must be optimized to achieve as much energy savings as possible until it can be replaced. The four most important optimization strategies include maintaining and operating the system as efficiently as possible; retaining condensate; and sending the right amount of heat at the right time. If optimization is pursued vigorously, it is possible to reduce energy use 20%, 30% or even 40% in extremely inefficient cases. A moderate investment would yield significant savings, help increase system uptime, and reduce heat outages.

Preventive maintenance & efficient operation

Operating and maintaining the boiler according to manufacturer instructions and best practices has a huge impact on overall energy use. Small, unnoticed changes in site or equipment conditions can result in 10% to 20% energy waste.

Efficient operation entails checking settings and taking measurements to make sure that the system is operating within its design parameters. Site staff must track trends like boiler stack temperature and condensate replacement rate. As these rise, efficiency



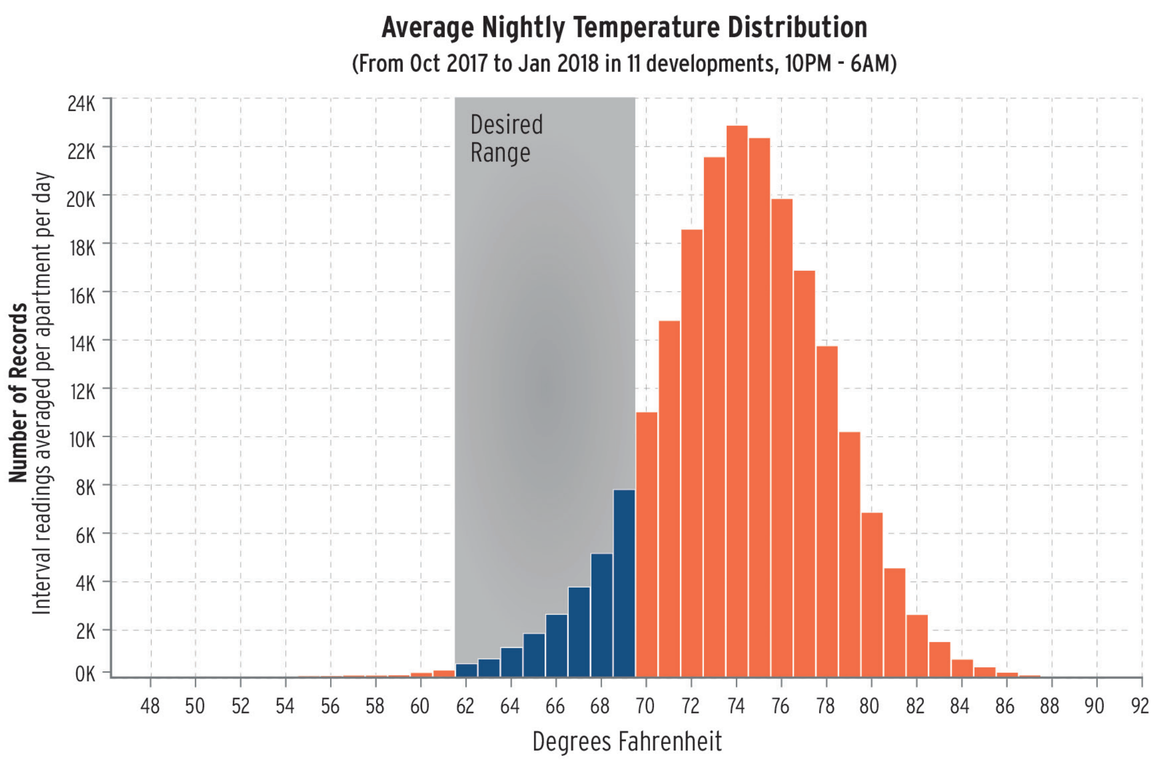


Figure 5. Daytime and nighttime apartment temperatures show pervasive overheating

begins to drift downward. Fuel burners must then be adjusted for maximum efficiency, and leaks must be located and eliminated. Short-cycling of burners (analogous to stop-and-go driving) must be addressed to improve fuel "mileage." Steam traps, zone valves, vacuum pumps and condensate pumps must be preventively maintained rather than being allowed to fail and sit unrepaired.

Retaining condensate

A steam system is ideally a closed system: all the steam that leaves the boiler should come back as hot water (condensate). When condensate does not return to the boiler (because it has leaked out somewhere, or is trapped in the distribution pipes), it causes many problems. Energy is wasted, the leaking water may cause equipment or property damage, and the new water that replaces it must be chemically treated. If the new water is not correctly treated, oxygen dissolved in the water can destroy the boilers and pipes. Where condensate is trapped it usually leads to water hammer, which is at best a nuisance to residents and at worst destructive of pipes and steam traps.

In order to retain condensate, boiler operators must make a concerted effort to find both major and minor leaks and make necessary repairs or upgrades to steam traps, radiator traps, vacuum pumps and condensate tanks. This requires a regularly-scheduled, systematic approach.

Sending the right amount of heat at the right time

Ideally, each apartment should have enough, but not too much, heat. To deliver the right amount of heat at the right time to every apartment, the steam system must be balanced (every radiator getting the right amount of steam) and the controls must be responsive to changing conditions. In reality, many apartments receive far more heat than they need. In buildings where the heat goes on or off according to the outdoor temperature, lack of information about the indoor temperature is partially to blame for overheating. The heating control systems simply detect that there is no need for more heat when, for example, the building's average indoor temperature is already 72°F regardless of a low outdoor temperature. Even when some apartments are overheated, others may not be receiving enough heat because of system imbalance.

With indoor temperature feedback, when the building is warm enough the system will stop sending more heat, and thus help eliminate overheating. Indoor sensors alone, however, cannot fix distribution imbalances that result in underheated rooms or apartments. In parallel to installing indoor temperature sensors, it is necessary to address underheating at the root causes, proactively whenever possible (i.e. before a heat complaint has been made).

Balancing a steam system so that every apartment is comfortable is very difficult to achieve; however, the “on-off” nature of steam radiators can be modified by the use of thermostatic radiator valves (TRVs). TRVs control the amount of steam entering a radiator, ensuring that every radiator gets the right amount of steam, compensating for solar gain and other conditions specific to the room. The TRV incorporates a temperature sensor that causes the TRV to close and stop the flow of steam when the TRV’s setpoint has been reached. This can improve the balance of the system, although it will have a more limited effect on underheating.

Troubleshooting underheating requires examining a multitude of possible causes on an apartment-by-apartment basis. Two of the most common reasons are excessive air infiltration and failed radiator traps.[20]

Electrification through Hydronic Conversion

Hydronic distribution systems circulate hot water instead of steam to the radiators. Building-specific hydronic systems are much more energy-efficient than campus steam systems because of higher combustion efficiency, lower circulating temperature, lower “off-cycle” losses, and no losses from campus-style distribution, among other factors. Electrification through hydronic conversion would entail replacing steam distribution systems with hot water distribution and using air-to-water heat pumps (AWHPs) or ground-source heat pumps to heat the water.

A Successful Hydronic Conversion

In 2019, RDC Development, a joint venture between MDG Design + Construction and Wavecrest Management, completed the rehabilitation of Ocean Bay-Bayside Apartments (see cover photo). As part of the rehab, the central steam plant was decommissioned, hydronic boilers were provided for each building, existing steam distribution piping was removed, and steam radiators were replaced with high-efficiency hot water convectors. The boiler “rooms” were assembled off-site in shipping-container-sized modules and lifted up to the buildings’ roofs. In addition to being more energy-efficient, Ocean Bay Apartments will no longer experience development-wide outages as a result of a central boiler plant failure.

Whether or when AWHPs that can meet the needs of buildings of NYCHA's scale will be available in the U.S. is unknown, although heat pump technology is pervasive in parts of Asia and Europe. Until AWHPs suitable for multifamily buildings become more widely available, electrification through hydronic conversion may entail two steps: first convert from steam to hydronic with gas-fired condensing boilers, then replace the boilers with heat pumps several years later.

The two-step approach, however, has three disadvantages. First, fossil-fueled boilers still require combustion, even if it is more efficient. Second, typical hydronic systems do not provide cooling (which is increasingly becoming a necessity because of climate change). Third, any gas-fueled system will require new gas service to the individual buildings, and continued availability of low-cost gas service is not guaranteed. Gas capacity is already severely constrained in some parts of the New York City metro area,[21, 22] and in February 2020, Mayor Bill de Blasio issued Executive Order 52 to stop any new infrastructure, such as power plant expansions, pipelines, or terminals that expand the supply of fossil fuels.[23]

Hydronic conversion requires work in every apartment to install new distribution pipes and new convectors to replace steam radiators. NYCHA must plan carefully to minimize disruption to residents. The recent hydronic conversion at Ocean Bay-Bayside has proven that careful planning can make unit access very efficient; developer MDG reported that all in-unit heating system work was completed in only one day per apartment.

Electrification through Air Source Heat Pumps (ASHPs)

All types of ASHP systems consist of outdoor units, which house the compressor, and indoor units, which distribute conditioned air into rooms. Variable Refrigerant Flow (VRF) systems employ centralized outdoor units to serve indoor units throughout an entire building. "Multi-split" systems require one or more outdoor units for every apartment. New York City's weather requires the use of so-called "cold climate" heat pumps that are certified by a third party.

ASHPs solve several problems. They are far more reliable than steam systems and require much less maintenance. Steam and heating hot water leaks are eliminated. ASHPs permit precise control of each room's temperature and virtually eliminate over- and underheating. Every apartment can now have air conditioning, which is critical for protecting the health and well-being of vulnerable, particularly senior, residents during hot weather (which is expected to become more frequent and severe as a result of the changing climate).

In a multi-split installation, if one heat pump fails, only one apartment is affected, not an entire building, and because each apartment has its own system, the apartment submeter can provide a feedback loop to encourage energy conservation.

Building Enclosure Retrofits

Mid-century multifamily buildings, including NYCHA's, leak a lot of air and have little or no wall insulation. No matter how efficient the mechanical system, the building enclosure limits how much energy can be saved. NYCHA must therefore seek out or develop cost-effective ways to airseal and insulate its buildings to achieve the best possible energy performance.

Modeled savings show that a combination of exterior insulation and airsealing can reduce heat loss from the building on the order of 50% to 80%; however, cost-effectiveness of exterior insulation retrofit systems has not been well-documented. Pre-fabricated insulated masonry panels are already available and if it can be shown that they (or systems with similar characteristics) have the advantage of eliminating the need for costly major repointing, the savings may make such a system worthwhile.

In addition to the direct energy reductions associated with high-performance envelopes, there are several additional potential benefits:

- Once a building's heating and cooling loads have been substantially reduced, it becomes possible to install smaller and less-costly heating and cooling systems.

Coefficient of Performance vs. Combustion Efficiency

The best heat pumps currently available are, on average, 6 to 10 times as efficient as a central steam system; how is this possible? It's possible because heat pumps move heat from outdoors to in (or indoors to out for cooling), rather than create heat through combustion. Energy, usually electricity, is used to power a compressor, and this compressor takes advantage of the laws of thermodynamics to move heat from one place to another.

It takes much less energy input to move heat than to create it. The measure of a heat pump's efficiency is the Coefficient of Performance (COP). A typical high-quality heat pump has an average COP of about 3.0, which means that it moves 3.0 times as much heat energy as it uses in input energy. The COP of any boiler-based system will always be less than 1.0. An inefficient steam system would have a COP of about 0.3 to 0.5.

A smaller mechanical system is less likely to require an electrical upgrade, is more likely to be able to operate on 120-volt circuits, and requires less refrigerant.[25]

- Once ASHPs are installed in a substantial proportion of buildings, the local utility's peak electrical demand will occur in the winter. Widespread adoption of envelope retrofits will allow many more buildings to install ASHPs before the peak is reached.
- Any highly-insulated building, regardless of the type of heating/cooling system, can remain habitable during an electrical service interruption[26] longer than a building with a typical mid-century envelope.[27] During extended cold spells, which are likely to increase in frequency, high-performance envelopes help minimize the impact of service interruptions.[28]
- Finally, a building with a high-performance envelope could reduce GHG emissions substantially even if it retained a fossil-fueled heating system; if the heating load is reduced 80%, fossil fuel GHGs would be reduced a similar amount.

Path Forward for Conservation and Electrification of Heat and Hot Water

Adopt Low-Carbon Requirements for Future Boiler Plant Replacements

NYCHA should attempt aggressive carbon reductions in every heating system capital improvement project, because not every project will be able to achieve deep reductions within NYCHA's financial constraints.

In 2019, NYCHA began to plan for heating system replacement projects at 11 developments (126 buildings, 10,050 apartments) using its newly-available design-build authority[29, 30] and established low-carbon goals as a primary design requirement. Using a fixed-budget/best value methodology for design-build, NYCHA developed a technology-neutral procurement process that uses anticipated carbon intensity in 2030 and 2050 as determinants of contract award. NYCHA's design-build program provides a maximum budget for each project, along with a prioritized list of non-price factors for proposal evaluation. The GHG performance criteria include:

Mission Critical: Minimum required for the project

- Out-perform GHG emissions limit of 6.75 mtCO_2e/ksf, averaged across all buildings and developments in the project

- Demonstrates clear pathway (through eQuest modeling of incremental technology adoption) from proposed system to meeting 2050 GHG emissions limit of 1.7 $mtCO_2e$/ksf, averaged across all buildings and developments in the project.

Highly Desirable: Not required by the project to proceed, but plays heavily into design-build team selection

- Meets the LL97 2030 goal of 5.1 $mtCO_2e$/ksf, averaged at the project level
- Meets LL97 2050 goal of 1.7 $mtCO_2e$/ksf at at least one building
- Meets the LL97 2030 goal of 5.1 $mtCO_2e$/ksf at each building

If Possible: Not required by the contract, but can play into design-build team selection if a number of design competition submittals are similar

- Meets LL97 2050 goal of 1.7 $mtCO_2e$/ksf at the project level (i.e. averaged across all buildings)

Although the evaluation criteria do not require specific technologies, the LL97-tied performance targets generally preclude replacement-in-kind of the existing campus steam systems.

Whether NYCHA's first design-build program participants can deliver the required performance at the fixed budgets available remains to be seen; however, the success of the Ocean Bay-Bayside hydronic conversion project demonstrates that system conversions can be implemented economically in NYCHA developments.

Optimize Campus Steam

Existing campus steam systems must be optimized. Carbon intensity across campus steam developments varies by a factor of two largely because some heating systems have been better maintained than others. With steam optimization at all developments, it is possible to reduce energy consumption and carbon intensity, and to greatly reduce the variation in performance. Although steam optimization alone will not be sufficient to achieve LL97's 2030 targets, a 15% reduction in gas consumption across the board would represent a quarter of the reduction in carbon intensity required by 2030.

Distribution maintenance and balancing: The NYCHA heating management department has already begun to adopt a more systematic approach to steam system maintenance. In 2018, for example, NYCHA replaced all steam traps on steam mains at five developments. NYCHA is also testing a conversion from radiator steam traps to orifice plates to eliminate steam in return lines and the need for radiator trap maintenance. NYCHA has also tested TRVs in several buildings and is evaluating their efficacy.

Indoor temperature sensors and new Building Management System (BMS): In 2011, NYCHA began installing indoor temperature sensors to eliminate overheating. NYCHA greatly expanded this effort in 2016 by using the HUD Energy Performance Contracting (EPC) program, which has the advantage of not requiring commitment of capital funds, as the primary implementation mechanism. As of March 2020, NYCHA's active EPCs are funding installation of indoor temperature sensors in 64 developments (629 buildings; 51,164 apartments). The new BMS and indoor temperature feedback controls are projected to reduce energy consumption and GHG emissions by 15%.

The 2019 agreement between HUD and the US Attorney for the Southern District of New York (SDNY)[32] obligates NYCHA to install indoor temperature sensors and BMSs throughout the NYCHA portfolio. Accordingly, in February 2020, NYCHA's board approved the future award of additional new EPCs of up to $400 million to four firms (Engie, Willdan, Johnson Controls, and Ameresco) to carry out this work.

The new BMS being installed replaces an existing proprietary system with limited capabilities. Among the advantages of the new system is that if a sensor component or control device fails, NYCHA will be able to source parts and services competitively from multiple manufacturers. Additionally, the new BMS allows enhanced reporting, analytics and alarms for every point monitored in the system. The BMS will monitor apartment temperatures; boiler plants, tank rooms, and hot water generating equipment; steam pressure and other distribution factors at various points in the system; water, gas, and electricity status; and other critical indicators.

The BMS enhances operations of the department responsible for the maintenance of heating systems. Work orders can be initiated automatically when maintenance issues are detected. Apartment temperature data can be used to determine which apartments and/or lines may need preventive maintenance such as radiator valve or trap servicing, and identify under- or overheated areas.

Distribution system maintenance and the EPC-funded work are complementary measures that must be undertaken together. Failure to maintain the distribution system jeopardizes NYCHA's ability to pay back the EPC-associated debt. EPCs are funded by bank loans, which are then paid back by a HUD subsidy sized according to the energy cost savings the EPC work delivers. In order to make sure that the cost savings materialize during the EPC term of up to 20 years, HUD requires annual monitoring and verification. Lack of distribution maintenance or poor operating parameters would result in failure to meet the savings targets, and the attendant loss of HUD subsidy. In such an event, NYCHA would need to repay the bank loan with its own resources.

Weatherize Small Buildings

LL97 does not apply to privately-owned buildings smaller than 25,000 sf, but it does apply to all NYCHA buildings regardless of size. Mechanical systems in NYCHA's small buildings differ from those in the large developments. For example, NYCHA's small multifamily buildings often have idiosyncratic distribution configurations—sometimes the boilers serve one building, and sometimes they serve several attached buildings. Therefore, small buildings tend to be best served by building-specific packages of interventions, rather than by standardized upgrades.

In 2015 NYCHA worked with New York State Homes and Community Renewal (HCR) to facilitate the use of the federally-funded, state-administered Weatherization Assistance Program (WAP) for NYCHA's small buildings. NYCHA pre-qualified 8,000 apartments for the program and pledged to pursue $30 million in WAP projects over 10 years. WAP delivers a package of energy-efficiency measures including boiler and window replacements, ventilation upgrades, and hot water-conserving fixtures. NYCHA pays 20-40% of the cost, with the balance contributed by the State's WAP grant. Construction is overseen by non-profit community-based organizations designated by HCR. Since 2015, 2,983 apartments in 163 NYCHA buildings have benefitted from WAP upgrades, resulting in typical savings of 24%.

Because CLCPA requires GHG emissions to be reduced 85% below 1990 levels by 2050, NYCHA should advocate for a CLCPA-compliant WAP option that delivers deeper carbon reductions than the standard WAP program. Such a program would also help the State meet the CLCPA requirement that no less than 35% of investments made under CLCPA must benefit underserved communities.

Retrofit Building Enclosures for High Performance Wherever Possible

Much of the infrastructure in NYCHA buildings dates from the original construction. This includes not only the heating distribution systems, but also the domestic and waste plumbing, electrical service to apartments, and the building envelope. Although it would likely be most cost-efficient to upgrade all systems at once, that option is also likely the most disruptive to residents when constructed conventionally.

NYCHA is currently participating in NYSERDA's RetrofitNY program to explore the possibility of using envelope recladding as a means to radically reduce the cost of plumbing, ventilation and electrical upgrades, and even high-speed internet. Launched in 2018, RetrofitNY seeks to catalyze a market for low-cost envelope improvements and to "crowd-in" new, modularized technologies that would enable existing buildings to reach net zero carbon emissions. Several multifamily retrofit projects are now in construction. In addition to highly-insulated and air-sealed building envelopes, these projects include energy-efficient, balanced mechanical ventilation systems to improve indoor air quality.

NYCHA has an active program of façade repairs (including repointing) that does not improve energy performance but is required by the Façade Inspection and Safety Program (FISP). Recent changes in the law are anticipated to increase costs of FISP compliance. A comprehensive envelope recladding program can improve energy performance, eliminate the on-going FISP costs, and also radically reduce the cost of plumbing, ventilation, and electrical upgrades.

Although it would be premature to anticipate the outcomes of this demonstration project, NYCHA's newly-acquired design-build authority makes a scaled-up program of enclosure plus infrastructure retrofits a practical possibility. NYCHA plans to pursue, initially at three developments, a comprehensive "gut" renovation program that would include heating system replacement. The buildings will be brought up to code, comply with the NYC Energy Conservation Code, and include energy performance criteria designed to meet LL97 goals.

Support and Monitor LL97 Efforts in PACT/RAD Developments

One of the most important tools at NYCHA's disposal for funding coordinated capital improvements is the Permanent Affordability Commitment Together (PACT)/Rental Assistance Demonstration (RAD) program. Because many buildings will receive substantial work that has energy co-benefits, it is important that NYCHA work closely with PACT/RAD developers to attain the greatest GHG emissions reductions possible. RAD is a HUD initiative that allows NYCHA and other public housing authorities to convert Section 9 (traditional public housing) subsidies to Section 8 project-based vouchers. Under PACT, converting the units to Section 8 generates funds needed for capital repairs while ensuring permanent affordability and maintaining resident rights equivalent to protections afforded residents of public housing. In 2018, Mayor de Blasio announced that 62,000 NYCHA apartments would receive comprehensive repairs through PACT/RAD by 2028.[32]

Since 2018, the PACT/RAD program has required several sustainability components. With LL97 in mind, the requirements were revised in 2019 to include:

- Present an analysis of pre- and post-rehab carbon emissions in tons of CO_2 equivalent per square ft.; and
- Present a long-term carbon reduction plan that either meets the emissions intensity limits defined in LL97 for occupancy group R-2 for 2024, 2030, and 2050; OR meet the emissions intensities equivalent to the NYCHA portfolio-wide reductions of 40% by 2030 and 80% by 2050 from a 2005 baseline.

PART 2

CONSERVATION AND ELECTRIFICATION WITHIN APARTMENT UNITS

A Third of NYCHA's Energy Use is Consumed Within Apartment Units

A substantial portion of the energy used within apartments is associated with four base uses: the refrigerator, lighting, air conditioning, and stove.[35] With the exception of the refrigerator, which runs continually, these uses depend largely on the efficiency of the equipment and are only somewhat dependent on user behavior (for example, how much the lights are left on). All other in-apartment uses, including TVs, hair dryers, computers, etc., vary greatly from household to household.

At NYCHA, the refrigerators are already as efficient as prevailing technology allows. NYCHA replaced incandescent lighting with CFLs starting in 2007 and began replacing all lighting with LEDs in 2017. The base uses that have not yet been addressed systematically are air conditioners and stoves.

NYCHA Residents are Unaware of How Much Energy They Use

Only about 6% of NYCHA's apartments are direct metered and billed for electricity.[36] The median value for electricity consumption per square foot in master-metered NYCHA developments is four times that of direct-metered NYCHA developments.[37]

Research has established that unmetered tenants use more energy than their counterparts in individually-metered apartments, because they lack both the means to measure how much energy they use and have no cost incentive to conserve.[38, 39] Master-metered utilities in public housing account for 22.3% of HUD's total utility expenditures.[40] In 1996, the Federal government required the use of individual meters for all public housing residents wherever the meters could be installed practically and affordably.[41]

Individual direct meters for each apartment can only be provided in buildings where there is a dedicated electrical riser for each apartment. Most NYCHA buildings were not built with dedicated risers, which makes individual direct metering prohibitively expensive. In addition, direct-metered residents pay a higher rate than NYCHA for their electricity; therefore, a conversion to direct metering would be less beneficial for residents.

Although NYCHA has periodically evaluated options for submetering, it has not yet prioritized in-apartment energy consumption reduction as a key part of its climate mitigation plan. Submetered billing was not previously pursued by NYCHA for a variety of reasons: NYCHA's below-market electric rates made it harder to justify the cost of submetering on the basis of cost savings, and HUD policies made it difficult to fund submetering from HUD Capital Funds.[42] Many commercially-available submetering technologies were platform-specific, requiring NYCHA to put all its eggs in one basket with either a single vendor or proprietary technology that would have limited options for enhancement or maintenance. In the context of LL97's aggressive carbon reduction goals, it is now critical to develop an approach to in-apartment energy reduction that includes submetering.

Master Metering and Individual Metering

Consumption of electricity and other utilities is usually measured one of two ways: master metering or individual metering.

Master Metering – Some buildings have a single utility-owned meter (a "master" meter) that measures the electricity use of the entire building, including apartments, commercial spaces (sometimes) and common areas. Master-metered accounts typically are charged a lower rate for electricity, partly because it costs the utility much less to administer a single meter and account than hundreds of accounts.

Direct metering – A form of individual metering in which utility-owned meters monitor the energy use of individual households. Direct-metered customers often pay a higher rate than master-metered customers. Almost universal in single-family houses, market-rate rentals and coops/condos, direct metering closes the feedback loop between billing and consumption, and as such almost always results in lower consumption, irrespective of any difference in cost per kWh.

Submetering (a/k/a "check metering") – A form of individual metering in which the utility-owned master meter remains, but each user has an individual meter ("submeter") owned by the building (not the utility). Residents benefit from the lower cost of master-metered electricity while paying for their own electric use. Under this arrangement, the total kWh of all the submeters in each month should equal the total on the master meter and the costs divided among users based on their consumption.

Summer Air Conditioning Increases Consumption and Demand

Cooling is becoming a necessity for reasons of public health and climate change.[43] The New York City Panel on Climate Change predicts that by the 2050s, mean average temperatures will increase between 4.0 and 5.7°F; by the 2080s, the Panel expects heat waves to triple from the pre-2000 baseline of two per year to six per year.[44] According to the Mayor's Office of Resiliency, "air conditioning was found to be the most effective and important way to protect at-risk individuals on hot days and to keep them from experiencing heat-related illnesses."[45]

Currently, air conditioning is already the largest driver of both electricity consumption and demand within NYCHA buildings, despite not being present in every apartment. Research conducted for NYCHA in 2017 by the Environmental Defense Fund found that in NYCHA apartments, the presence of a single air conditioner increased electricity use by 30% during the summer; multiple units had an even larger impact. As mechanical cooling becomes a public-health imperative, the challenge to reduce electricity consumption and demand will become more difficult.

Options for In-Apartment Conservation and Beneficial Electrification

Provide Price Feedback to Residents Through Electricity Submetering

Any transition to submetering must be carefully managed, but the savings to both NYCHA and the residents will be substantial, and the residents' increased agency will give them a greater sense of control and improve their quality of life. According to NYSERDA's Residential Electrical Submetering Manual, buildings reduce their kWh consumption by about 18% on average, and their kW demand by about 24% on average when submeters are installed in master-metered buildings and residents are billed for the electricity they consume.[46] Since NYCHA's average master-metered use is so much higher than its average direct-metered use, savings can be expected to be significantly greater.

If utility allowances were provided to NYCHA submetered residents in the same way they are provided to their Section 8 counterparts, they would receive a rent reduction in the amount of the utility allowance. And, they no longer would have to pay the appliance surcharge for their air conditioners.[47] Since NYPA electricity costs roughly 25% less than electricity from the local utilities, the cost of submetered electricity to residents would be lower for a given amount of consumption than if they were direct-metered by the local utilities.

If residents were to use less than the amount of the utility allowance, submetering would present an opportunity to reduce their total monthly outlay for rent and utilities. The latest available submeters can provide real-time information so energy users can identify waste and adjust consumption as needed. In the future these meters may help residents benefit from electricity rates tailored to discourage consumption during peak periods.

NYCHA has the infrastructure already in place to test the effect of making consumption data available to residents.[48] In 2011, NYCHA began to deploy submeters to study resident electricity use and engage residents in a behavior-change program. Although NYCHA tracked consumption reductions, the meter data was not made available to the residents and the meters themselves did not have readouts that would allow residents to track their own use. Because these submeters are already in place, NYCHA can show electricity consumption and costs on residents' rent bills. NYCHA can then test to what extent the knowledge of consumption can change consumption behavior, with and without additional conservation campaigns.

Provide Cooling with NYCHA-Owned, Centrally-Managed Equipment

The purpose of providing NYCHA-owned, centrally-managed air conditioning is to ensure access to cooling as a public health measure while minimizing its costs and GHG impacts.

Networked Smart Window ACs

Typical older New York City apartment buildings are cooled with window AC units. Cooling with window ACs has the advantage of being easily deployed without capital improvements. The disadvantage is that because window ACs are not normally centrally managed, they contribute disproportionately to peak electrical demand. The demand impact of unmanaged ACs contributes to peaks that cause the most polluting "peaker" generating plants to run.

NYCHA's Meltzer Tower Smart AC pilot tests the costs and benefits of providing state-of-the-art, networked ACs to residents at no cost to them. The air conditioners connect wirelessly to a proprietary remote management system, which is monitored by NYCHA's BMS. Although residents retain manual control of their ACs, the BMS can remotely "modulate" the ACs during hot weather to ensure residents' rooms remain at a comfortable temperature while minimizing peak demand and energy costs. Central management also enables NYCHA to turn on ACs that have been turned off during a declared heat emergency. The networked ACs were installed in 2019; NYCHA will test the management system and the emergency "on" feature in 2020.

Air Source Heat Pumps

ASHPs provide cooling in the summer and heat in the winter. NYCHA is retrofitting ASHPs into seven apartments on the top floor of one of the 22-story towers in the Fort Independence development. Each apartment will receive an ASHP and will rely on it exclusively for both space heat and cooling. DHW will continue to be supplied by the existing central system. The apartments will be monitored for energy consumption and other key indicators.

Adoption of ASHPs at NYCHA will be driven primarily by the capital available to replace campus steam heat. For that reason, it is unlikely that cooling via ASHP will become the norm in the near future. Nonetheless, the public health benefit of cooling should be considered an important co-benefit of ASHPs when comparing alternative heating technologies.

Replace Gas Stoves with Electric Induction Stoves

Most NYCHA buildings have gas stoves. Gas stoves consume a relatively small amount of fossil fuel, but they create many problems for NYCHA: Gas stove combustion is very inefficient–perhaps 40% at best. The gas flame presents a significant fire hazard and CO presents an asphyxiation hazard. Some residents use the stove as a supplemental heat source, which is dangerous. Much of the gas piping is original in any given building, and as such is subject to leaks and subsequent shutdowns of the entire gas system in the building until costly repairs are completed. FDNY-mandated gas shutoffs affect every apartment in an entire building or even an entire development, even if a leak is localized. The loss of gas service—sometimes for months at a time—means residents cannot prepare meals without relying on hot plates or microwave ovens, which is annoying at best and a hardship at worst. Mostly because of the age of the gas lines, the immediate replacement need is large: gas riser replacement projects planned through funding year 2023 total $145 million.

Electric induction stoves have been available in the US since the 1970s, but only recently have they begun to increase market share to a noticeable level. Unlike standard resistance electric stoves, induction units transfer heat via a magnetic field. This method of heat transfer conveys several advantages, including faster heating of food, more-efficient heat transfer (and thus higher energy-efficiency) and sharply-reduced risk of burns or kitchen fires. If the oven is used as supplemental heat in an apartment, there is less risk of fire and no danger of asphyxiation.

PART 3

QUESTIONS TO BE ANSWERED THROUGH APPLIED RESEARCH

The broad outline of the actions NYCHA must take to meet 2030 and 2050 GHG emissions reduction goals is clear; however, answers to many critical questions remain unknown. As NYCHA works to scale up projects that deliver deep reductions, its program of applied research must be dramatically expanded.

Can NYCHA spur the development of a market in New York for efficient window-based heat pumps that operate on 120V?

ASHP retrofits in NYCHA apartments will entail costly capital projects. To bring as many ASHPs to as many residents as possible, these costs must be reduced. A window-sized ASHP eliminates most of the labor costs by obviating the need for new electrical and condensate lines and any associated finish carpentry, and the need for core drilling. It would also reduce the duration and complexity of in-apartment work, reducing disruption for residents.

Currently, no product exists that meets this specific need, although no new technologies are needed to create it. NYCHA should use its purchasing power to work with manufacturers to bring such a product to market.

What air-to-water heat pump technologies are available or near-ready to electrify hydronic heat and DHW? Under what conditions can they be deployed at NYCHA?

NYCHA should work with manufacturers to bring to the U.S. market technology suitable to meet NYCHA's needs. NYCHA, working with NYPA, previously pursued this approach with great success in the Super-Efficient Refrigerator Program, which helped create a market for apartment-sized energy-efficient refrigerators.

What technologies and methods can NYCHA use to dramatically improve building enclosure performance and make comprehensive upgrades feasible?

NYCHA should take advantage of previous research and identify new opportunities to test recladding. NYCHA commissioned building recladding studies under the Superstorm Sandy recovery and resilience program. Though these designs were not implemented, NYCHA can use them to inform future research. NYCHA, in partnership with NYSERDA in the RetrofitNY Program, is also investigating the cost-effectiveness and feasibility of building enclosure upgrades that improve building performance.

What are the costs and savings to NYCHA and to residents from submetering and billing residents for electricity?

Many studies have quantified the savings potential of submetering, but those studies typically involve market-rate apartments and may not accurately capture the unique variables that affect HUD-subsidized buildings. Quantifying the savings potential for NYCHA's housing stock would help firmly establish submetering as a cost-effective energy-efficiency measure.

Can NYCHA obtain substantial reductions in consumption without billing submetered residents? What role can/should incentives play?

Past research has shown that resident engagement programs that do not include financial incentives produce short-term energy savings that rebound in the long run, whereas submetering and billing residents produce permanent reductions.[49] While pursuing the regulatory approvals needed to submeter and bill residents, NYCHA should explore how to elicit energy reductions through resident education and/or financial incentives. It is possible to test various approaches at the 14 developments with submeters.[50] It may be possible to work with partners, including NYSERDA and local utilities, to create incentive programs that are allowable under HUD rules.

Is it possible to install both ASHPs and induction stoves without requiring an electrical service upgrade?

Installing both ASHPs and induction stoves in the same building would be expected to require a costly electric service upgrade because in most apartments it would not be possible to run both at the same time without tripping circuit breakers. A control system that managed peak load in each apartment by modulating the demand of the ASHP could avoid a costly upgrade. Similar controls have been available in Europe for almost 30 years.

Notes

[1] Constantinides, C. et al., “Local Laws of the City Of New York for the Year 2019, No. 97” (2019). https://www1.nyc.gov/assets/buildings/local_laws/ll97of2019.pdf

[2] Heat and hot water constituted 71%, 73% and 75% of GHG emissions for all NYCHA-paid utilities in 2016, 2017, and 2018.

[3] Gross, Gordon, “The Energy Conservation Implications of Master Metering of Electric Service in Apartments” (1975). UMR-MEC Conference on Energy. 58. https://scholarsmine.mst.edu/umr-mec/58

[4] Christian, R. and Ucar, F., “Energy Efficiency Goldmine Hiding in Plain Sight in Half a Million NYC Apartments” (Jan. 31, 2019). http://blogs.edf.org/energyexchange/2019/01/31/energy-efficiency-goldmine-hiding-in-plain-sight-in-half-a-million-nyc-apartments/

[5] As of January 1, 2019

[6] The Intergovernmental Panel on Climate Change (IPCC),“Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by governments” (Oct. 8, 2018). https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/

[7] Billimoria, S. et al.,“The Economics of Electrifying Buildings” (2018). Rocky Mountain Institute.https://rmi.org/insight/the-economics-of-electrifying-buildings/

[8] Steinberg, D. et al., “Electrification & Decarbonization: Exploring U.S. Energy Use and Greenhouse Gas Emissions in Scenarios with Widespread Electrification and Power Sector Decarbonization” (July 2017). National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy17osti/68214.pdf

[9] New York State Clean Energy Standard (CES), https://www.nyserda.ny.gov/All-Programs/Programs/Clean-Energy-Standard

[10] New York State Energy Research and Development Authority (NYSERDA),“New Efficiency: New York, Analysis of Residential Heap Pump Potential and Economics Final Report” (Jan. 2019). https://www.nyserda.ny.gov/-/media/Files/Publications/PPSER/NYSERDA/18-44-HeatPump.pdf

[11] The Regulatory Assistance Project, an independent non-governmental organization dedicated to accelerating the transition to a clean, reliable, and efficient energy future, suggests that electrification is “beneficial” when it achieves at least one of three criteria without adversely affecting the others: 1. Saves customers money long-term, 2. Reduces environmental impacts, and 3. Enables better grid management. https://www.raponline.org/wp-content/uploads/2018/10/rap_farnsworth_shipley_ee_2.0_be_2018_sep_21.pdf

[12] Billimoria, S. et al., “Economics of Electrifying”

[13] Steinberg, D. et al., “Electrification & Decarbonization”

[14] Ibid.

[15] NYSERDA, “Analysis of Residential Heap Pump”

[16] Billimoria, S. et al., “Economics of Electrifying”

[17] See “Coefficient of Performance vs Combustion Efficiency” sidebar

[18] NYSERDA, “Analysis of Residential Heap Pump”

[19] Arena, L. and Faakye, O., “Optimizing Hydronic System Performance in Residential Applications” (Oct. 2013). US Department of Energy, The National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy14osti/60200.pdf

[20] There can be thousands of radiator traps at a development; when they fail, they allow steam into the returns and cause both underheating and tank room equipment failures.

[21] ConEdison, “About the Westchester Natural Gas Moratorium” (2019) https://www.coned.com/en/save-money/convert-to-natural-gas/westchester-natural-gas-moratorium/about-the-westchester-natural-gas-moratorium

[22] National Grid, “National Grid to Lift Natural Gas Moratorium Immediately for Customers in Brooklyn, Queens and Long Island” (Nov. 25 2019) https://www.nationalgridus.com/News/2019/11/-National-Grid-to-Lift-Natural-Gas-Moratorium-Immediately-for-Customers-in-Brooklyn,-Queens-and-Long-Island/

[23] The City of New York Office of the Mayor, “Executive Order No. 52” (Feb. 6, 2020) https://www1.nyc.gov/assets/home/downloads/pdf/executive-orders/2020/eo-52.pdf

[24] NYCHA, “Sheltering Seniors from Extreme Heat” (Apr. 21, 2019) https://www1.nyc.gov/assets/nycha/downloads/pdf/n20-sheltering-seniors-from-extreme-heat.pdf

[25] Many refrigerants are extremely potent greenhouse gases, which raises the concern of refrigerant leaks. Research is being conducted to adopt more environmentally-friendly alternatives, such as CO_2.

[26] Fossil-fuel-burning heating systems require electricity to operate and thus provide no advantage over electrified systems during a power outage.

[27] Urban GreenCouncil, “90 by 50: NYC Can Reduce Its Carbon Footprint 90% by 2050” (2013).https://www.urbangreencouncil.org/sites/default/files/90_by_50_report.pdf

[28] NYCHA, “Sheltering Seniors”

[29] New York State Governor’s Press Office “Governor Cuomo Announces $250 Million Investment to Address Health Hazards and Improve Living Conditions at NYCHA” (Apr. 2, 2018). https://www.governor.ny.gov/news/governor-cuomo-announces-250-million-investment-address-health-hazards-and-improve-living

[30] Deffenbaugh, R. "Cuomo signs design-build bill to speed up city construction projects" (Jan. 2, 2020) Crain's New York Business.

[31] Apartment temperature sensors in EPCs: 12 developments have temperature sensors in every apartment. The remainder have temperature sensors in 30% of the apartments in each building.

[32] "Agreement by and between US Department of Housing and Urban Development, NYCHA, and New York City" (Jan. 31, 2019). https://www.hud.gov/sites/dfiles/PA/documents/HUD-NYCHA-Agreement013119.pdf

[33] FISP (formerly Local Law 11) requires NYC buildings taller than six stories to have their facades inspected and repaired every five years. The inspection rules were substantially revised in January 2020. https://archinect.com/firms/release/18781826/big-changes-to-nyc-local-law-11-facade-inspection-and-safety-program-fisp-for-cycle-9/150182196

[34] The City of New York Office of the Mayor, "Mayor de Blasio Announces 62,000 NYCHA Apartments to Receive Comprehensive Repairs" (Nov. 19, 2018). https://www1.nyc.gov/office-of-the-mayor/news/565-18/mayor-de-blasio-62-000-nycha-apartments-receive-comprehensive-repairs#/0

[35] According to the 2015 Residential Energy Consumption Survey (RECS), these uses constitute on average 48-54% (depending on unit size) of the total energy use in multifamily apartments.

[36] The direct-metered buildings are primarily those acquired from the City or State by NYCHA.

[37] Analysis conducted in 2020 on 2018 consumption, using NYCHA data for master-metered developments and aggregated consumption data from ConEdison for direct-metered developments. The model assumed a uniform common-area electric intensity of 2 kWh per square foot in master-metered buildings. This comparison of averages obscures any building-by-building variation: Even for direct-metered buildings, the kWh/sf metric ranges from below 2 to above 5, with the higher intensities corresponding to buildings with larger (by bedroom count) apartments.

[38] Levinson, A. and Niemann, S., "Energy Use by Apartment Tenants when Landlords Pay for Utilities" (2004). Resource and Energy Economics 26, 51–75. http://faculty.georgetown.edu/aml6/pdfs&zips/EnergyTenantsREE2004.pdf

[39] Pazuniak, R., Reina, V., and Willis, M., "Utility Allowances in Federally Subsidized Multifamily Housing" (Jun. 10, 2015). NYU Furman Center. https://furmancenter.org/research/publication/utility-allowances-in-federally-subsidized-multifamily-housing

[40] U.S. Department of Housing and Urban Development (HUD) “Affordable Green: Renewing the Federal Commitment to Energy-Efficient, Healthy Housing” (Dec. 2012). https://www.hud.gov/sites/documents/OSHCENERGYREPORT2012.PDF

[41] 24 C.F.R § 965 2002, https://ecfr.io//Title-24/pt24.4.965#sp24.4.965.d

[42] Ibid, 24 C.F.R. § 965.403

[43] NYCHA “Sheltering Seniors”

[44] Rosenzweig, C. and Solecki,W., “Building the knowledge base for climate resiliency: New York City Panel on Climate Change 2015 Report” (2015). Annals of the New York Academy of Sciences, 1336: 1–150.https://nyaspubs.onlinelibrary.wiley.com/doi/10.1111/nyas.12653

[45] The City of New York Mayor’s Office of Resiliency, “Cool Neighborhoods NYC: A Comprehensive Approach to Keep Communities Safe in Extreme Heat” (2017). https://www1.nyc.gov/assets/orr/pdf/Cool_Neighborhoods_NYC_Report.pdf

[46] Hirschfeld, H. et. al., “Residential Electrical Submetering Manual” (1997). NYSERDA

[47] Resident’s share of rent in federally assisted public housing may not exceed 30 percent of the household’s monthly income. HUD defines gross rent to include both shelter and reasonable utility costs. HUD requires local housing agencies to set annual schedules of utility allowances that determines the amounts that represent the resident’s reasonable utility costs.

[48] The 10 developments where NYCHA installed submeters are Castle Hill, 344 East 28th St., Washington, Lexington, 131 St. Nicholas, WSURA Brownstones, East 180 Monterrey Ave., Hope Gardens (RAD), Stebbins-Hewett, and Murphy (RAD).

[49] Gross, “Master Metering of Electric Service”

[50] In addition to the 10 developments (see note 48) that have submeters, 6 developments in the Sandy Recovery and Resiliency portfolio will soon have them.

Cover photo: NYCHA/Leticia Barboza

APPENDIX A

TECHNICAL CONSIDERATIONS FOR APARTMENT SUBMETERING

Submetering Options

NYCHA can pursue a variety of approaches to metering apartments individually. Each approach includes unique characteristics that must be weighed against current operational, legal and logistical realities.

The submeters could be installed like a traditional bank of utility meters, but several vendors have developed compact multiple meter modules that can meter several apartments at once at a much lower cost of installation (see Figure A1).

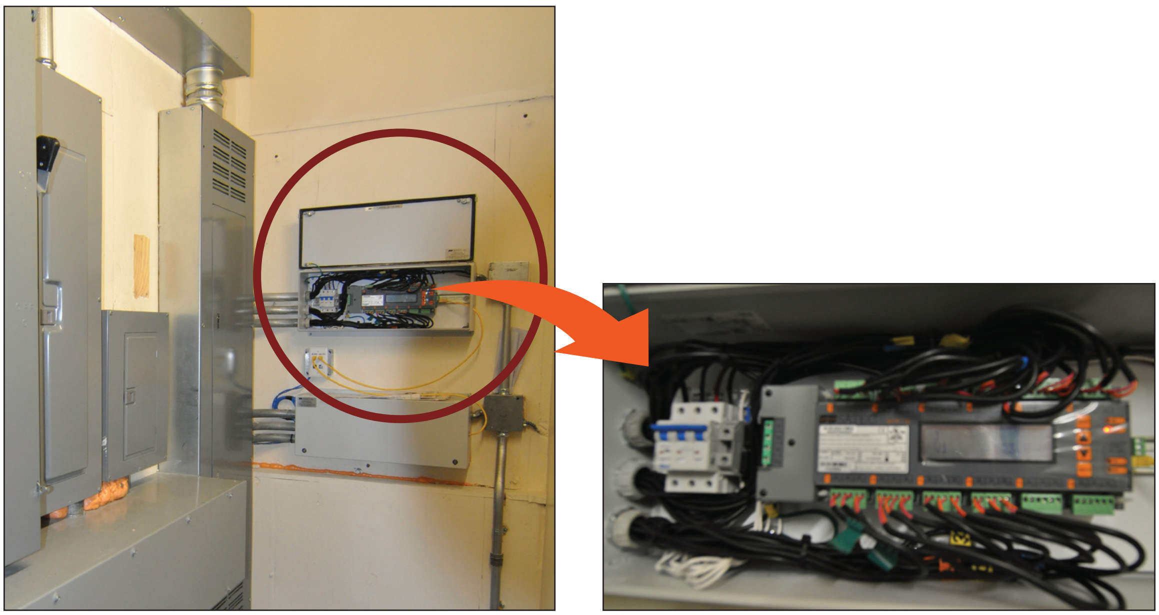


Figure A1. New, more compact submetering systems reduce installation cost dramatically. Multiple meter module circled above can monitor dozens of apartments in a very small package. (Photos: Sahagian)

Unfortunately, many NYCHA buildings, particularly the high-rises, run a large 3-phase 4-wire riser for each line of apartments and tap off two legs at each apartment electrical panel. This practice reduces the cost of bringing electrical service to the apartments, but presents several disadvantages for a submetering retrofit.

The installers must gain access to every apartment; the multiple meter module usually cannot be used; the installation may require minor demolition, patching and finish work; and the meters physically are widely separated from each other, which can make downloading data from them more complex, difficult or expensive. All these factors add significantly to the installed cost of the system.

Determine Possible New Electric Riser Configuration and Locations

All apartments with main breakers of 60 amps or less may require new electric risers if both induction stoves and heat pumps are planned. New risers could be installed in one of two ways:

1. *Remove the existing risers, install new, larger ones, and connect the new risers to the existing electrical panels*

   Advantages: All-new risers with plenty of capacity; less need for in-apartment demolition; new core drilling (between floors) possibly not needed.

   Disadvantages: More labor-intensive; may require new apartment panels if there are not enough spare breaker spaces in existing (see Fig. A2) or if the panel amp rating is too low; zero power to apartments during installation; somewhat more difficult to selectively submeter; may require some demolition of existing basement and/or riser conduits.

2. *Leave the existing risers and panels in place and install new risers and panels next to or near the existing panels*

   Advantages: No disruption of service; easier to pull smaller riser cables; no need to re-land all existing conductors in existing panel; easier to selectively submeter (i.e., don't meter ASHP or stove usage, as appropriate); much easier to pull riser if there is an existing pathway in open space (see Fig. A3); both risers and panel will be all-new.

Figure A2. Some apartment panels, like this one, will have space for new breakers; others will not (Photo: Sahagian)

Figure A3. Floor penetration for gas riser may be large enough for a new electrical riser conduit (Photo: Sahagian)

Disadvantages: May be problematic if gas risers are buried; may be more difficult to submeter if new panel is distant from existing panel; visible conduit is unattractive; may require core drilling anyway if gas riser is smaller than new conduit needs to be.

Access the Full Electrical Capacity of Each Apartment

Reducing apartment demand is one way of increasing capacity for new loads. Another way is to see if the existing wiring can accommodate more amps.

The typical minimum apartment service in New York City is 40 amps at 208 VAC, i.e., two "legs" at 40 amps each (about 8.3 kW). Many apartments, including some NYCHA apartments, have two 60-amp or even 100-amp legs.

Sometimes the conductors feeding an apartment panel can accept a higher current than the rating of the main breakers in place. For example, #8 wires (with the appropriate insulation) with 40-amp breakers could be upgraded to 50-amp breakers. Such an upgrade must also be consistent with the capacity of the riser feeding the line of apartments, or else the riser could become overloaded or experience excessive voltage drop. The point is, there may be some "free" electrical capacity hiding in the system.

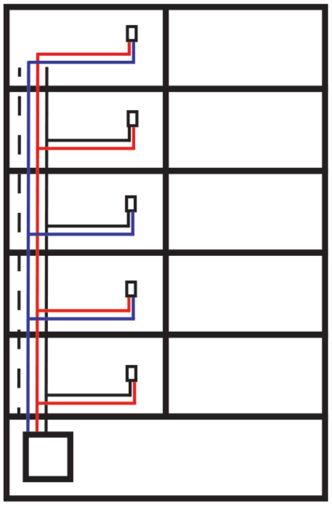
Potential Barriers to Apartment Electrification

Ampacity

The current-carrying capacity ("ampacity") of the two voltage "legs" to an apartment's electrical panel determines how many amps of service the apartment can have.
The minimum in NYCHA buildings appears to be two 40-amp legs, but many have two 60-amp or even 100-amp legs. The more amps of existing service, the less likely the need to increase it.

The two possible load increases of greatest interest to NYCHA will be electric induction stoves and ASHPs. A typical electric induction stove requires a 40- or 50-amp 2-pole breaker, and a typical ASHP requires a 40-amp 2-pole breaker. Although it is highly possible for an apartment with as little as 40-amp service to be able to add an ASHP without increasing the service, it is more difficult to add both an induction stove and an ASHP without increasing service capacity–a costly prospect.

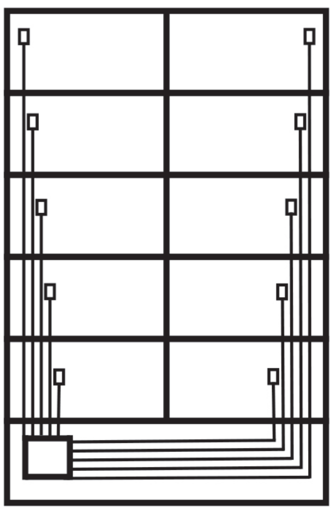
This problem may be conquered, however, through the use of controls that would limit demand in the apartment so that either no service upgrade, or a much smaller



Shared Riser

Most NYCHA apartment lines are served by a 3-phase, 4-wire 120/208 VAC riser. Two of the three phase wires are tapped off the riser into each apartment in the line. For example, the first-floor apartment might be phases A and B; 2nd floor B and C; and 3rd floor C and A, and the pattern continues to the top floor.

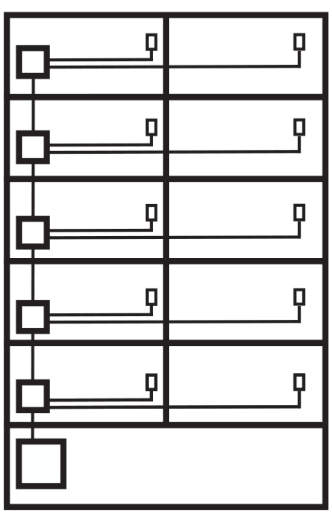
With this topology, a meter is usually required in each apartment.



Dedicated Riser

In low-rise buildings, each apartment usually has its own dedicated riser.

A multiple meter module can be installed in the basement at the electric service entrance. This eliminates the need to enter apartments, confines the work to a relatively small area, and results in substantial installation savings over meters in each apartment.



Shared Riser with Distribution Panels

In some buildings, the electric riser feeds a small electrical closet on each floor or wing of each floor, and a separate branch feeds each apartment.

In such cases the same type of multiple meter module could be used in each floor's electrical closet with the dedicated riser configuration.

Figure A4. Electric Wiring Topology

than expected upgrade, would be needed. The technology exists, although it is not commercially available in the US.

Topology of Risers and Distribution

NYCHA's electrical infrastructure varies widely from building to building. Some buildings still have their original switchgear and wiring, while others have had theirs renovated. The cost and complexity of a submetering installation depends heavily on the topology of the electric risers and distribution to the apartments (See Figure A4).

APPENDIX B

SUBMETERING REGULATIONS

Housing and Urban Development Regulations

Prior to pursuing submetered billing, NYCHA would be required to seek approval from HUD. Submetering without billing does not require prior HUD approval.

In February 1996 HUD established (in 24 CFR 965(d)) that all resident utility service be individually metered for future residential housing facilities funded by HUD. Existing facilities are required periodically to evaluate the cost-effectiveness and practicality of submetering. If submetering is found cost-effective, the PHA is required to pursue it. HUD allows for exceptions to this requirement if individual metering is either impractical (e.g. for central heating systems), not financially justified based upon a benefit/cost analysis, or not permissible under State or local law or under policies of the specific local utility.

HUD is currently pursuing a study of the efficacy of submetering in HUD-funded projects. The findings are expected in 2021.

New York State Public Service Commission (PSC) Rules and Approval Process

Before a building owner can submeter, a "Notice of Intent to Submeter" must be filed with the NYS PSC. The notice must include a description of the submetering system, the method used to calculate the bills for individual residents, a plan for complying with Home Energy Fair Practices Act (HEFPA) provisions, a "Submeterer Identification Form" and a description of the method to be used to back out electric charges from the rent, among other requirements.[1, 2]

The PSC identifies conversion from master-metering, conversion for provision of electric heat, and replacement of direct metering with submetering as distinct events, each with unique characteristics.

Once a building is approved to be submetered, there are numerous PSC rules for notifying tenants, setting rates, and other conditions to which the building owner and, if applicable, the service provider must conform.

Additionally, NYS HCR has established guidelines for submetering in its Operational Bulletin 2014-1. These guidelines highlight operational and financial changes required of any residential building that pursues submetering.

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[1] New York State Public Service Commission, "Home Energy Fair Practices Act: Rules Governing the Provision of Gas, Electric and Steam Service to Residential Customers" (2004). http://www.dps.ny.gov/HEFPA_Brochure_12-08.pdf

[2] 16 NY 96.5 Notice of Intent to Submeter and Petition to Submeter. https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b-45a3c6485257688006a701a/d4f1e6b0f51ac85785257687006f39cc/$FILE/16%20NYCRR%20Part%2096%20-%20Submetering%20Regulations.pdf

APPENDIX C

SUBMETERING DESIGN CONSIDERATIONS

Submetering Should Not Increase Residents' Overall Housing Cost Burden

Once submeters have been installed, NYCHA will still receive a monthly master-meter bill from the electric utility, but will now be able to bill each apartment for the electricity it consumes during the same period. Although residents would then be required to pay for their electricity consumption, HUD utility allowances would offset the submeter bill, and possibly result in a net savings if the resident reduces their consumption sufficiently.

To keep assisted housing affordable for lower-income households, federal law directs that the resident's share of rent in federally-assisted public housing should not exceed 30% of the household's adjusted monthly income. In interpreting the federal law, HUD has defined the Total Resident Payment for "rent" to include both shelter and the costs for reasonable amounts of utilities. The utility allowance is currently provided only to residents who pay for their own utilities (i.e., direct-metered residents).

Program Should be Designed to Elicit Strong Support From Residents

Resident support is critical to the success of any submetering program. The program should be designed to allay resident concerns:

- **Privacy** – the program must protect the privacy of resident data
- **Consequences of non-payment** – HEFPA regulates submetering and specifically forbids eviction for non-payment of electric bills. Also, NYCHA must assure residents it will not terminate service for non-payment.
- **Financial concerns** – Even if the residents' rent is reduced fairly and the net financial impact on them is zero, they often perceive efforts to convert from master metering to submetering as an attack on their quality of life and the loss of a benefit.

According to the NYSERDA submetering manual, 60% to 70% of newly-submetered apartments will experience lower overall monthly outlays (rent plus electricity) after submeters are installed, even if they don't change their habits.

NYCHA will need to work closely with residents and their representatives, and provide information sessions to answer the many questions that arise. Once the submeter readings start to come in, NYCHA must also provide information about how to reduce consumption so that savings increase for as many apartments as possible.

APPENDIX D
HOW CAPITAL PROJECTS ARE FUNDED

Meeting NYCHA's LL97 goals will require tremendous effort and resources. At the same time, NYCHA must address the housing quality obligations of NYCHA's HUD-SDNY agreement. The long-term needs of the portfolio are great, and there is no simple answer to how they will all be met; however, it is useful to understand the sources of funding currently available to NYCHA.

Programs Managed by NYCHA Capital Projects Division (CPD)

CPD oversees all capital improvements, which have been customarily defined by NYCHA as upgrades to buildings and building infrastructure at the development level. Replacements or upgrades that address one or a few buildings within a development, or that are maintenance repairs, are undertaken by NYCHA Operations.

CPD manages funds from multiple sources, typically mixing and matching them as necessary to fully fund projects. Sources include federal (HUD Capital Grant and EPCs), New York State (State general obligation bond proceeds allocated by the Governor) and City of New York (municipal bond proceeds allocated by the Mayor). Because the State and City sources are bond proceeds, they have different, often less flexible, requirements than HUD Capital Grants as to what work can be funded.

The **Federal Public Housing Capital Fund** has historically been the primary source of funds for capital improvements. Administered by the Public and Indian Housing Office of Capital Improvement, these capital grants provide funds annually to NYCHA for the development, financing, and modernization of its housing developments and for management improvements.[1] Federal capital grants from this fund have fluctuated significantly over the last 20 years because of inconsistent Congressional appropriations.

A new federal capital grant is awarded each year. Each award typically has a term of four years. Because of the overlapping terms, NYCHA has four to five awards open at any given time. HUD requires that these awards be 90% to 100% committed within two years of the start date and 100% expended within four years.

Capital funds from the City of New York represent 42% of the current NYCHA Capital Plan.[2] This unprecedented level of funding is the result of the de Blasio administration's commitment to preserve and create affordable housing. Should similar commitments be made by future administrations, capital funds from the City of New York could be a powerful tool for leveraging private financing, which could expand the size and scope of capital projects. Unlike Federal capital grants, City capital funds can be incorporated into projects financed with third-party funds without penalty.

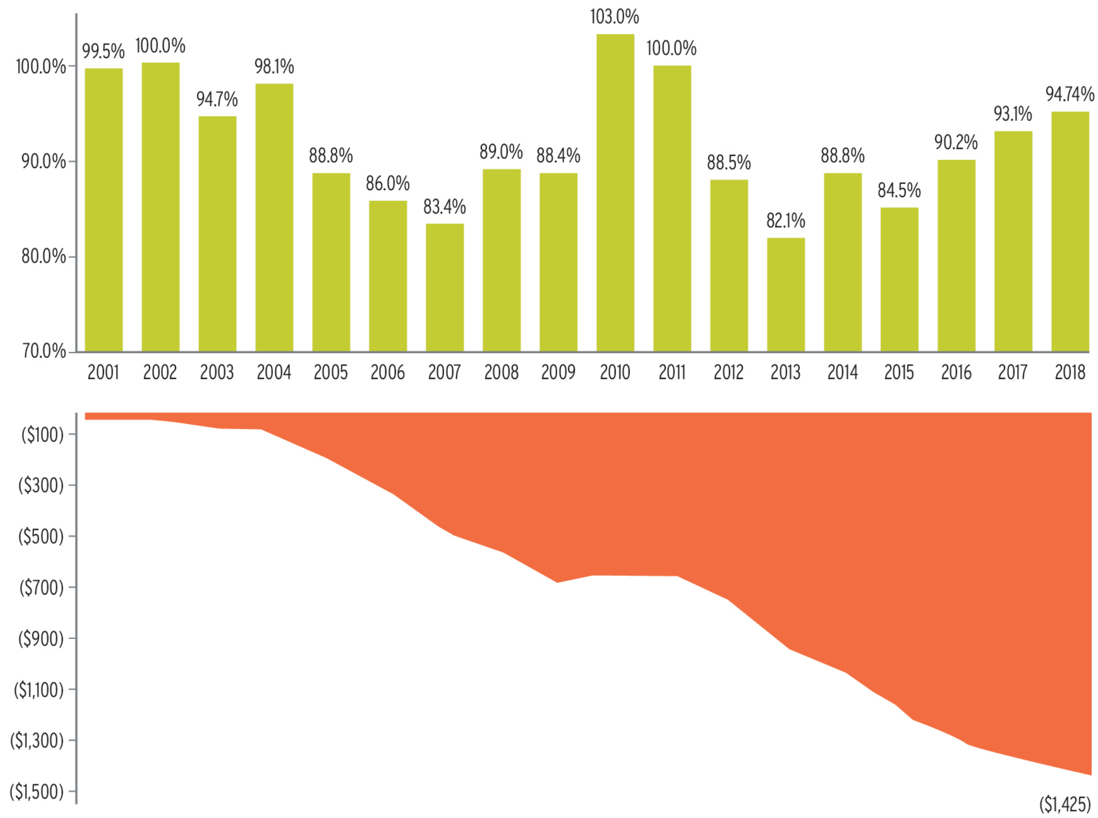


Figure D1. Historical Operating Subsidy Proration and Cumulative Loss ($ in Millions)[3]

Energy Performance Contracting (EPC) is a HUD program that allows housing authorities to use cost savings from reduced energy consumption to repay the cost of installing energy conservation measures.[4] HUD reports that as of 2016, over 315 EPCs, affecting roughly 250,000 units nationwide, were approved.[5] EPCs allow PHAs to take loans to pay the up-front cost of energy improvements and pay back by the loan from a dedicated HUD subsidy equal to the energy savings. Current EPC rules include several restrictions that affect how EPCs can be combined with other project delivery methods. Improvements must be financed with third-party loans and HUD funding cannot be incorporated into the project.

In most HUD EPCs, a single contractor (the Energy Service Company or ESCO) oversees a wide array of capital improvements, including lighting, weatherization, heating system upgrades and more. The ESCO oversees the process from start to finish by conducting the necessary energy audits, installing the retrofits and guaranteeing the energy savings.

Since 2016, NYCHA has secured approval of four EPC projects totaling $272 million and serving 145,829 residents in 72 developments.

Programs Managed by NYCHA Real Estate Development Department (REDD)

NYCHA's Real Estate Development Department is responsible for implementing the preservation programs of NYCHA 2.0, a comprehensive plan to bring $24 billion in vital repairs to NYCHA developments announced by Mayor de Blasio in December 2018.[6] The NYCHA 2.0 preservation program includes three initiatives. "Build to Preserve" (BTP) and "Transfer to Preserve" (TTP) generate revenues to fund renovations at NYCHA developments by building new mixed-income residential buildings on NYCHA-owned land and by, respectively, selling NYCHA's unused development rights to neighboring sites. "Permanently Affordable Commitment Together" (PACT) converts public housing (Section 9) apartments to permanently affordable housing using HUD Section 8 programs, including the Rental Assistance Demonstration (RAD).[7]

RAD was conceived by HUD in 2012 as a pathway to address the deferred maintenance in public housing nationwide. The conversion to Section 8 results in two positive financial changes: Section 8 funds are more consistently allocated by Congress than those traditionally provided to public housing; and NYCHA can establish partnerships with private investors, using the asset as collateral, to finance major capital improvements. Converted developments can access financing mechanisms available to privately-owned income-regulated affordable housing, but not available to public housing, such as low-income housing tax credits. Under the conversion, NYCHA continues to retain ownership of the land and buildings as well as control over major decisions, and residents retain tenancy rights and protections equivalent to public housing. NYCHA has established a 62,000-unit program that will address roughly $12.8 billion of capital needs by 2028.

In general, CPD will manage renovations funded through BTP and TTP, which NYCHA hopes will generate about $3 billion by 2028. In contrast, renovations under PACT are managed by affordable housing developers, according to standards set by NYCHA and the City. NYCHA has already incorporated references to LL97 compliance in PACT solicitations.

Programs New to NYCHA

Energy as a Service (EaaS) is a financing model used in commercial buildings to optimize building energy-efficiency and procure energy from more sustainable sources.

A service provider takes ownership of critical building equipment, and the customer pays for the services rendered by the equipment. The service provider is responsible for maintaining the equipment and achieving all performance goals (e.g. continuous operation, temperature setpoints, etc.) required by the building owner.[8]

This approach often requires little or no upfront capital from the building owner. The owner pays project costs through periodic fees, typically monthly, but sometimes quarterly or annually. A shared-savings approach, similar to EPC, is also sometimes incorporated.

Interest in this model has steadily increased, primarily as a result of new accounting requirements established by the Financial Accounting Standards Board in 2016. The new standard (ASU 2016-02) requires companies to recognize operating lease assets and liabilities on their balance sheet.[9] EaaS allows companies to avoid investing large amounts of capital in new equipment or taking on new debt.

It may be possible for NYCHA to use EaaS for capital projects, including HVAC, DHW and lighting improvements. Given similarities between EaaS and EPCs, it's likely that EaaS will require a similarly-lengthy approval process, which can take years. Clarity from HUD on this matter should be obtained prior to pursuing this approach.

Appendix D Notes

[1] For more information, see HUD PIH Office of Capital Improvements: https://www.hud.gov/program_offices/public_indian_housing/programs/ph/capfund

[2] NYCHA, "Adopted Budget for FY 2019 And The Four-Year Financial Plan FY 2020-2023" https://www1.nyc.gov/assets/nycha/downloads/pdf/nycha-2019-budget-book.pdf

[3] Ibid.

[4] For resources on HUD EPCs, see https://www.hud.gov/program_offices/public_indian_housing/programs/ph/phecc/eperformance

[5] Early, M. et al., "Energy Performance Contracting in HUD's Public Housing Stock: A Brief Overview" (Jun 2017). U.S. Department of Housing and Urban Development Office of Policy Development and Research. https://www.huduser.gov/portal/sites/default/files/pdf/EPC.pdf

[6] NYCHA, "Part 1: Invest To Preserve: Assuring Quality Affordable Housing For All NYCHA Residents" (2018). https://www1.nyc.gov/assets/nycha/downloads/pdf/NYCHA-2.0-Part1.pdf

[7] For more information, see https://www.hud.gov/RAD

[8] American Council for an Energy-Efficient Economy (ACEEE), "Energy As a Service" (Feb 12, 2019). ACEEE Emerging Opportunities Series.https://www.aceee.org/sites/default/files/eo-energy-as-service.pdf

[9] Financial Accounting Standards Board (FASB), "Update 2016-02—Leases (Topic 842) Section A—Leases: Amendments To The FASB Accounting Standards Codification" (Feb. 2016). https://www.fasb.org/jsp/FASB/Document_C/Document-Page?cid=117616790101

APPENDIX E

ENERGY CONSUMPTION AND GHG INTENSITY PORTFOLIO ANALYSIS

Background

With Introduction No. 1745-2017 (Int. 1745) in October 2017[1], the New York City Council began public discussions to set absolute energy use limits for on-site fossil fuel consumption, in support of the City's carbon reduction goals. For campus configurations like NYCHA's, Int. 1745 set a limit of 70 kBTU per square foot per year by 2030. NYCHA engaged Steven Winter Associates (SWA) to study the NYCHA portfolio and propose retrofit packages that would bring NYCHA into compliance with the 70 kBTU/sf/yr limit.

In November 2018, a substantially revised bill (Int. 1253[2]), which ultimately became LL97 in May 2019, changed the proposed limits from on-site fuel consumption to greenhouse gas (GHG) emissions. NYCHA again engaged SWA to consider the degree of electrification required to achieve the LL97-mandated GHG limits in 2030 and in 2050.

Summary of Findings

SWA examined the NYCHA portfolio to identify opportunities for fossil fuel and GHG reductions. Because campus steam is the dominant heating technology at NYCHA (83% by floor area and 87% by GHG emissions), SWA developed two scenarios: in the first, NYCHA retains campus steam but aggressively improves GHG performance by 2030. In the second, NYCHA pursues immediate electrification of heat and DHW. The first scenario showed that while the 2030 goal may be achieved while retaining campus steam, it would not be sufficient to achieve 2050 goals. The second estimated the proportion of the campus steam portfolio that would have to be electrified to achieve 2050 goals.

This scenario analysis (retaining campus steam vs. electrification) is intended to show possible future outcomes and is not meant to present prescriptive plans. Both scenarios assumed that the State achieves its clean grid goals in 2030 and 2050, and that no building envelope improvements are made.

Scenario 1: Retain Campus Steam

Finding: Campus steam system improvement strategies can result in substantial aggregate savings and may meet the 2030 GHG goal, but will not meet the 2050 goal.

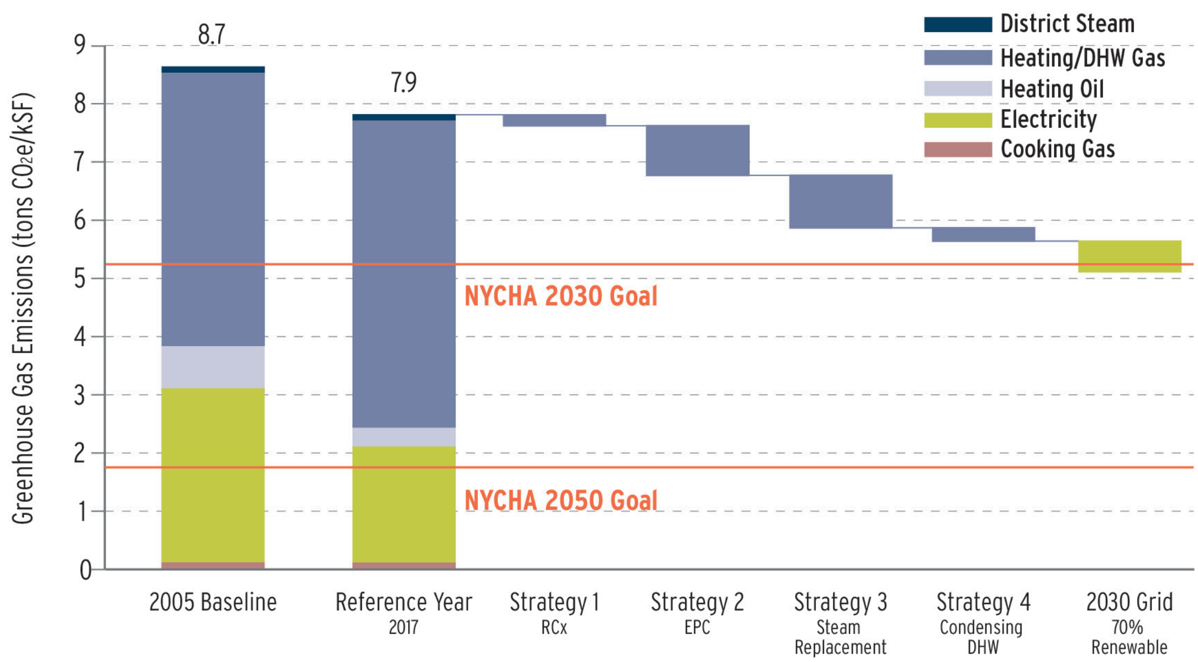
If NYCHA continued to use campus steam, various improvements would need to be made to reduce GHGs. SWA modeled four strategies that retain campus steam, reduce fuel use, and result in an estimated reduction of 25% of portfolio-wide GHG emissions.

[1] https://legistar.council.nyc.gov/View.ashx?M=F&ID=5527628&GUID=EEF7373D-B0B9-4B15-8649-0F2794278D5E

[2] https://legistar.council.nyc.gov/LegislationDetail.aspx?ID=3761078&GUID=B938F26C-E9B9-4B9F-B981-1BB2BB52A486

Assuming NYS achieves its goal of reducing the GHG intensity of electricity generation 70% by 2030[3], NYCHA could achieve the 2030 goal while retaining campus steam. This is problematic, however, for three reasons: first, the savings depend on high-quality maintenance and operations that is difficult to achieve and sustain; second, all boiler plants would have to be replaced, which is logistically unlikely; and third, continuing to invest in in-kind steam plant replacements makes the necessary electrification more urgent and difficult in later years.

Figure E1. Impact of Fuel Efficiency Measures on GHG Intensity



Strategy 1: Retro-commission the worst-performing developments (2% GHG reduction)

Retro-commissioning entails making repairs and changing operating parameters to bring an existing heating system closer to its original design efficiency. SWA proposed that the worst-performing 20% of developments could be improved to equal the current 80th-percentile performance by retro-commissioning.

[3] New York's Public Service Commission requires utilities to implement an energy transition such that by 2030 a minimum of 70% of the statewide electrical energy requirements shall be generated by renewable energy systems, and that by 2040 "...the statewide electrical demand system will be zero emissions." NYS Public Service Law §66-p(2) https://www.nysenate.gov/legislation/laws/PBS/66-P*2

Strategy 2: Expand NYCHA's Energy Performance Contracts (EPCs) (10% GHG reduction)

NYCHA's EPC base scope of work includes installation of low-flow water fixtures for domestic hot water (DHW) savings, installation of indoor temperature controls, and replacement of the legacy building management systems (BMS). Strategy 2 assumes implementation of the EPC scope at all campus developments.

Strategy 3: Replace and optimize campus steam (11% GHG reduction)

This strategy modeled comprehensive steam system optimization, including repair of leaks, steam orifice installation, thermostatic radiator valves, vacuum pump repair and apartment temperature monitoring. At the time of the analysis (2018), 33 out of 152 boiler plants (22%) were planned for replacement by 2023. Strategy 3 assumes all boiler plants would be replaced with new, optimized steam boiler plants and distribution systems.

Strategy 4: Install condensing gas boilers for DHW (2% GHG reduction)

Replace indirect DHW generation with decentralized condensing gas boilers to increase efficiency and eliminate the need to operate the campus steam systems during the summer.

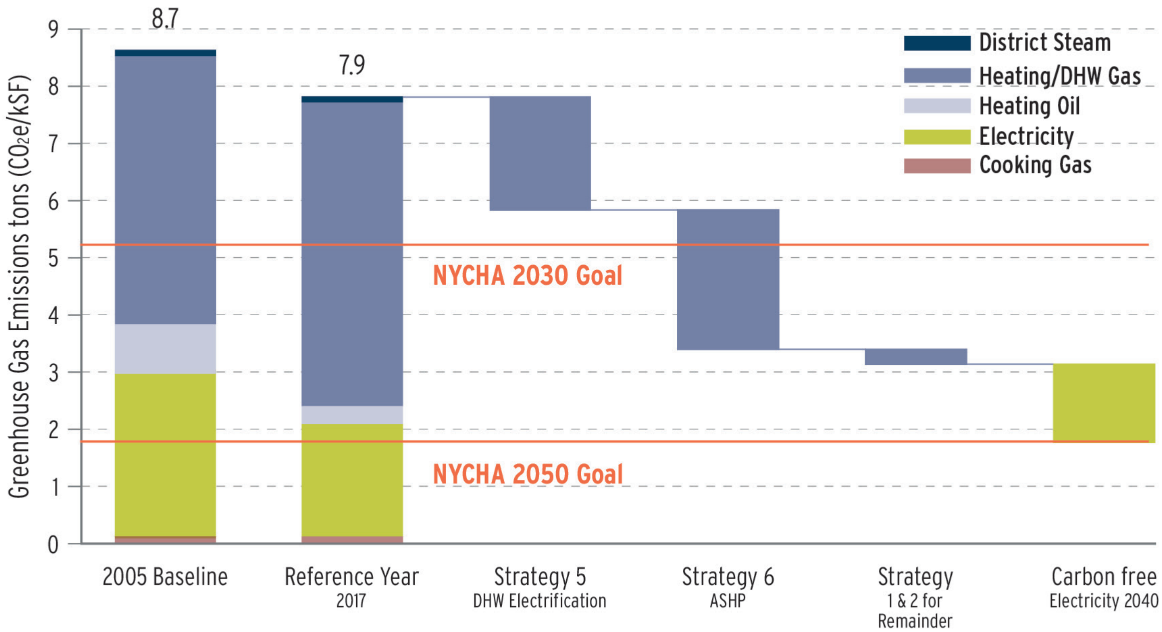
Scenario 2: Electrification

Finding: Meeting the 2050 goal requires a large-scale program of electrification.

Strategies 1 and 2 are steam system improvements that essentially must be implemented as long as NYCHA has campus steam systems in its portfolio. Even if both strategies are implemented, however, NYCHA would still fall short of the 2050 goals by 3.1 $mtCO_2e$/ksf. This shortfall cannot be met solely by retaining campus steam (Strategies 3 and 4); therefore, any combination of solutions that achieves the 2050 goals must include electrification.

There are many ways that electrification strategies can be combined to meet the 2050 goal. For this analysis, SWA found that a conversion of 100% of DHW to air-to-water heat pumps (AWHPs), and 60% of the campus steam developments to air-source heat pumps (ASHPs), some of which could be hydronic heat with AWHPs, would be sufficient. In total, 75% of fuel use would be electrified.

Figure E2. Impact of Electrification Measures on GHG Intensity



Strategy 5: Electrify DHW (25% GHG reduction)

SWA calculated the GHG impact of converting all DHW systems from fossil-fuel heaters to AWHPs. The GHG savings calculation assumes the 2030 electricity supply has a lower GHG intensity than today (see Table E2).

Strategy 6: Electrify space heat via ASHP (32% GHG reduction)

SWA calculated the GHG impact of converting 60% of space heating energy to ASHPs. The GHG savings calculation assumes the 2040 electricity supply will have the GHG intensity of a net-carbon-neutral grid – that is, zero. For the remaining 40% of space heating, Strategies 1 and 2 are assumed to have been fully implemented.

Methodology

Historic Consumption and Data Cleaning

SWA compiled and analyzed NYCHA energy consumption using historical data from all developments. NYCHA supplied 10 years of utility data, covering 331 distinct developments encompassing 175 million square feet in 2017. SWA separated the data into natural gas, district steam, electricity, and heating oil.[4] The data for the 2005 calendar year was used to determine the baseline. SWA cleaned the data by removing developments according to the criteria in Table E1. The data remaining after cleaning included 152 campus steam sites, representing 90% of campus steam developments and 46% of all NYCHA developments.

Table E1. Data cleaning criteria for energy use analysis

Cleaning Step	# Developments	% Of Developments
Total developments with energy data	331	100%
Properties with electric heat	1	0.3%
Property without square footage (SF) data, or where SF varied between years	14	4.2%
DHW baseload was calculated using July and August data. If the projected annual DHW usage was higher than the annual consumption the data was removed	2	0.6%
Annual heating energy use metric of less than 5 BTU/SF/HDD or greater than 40 BTU/SF/HDD	5	1.5%
Summer fuel use (July + August) intensity was less than 1.67 kBTU/SF or greater than 13.33 kBTU/SF and was assumed to be data or metering errors	19	5.7%
Total developments after cleaning	290	87.6%
Non-campus-steam developments after cleaning	138	41.7%
Campus steam developments after cleaning	152	45.9%

In order to estimate the effects of NYCHA continuing with "business as usual" operation, SWA analyzed annual NYCHA-wide consumption for the years 2005-2014 and extrapolated the data into the short-term future.

The per-development fuel-consumption analysis for Scenario 1 used energy consumption data from calendar year 2016, the most recent year available at the time. SWA then applied the reductions of each strategy in Scenario 1 to the energy consumption data of calendar year 2017 for the GHG emissions analysis.

Greenhouse Gas Emissions Analysis

LL97 requires NYCHA to reduce GHG emissions 40% below the 2005 level by 2030 and

80% by 2050. SWA totalized the 2005 utility consumption for all developments and calculated the resulting GHGs using the coefficients in Table 2 to create the baseline year emissions. The same was done for 2017 to create a reference year for savings projections.

The carbon intensity of electricity generation in New York State was higher in 2005 than in 2017. As a result, each unit of electricity is now responsible for lower carbon dioxide equivalent (CO_2e) emissions than in 2005. Going forward, NYS plans for in-state electricity generation to be carbon-neutral by 2040.[4]

Table E2. GHG emission intensities for various fuels

Energy Type	Tons CO_2e/kBTU	Source
Natural Gas	0.00005311	LL97 / EPA
#2 Fuel Oil	0.00007421	LL97 / EPA
District Steam	0.00004493	LL97
2005 Electricity	0.00012123	NYC 2005 GHG Inventory[5] page 15, converted to kBTU
2017 Electricity	0.000085	LL97 / EPA EGRID2016
2030 Electricity	0.000060	CLCPA 70% clean grid[6]
2040 Electricity	0.0000027	Assumed net carbon neutral per CLCPA

2030 and 2050 Scenario Analysis

Scenario 1: Retain Campus Steam

The 2016 report "One City Built to Last Technical Working Group Report" (TWG),[7] made a series of recommendations, which, if implemented by NYCHA, would result in NYCHA

[4] "Governor Cuomo Announces Green New Deal Included in 2019 Executive Budget". https://www.governor.ny.gov/news/governor-cuomo-announces-green-new-deal-included-2019-executive-budget

[5] https://www1.nyc.gov/assets/sustainability/downloads/pdf/publications/GHG Inventory Report Emission Year 2016.pdf

[6] According to NYISO 2019 Annual report, the state's grid in 2018 was 42% fossil fuels by annual consumption. The balance of consumption is nuclear and renewables, both emissions-free in operation. A 70% emissions-free grid would be at most 30% fossil fuels, so the emissions intensity would be 30/42 or 71% of the current amount by 2030. See Page 45 – "Summary of 2018 Electric Generation". https://www.nyiso.com/documents/20142/2226333/2019-Gold-Book-Final-Public.pdf/a3e8d99f-7164-2b24-e81d-b2c245f67904?t=1556215322968

[7] https://www1.nyc.gov/assets/builttolast/downloads/OneCity.pdf

meeting the 2030 requirements of LL97 (assuming 70% grid decarbonization).

The chart below summarizes the results of implementing the TWG recommendations:

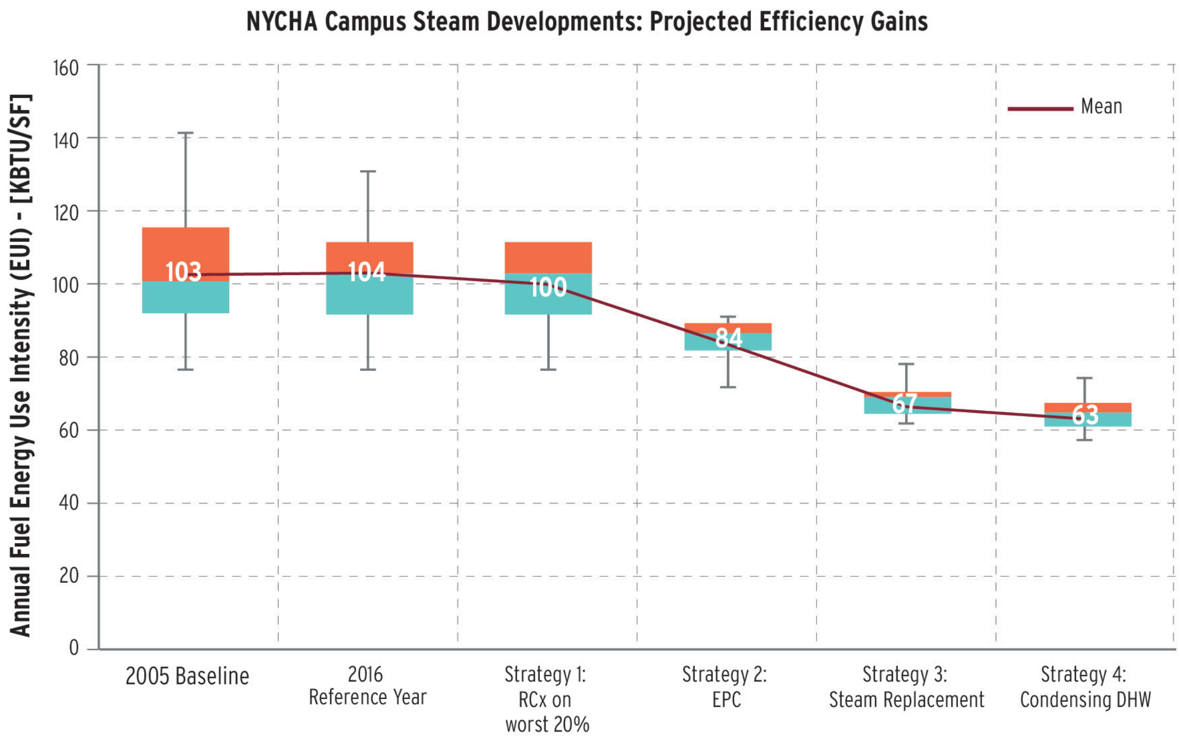


Figure E3. Quartile summary of NYCHA development-wide fuel reduction options if steam heating and most fuel-fired DHW systems are retained. Outlier developments in the top and bottom 5% are excluded. Each strategy builds on the previous one to progressively reduce fuel use.

Strategy 1: Retro-Commissioning

SWA examined fuel usage in the 20th percentile of properties that consume the most fuel per square foot. If all buildings in this worst 20th percentile were brought to the level of 2016's 80th percentile by addressing these and other necessary repairs, it would result in a 2% fuel savings across the entire NYCHA portfolio. NYCHA inspected boiler plants and tank rooms at 34 of the worst-performing developments during the 2016-2019 heating seasons. Results indicated significant issues with the distribution systems—a common problem in steam-heated buildings—including condensate receiver failure, steam trap failure, and a lack of make-up water treatment.

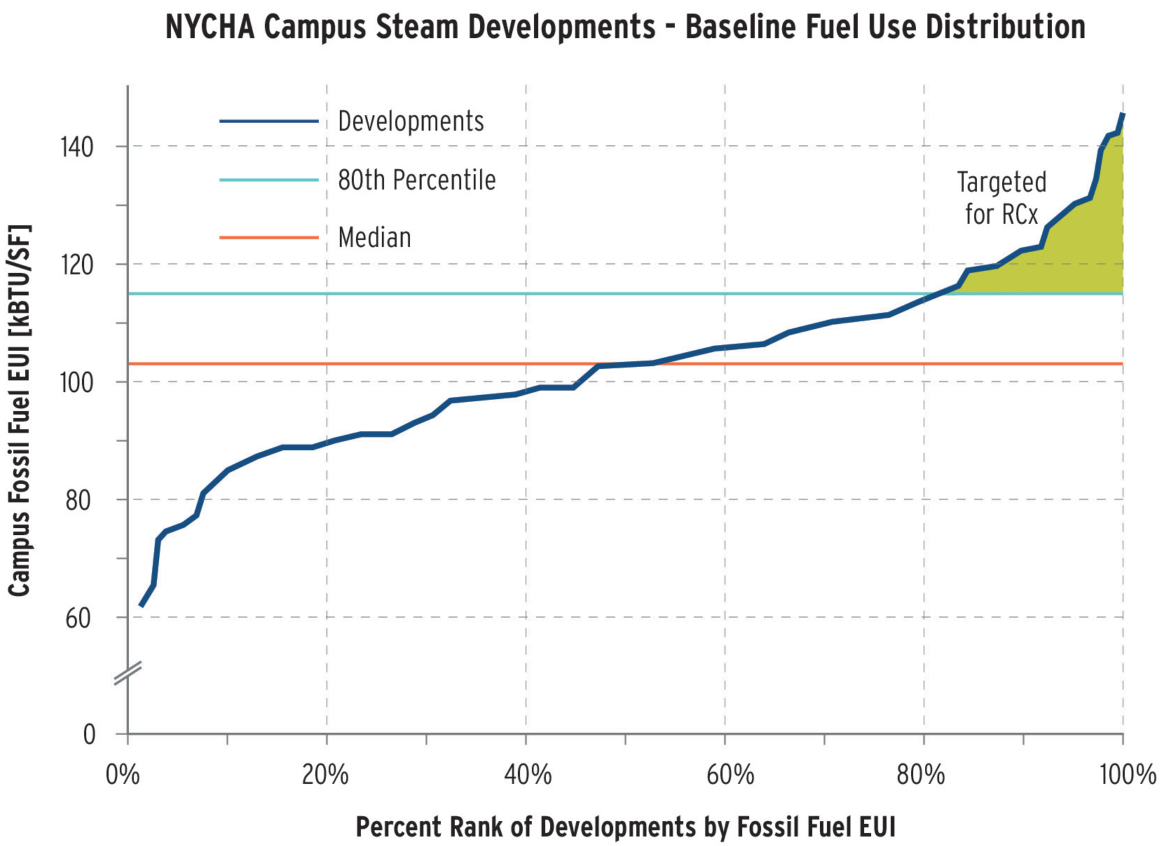


Figure E4. Campus steam developments ranked by fuel use intensity.

Strategy 2: Expand NYCHA's Energy Performance Contracts (EPCs)

To estimate the impact of implementing basic fuel-saving measures in all campus steam developments, SWA first projected the GHG impact of NYCHA's in-progress EPCs with the energy conservation measures (ECMs) shown in Table E3. SWA then calculated the impact of universal implementation of low-flow fixtures and indoor temperature sensors. NYCHA expects to realize development-specific fuel reductions of 12-18% at the sites in the four EPCs active as of 2018. SWA's model finds that expanding the EPC program to all developments would result in a 16% reduction in portfolio-wide fuel use.

NYCHA's four existing EPC contracts include a mix of electricity ECMs (primarily LED lighting) and fossil-fuel ECMs. For this analysis, SWA included only the fossil-fuel ECMs. At most developments, these included installation of indoor temperature feedback sensors, BMS replacement, and low-flow fixtures. At a small number of developments, gas condensing boilers and steam distribution balancing were included.

Table E3. Projected typical energy savings per end use for planned measures, using industry literature for estimates. At each development where a particular measure was planned, these savings values were applied and adjusted based on the energy intensity of that development.

Fossil-fuel-saving ECMs in Existing EPCs	End Use	% Savings of End Use (ECM Typical)	Number of Developments With Planned Measure
Low-flow water fixtures (e.g. faucets+ showerheads)[8]	DHW	15%	23[9]
Indoor temperature feedback sensors for boiler control[10]	Heating	10%	44
Supply-side orifice plates for balanced steam heat[11]	Heating	20%	1
Distributed, high-efficiency gas DHW heaters	DHW	25%	40

[8] From NYS Technical Resource Manual 2019, Sections "Low Flow - Faucet Aerators" and "Low Flow - Showerheads" (pages 100-106). Percent savings shown is a blended average of faucets and showerheads and scaled down assuming that load reduction is only part of DHW energy use, and assuming recirculation losses are ~1/3 of energy use.

[9] Developments not receiving low-flow fixtures will have them installed in a future EPC project.

[10] Assumes an average building temperature decrease of 3-4 degrees F in the winter from this measure. Each degree is assumed to be a 3% drop in heating use. Literature suggests 1% per degree of 8-hour setback with thermostats, and this measure is expected to be effective 24 hours per day. http://www.ualberta.ca/~cbeedac/publications/documents/progtherm1_000.pdf

[11] https://www.energyefficiencyforall.org/resources/clanging-pipes-and-open-windows-upgrading-nyc-steam-systems-for-the-21st-century/

To estimate the impact of expanding the EPC program to all campus steam developments, SWA assumed that the scope of work would include only DHW-conserving low-flow fixtures and the installation of indoor temperature feedback with BMS replacement, which are consistently applied in NYCHA's existing EPCs as the fossil-fuel-saving scope of work and which NYCHA expects to be included in all future EPCs.

HUD EPC savings calculations are made according to the program's rules and constraints, and are not easily compared to non-EPC savings estimates. To provide savings estimates with uniform assumptions, SWA calculated the fuel savings for each EPC development, using the specific planned ECMs, applying savings assumptions consistent with the literature (as noted in the footnotes for each measure).

Developments with high energy use were assumed to achieve correspondingly greater energy savings by eliminating operational waste. Conversely, those already performing better than the median were assumed to save less. To give credit for this, the typical savings from Table E3 were adjusted using the following equation:

*ECM savings % = 5% + (ECM_typical * 1.4 * P)*
Where P = percentile rank of the development's reference year fuel EUI

In this calculation, measures are expected to save a minimum of 5% just by undertaking a scope of work. The factor of 1.4, multiplied by the rank, scales the typical savings of a measure so that the worst performing development saves 60%-80% more than the median development.[12] The 1.4 value was chosen because, given the distribution of developments' baseline energy use, the application of these measures tightens the distribution to a narrower band without making the high-baseline developments better than the low-baseline developments post-retrofit.

Using this calculation on a building with a fuel EUI at the median (the 50^{th} percentile, which can be written as a rank of 0.5) would result in a savings of 5% + ECM_typical * 1.4 * 0.5 (rank) = 5% + 0.7*ECM_typical.

If, for example, the measure was "Indoor Temperature Feedback" with a projected savings of 10%, the total savings applied to the development would be 5% + (0.7*10%) = 12% of heating energy use. The building at the lowest end of the EUI distribution would save 5% of the end use, and the building at the highest end of the EUI distribution would save 5% + 1.4 * 10% = 19% of that building's fuel.

[12] Most projects do not save 100% of the projected savings, as documented in DBLC's "Recognizing the Benefits of Energy Efficiency in Multifamily Underwriting", Figure 14. https://www.db.com/usa/img/DBLC_Recognizing_the_Benefits_of_Energy_Efficiency_01_12.pdf

Strategy 3: Replace and optimize campus steam

A balanced steam distribution system delivers heat to all apartments evenly. To do this, boilers must supply dry steam at a consistent pressure, and pipes and radiators must vent air evenly and quickly. Most steam systems don't do this now and need redesign in the boiler room and throughout the buildings to do so.

NYCHA plans to replace 33 out of the 152 campus boiler plants in this analysis in the next five years. At this rate it would take until about 2045 to replace all 152 boiler plants. Comprehensive steam system optimization requires new boiler plants and in-unit radiator work.

SWA evaluated what savings were possible if all developments received comprehensive steam optimization by 2030. This included improvements to NYCHA's boiler specifications, assumed a balanced distribution system, and assumed that the site distribution system was operating within original design parameters. In addition to boiler replacements, all radiators would receive fixed orifice plates, thermostatic radiator valves, and any venting improvements needed to balance riser steam flow.[13]

SWA assumed ECM_typical savings of 20% for all comprehensive steam system optimization projects. Using the same scaling factor for ECM_typical as described in Strategy 2, the measure was applied to all campus steam developments.

Strategy 4: Install condensing Boilers for Domestic Hot Water

At most campus developments, DHW is generated using steam-to-water heat exchangers in each building. The inefficiency of the boilers and the underground steam piping results in a relatively inefficient DHW system. High-efficiency "condensing" gas water heaters are close to 90% efficient, and if installed directly in buildings to eliminate underground piping, can improve overall DHW efficiency dramatically.

By removing the underground losses and increasing combustion efficiency, thermal energy delivery increases from 45% (80% efficiency - 35% distribution losses) to 90% (90% - 0% distribution losses), decreasing fuel use for DHW by 50% in the summer. Since this happens for six months of the year, annual savings for this measure are 25%. SWA applied this value for DHW measure savings to all developments, incorporating the scaling factor as described in Strategy 2.

[13] Supra 10 for description of this measure on two-pipe steam systems.

Based on prior experience with non-NYCHA campus steam systems, SWA assumed that campus-type steam distribution systems result in an annual average loss of ~20%. When space heating steam is not needed at each building (for about 6 months of the year), 35% thermal energy loss was assumed.

The energy savings are realized almost entirely in the summer, regardless of whether the DHW boilers run only half the year or all year-round, because the steam system has to run for heat in the winter.

Scenario 2: Electrification

SWA calculated the extent of electrification needed to achieve the 2050 GHG goal. SWA assumed that the average overall efficiency of optimized campus steam fuel-based systems would be about 60%[14] and that electric heat pumps would have an overall efficiency of 200%.[15] The resulting ratio of site energy use for fuel-based versus heat pump systems is thus 30%. This ratio was used to determine the site energy use and GHG emissions and was applied to both DHW and space heating systems.

The analysis determined how much NYCHA's GHG emissions would be, portfolio-wide, if campus steam space heating systems were converted to heat pumps in 60% of developments, with some of those being AWHPs with hydronic systems, with the remaining 40% of developments retaining campus steam. All DHW generation was assumed to be converted to heat pumps. For all heat pump systems, no fuel-based or resistance-electric backup was assumed; that is, the heat pumps would meet 100% of their respective loads.

This scenario takes advantage of a carbon-neutral electricity supply by shifting nearly all fossil-fuel systems to electric heat pumps, which, in addition to using 30% of the energy of fuel-based systems, will have very low GHG emissions because of the low-carbon electricity supply.

Strategy 5: Electrify Domestic Hot Water

Because this measure does not require repeated apartment access, SWA prioritized it to be widely implemented before electrifying space heating.

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[14] An efficiency of 60% means for every 1 BTU of gas or oil fed to the central plants, 0.6 BTU is useful energy for space heating and DHW.
[15] An efficiency of 200% means that for every 1 BTU of electricity input, 2 BTUs are delivered as useful space heating or DHW energy. This could also be stated as a coefficient of performance (COP) of 2.0. This is conservative compared to manufacturer ratings, but field-verified heat pump efficiencies range widely.

SWA analyzed the impact of electrifying 100% of the DHW loads in all NYCHA developments. Fuel use for DHW is eliminated, and the additional electricity load is a factor of the relative efficiencies of the campus steam-based system and the new heat pump system.

Strategy 6: Electrify Space Heat via ASHP

Similar to DHW, the electrification of space heating compared the relative efficiencies of the fuel-based and heat pump systems to determine the impact on energy and GHG emissions. This analysis is agnostic to heat pump technology, which could be either a central (in each individual building) system with refrigerant distribution, a central system with hydronic distribution, or individual heat pumps serving each apartment or room. The most applicable technology for each development depends on site-specific factors outside the scope of this analysis.

As an interim step, campus steam systems can be converted to distributed hydronic systems, even if still using gas-fired boilers for space heating. By locating boiler rooms in each building and using a heating hot water distribution system instead of steam, space heating energy use could be reduced by 50%.[16] The hot water boiler plants could then be replaced with heat pumps as needed while retaining the hot water distribution in the apartments.

If all developments converted to heat pumps, NYCHA would comfortably meet the 2050 goal. However, the difficulty and cost of 100% implementation may not be necessary. SWA calculates that if 60% of all space heating systems were converted to heat pumps, the 2050 goal could be met. This assumes that Strategies 1 and 2 have been implemented across the remaining steam developments to optimize those systems. If Strategies 1 and 2 are not pursued at all, 65% of all space heating would need to be electrified with heat pumps.

[16] See buildings S2H-3 and S2H-4, which replaced both central plants and distribution systems, saving 50% and 48% respectively of heating energy through hydronic system retrofits. ASHRAE Journal, May 2010. https://www.taitem.com/wp-content/uploads/SteamBoilerReplacements.pdf

APPENDIX F

FEASIBILITY OF AIR SOURCE HEAT PUMPS FOR DOMESTIC HOT WATER AT NYCHA CAMPUS STEAM DEVELOPMENTS

Summary

NYCHA tasked SWA with assessing technical feasibility for domestic hot water (DHW) electrification using heat pumps. SWA studied two developments: LaGuardia Houses and Vladeck Houses. The results from this study's limited sample indicate that there is potential for large energy savings and GHG reductions because of the condition of the current DHW equipment and distribution system.

SWA examined numerous possible plant locations and capacities. The final recommendation is for heat pump DHW installations located outdoors that can meet year-round DHW needs. With relatively minor design changes, heat pump technology is applicable to nearly all NYCHA campus steam developments system.

At the two study sites, air-to-water heat pumps are projected to reduce DHW GHG emissions by 62% and 74%, respectively, if operated year-round, given today's electricity grid generation fuel mix. As NYC and NYS move toward cleaner electricity sources, these emissions reductions will grow relative to fuel-based DHW systems, approaching carbon-neutral DHW production with a carbon-neutral electricity grid.

Introduction

In NYCHA buildings DHW is typically generated by steam-to-hot-water heat exchangers located in the basement of each building. Steam is either produced in a central boiler plant or supplied by the Con Edison district steam system. The need to produce DHW means that steam must be produced or purchased year-round, which is inefficient and costly. The buried steam pipes connecting satellite buildings to the central boiler plant or steam room may leak and/or lose heat to the ground, both of which reduce system efficiency. Finally, a centralized system has the potential for reliability issues; a failure at the central plant disrupts DHW supplied to all buildings in a development, whereas a failure in a decentralized system only affects a single building.

This report presents general design guidelines to convert typical campus steam NYCHA buildings–which have steam-to-hot-water heat exchangers that are fed year round from the boiler plant–to decentralized air-source heat pump DHW systems. Air source heat pumps can generate DHW by extracting heat from the outside air–even in outdoor temperatures down to -20°F.

The heat pump considered in this report uses carbon dioxide as a refrigerant, which has a few advantages in a DHW application. The carbon dioxide refrigerant cycle is well-suited for production of DHW. CO_2 heat pumps can produce very hot water in a single pass and operate best when supplied with colder return water. This “high lift” operation works very well for charging a hot water tank, but makes them currently ill-suited for heating and cooling applications, which require “lower lift” operation.

Conversely, heat pump technology currently available in the US that uses hydrofluorocarbon (HFC) refrigerants can’t maintain high output temperatures at cold outdoor temperatures. To maintain storage tank temperatures above 140°F throughout the entire year, either a backup electric resistance or fuel-based system would be needed for HFC-based heat pumps, or two heat pumps in series would be needed. Further, a major concern with HFC-based heat pumps is the high global warming potential of common refrigerants, such as R-410a. Because one pound of R-410a has the same global warming potential as roughly 2,000 pounds of carbon dioxide, the production, use, and disposal of R-410a presents a significant risk to greenhouse gas reduction planning.[1,2]

One disadvantage of CO_2 heat pumps is that the equipment tends to be more expensive than similar HFC heat pumps. At the time of this study, there was only one make and model of CO_2 heat pump available in the US. The cost differentials may change over time as the market for heat pumps for cold-weather DHW induces manufacturers to diversify the products and technology available.

Study Sites

Two NYCHA developments were selected as study sites. These were selected because the DHW systems would be easy to access–there was related work already in progress–and because they are broadly representative of NYCHA campus developments. The sites represent typical mid-rise and high-rise NYCHA developments with a central boiler plant supplying steam for heating and DHW to satellite buildings.

LaGuardia Houses

LaGuardia Houses is a complex of 10 high-rise buildings in Manhattan’s Two Bridges neighborhood. The original nine 16-story buildings were completed in 1957 with an additional 16-story building completed in 1965. Each building has 108 to 150 apartments.

[1] EPA, https://www.epa.gov/sites/production/files/documents/RefrigerantUpdates.pdf, pg 11

[2] For more context on refrigerant use in multifamily buildings, see “Heat Pumps Use Refrigerants” section on page 7 of this NRDC report prepared by SWA: https://www.nrdc.org/sites/default/files/heat-pump-retrofit-strategies-report-05082019.pdf

Figure F1. LaGuardia Houses (from Google Maps)

Similarly-sized steam-heated high-rise buildings make up 25% of NYCHA's total built floor area, and buildings of this size would all likely have very similar heat pump plants, which can be verified through a relatively simple short-term flow measurement at each site (as was done in this study) before final design.

The boilers at 300 Cherry Street supply steam to the satellite buildings through buried pipes. To generate DHW, steam is passed through a coil in a large hot water tank in each satellite building. The flow of steam is controlled to maintain the water in the tank at 130°F. DHW is supplied directly from the top of the tank to the distribution piping. There is hot water return piping that mixes with cold make-up water fed into the bottom of the tank, but there is no recirculation pump. Without a recirculation pump it is likely that DHW temperature in the building is inconsistent and residents may have to run their taps before receiving hot water. The current building code requires a DHW recirculation pump to prevent water waste while waiting for hot water.

Vladeck Houses

Vladeck Houses is a complex of 24 low-rise buildings on Manhattan's Lower East Side. The 6-story buildings were completed in 1940. Each building has 60-108 apartments.

Similarly-sized steam-heated low-rise buildings with less than 150 apartments make up 26% of NYCHA's total built floor area.

The development is split into east and west halves, each with its own central boiler plant. Buried steam pipes run from the central boiler plant to each satellite building in the half it serves. In each satellite building steam is used to generate DHW with an instantaneous steam-to-hot-water heat exchanger.

Figure F2. Vladeck Houses (from Google Maps)

A mixing valve reduces the hot water temperature to 120°F before it is supplied to the building. A recirculation pump runs continuously to prevent water from cooling off during low-use periods.

Flow Profiles from Site Measurements

Hot water flow profiles were developed using flow and temperature measurements. SWA assessed the water piping layout and distribution during site visits and NYCHA staff interviews.

Table F1. Measured DHW Consumption

Development	Number of Apartments	Peak Total DHW Consumption (Gal/Hr)	Peak DHW Consumption Per Apartment (Gal/Hr/Apt)	Daily Total DHW Consumption Per Apartment (Gal/Day/Apt)
LaGuardia Houses	124	655	5.3	60
Vladeck Houses	108	509	4.7	69

The DHW usage was logged for a week at one satellite building in each development. The monitored buildings were 250 Clinton Street at LaGuardia Houses and 640 Water Street at Vladeck Houses. An ultrasonic flow meter was attached to the DHW supply pipe upstream of any takeoffs to capture the full flow supplied to the building. The measured flow profiles averaged over the week are shown in Table F1. The data shown for

Figure F3. LaGuardia Houses (250 Clinton St.) DHW Consumption

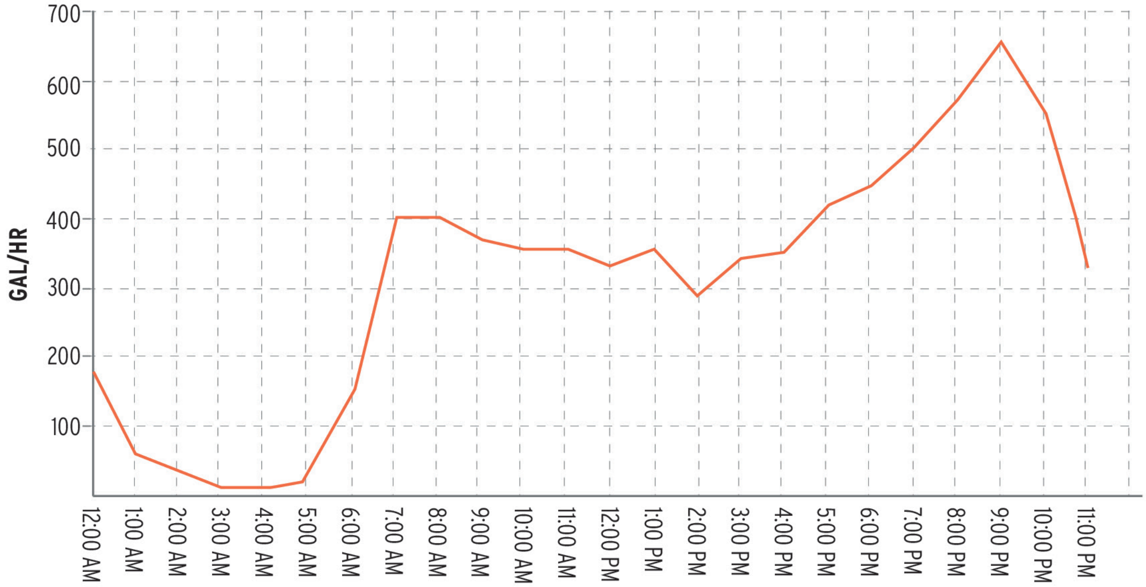
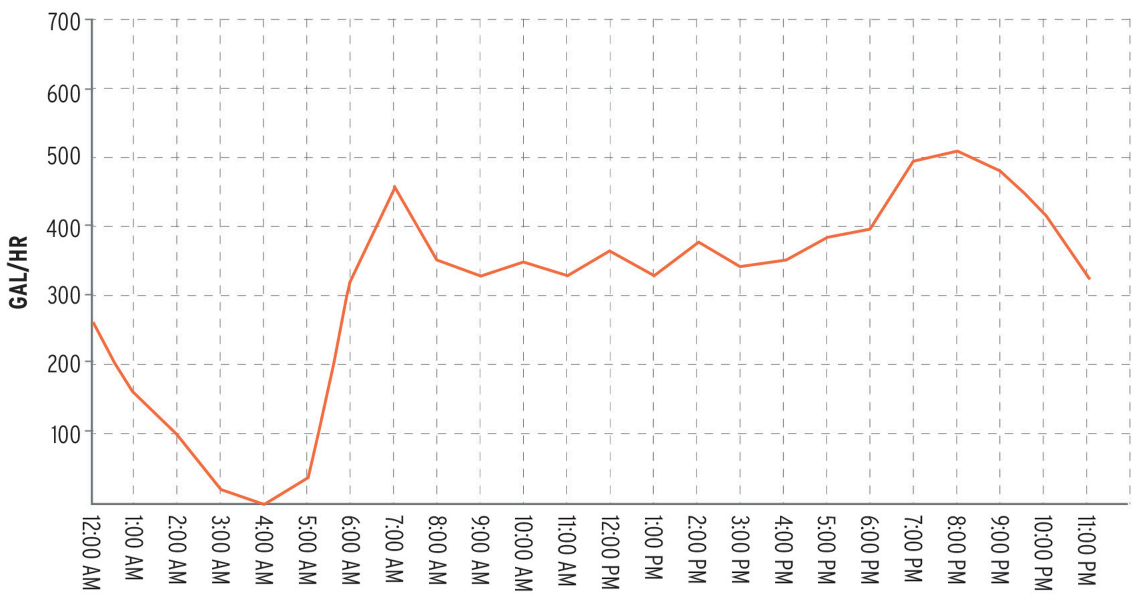


Figure F4. Vladeck Houses (640 Water St.) DHW Consumption



Vladeck Houses is the net flow rate after the recirculation flow has been removed. Both buildings have a dual-peak flow profile, with a morning peak followed by a higher evening peak, and near zero consumption overnight. This is a common flow profile seen in many residential buildings.

Plant Sizing and Costs

A measured flow profile is used to size the air-source heat pump DHW plant just as one would for a traditional DHW boiler plant. It is always preferable to measure the actual flow profile rather than use standard engineering estimates, which frequently significantly over-estimate DHW consumption. To size the heat pump DHW plants at LaGuardia Houses and Vladeck Houses the DHW energy usage was aggregated on an hourly basis. Losses due to recirculation are included for both buildings.

Sanden SANCO2 heat pump water heaters were evaluated.[3] At the time of this study, the Sanden product available in the US was the only air-water heat pump that could meet year-round DHW demands using outdoor air without supplemental backup. Other products appear to be coming to market in different capacities and capabilities as the demand for DHW heat pumps is anticipated to grow.

Figure F5. Sanden SANCO2 Heat Pump

Each heat pump has a rated output of 15,400 BTU per hour. The advantages of Sanden heat pumps include the following:

- Packaged units minimize the potential for refrigerant leaks
- No field-installation of refrigerant piping is required
- They have built-in water pumps

The drawbacks include:

- Because the only size available is residential, numerous individual heat pumps are needed for larger buildings. As a result, the heat pump plant takes up a lot of space and involves a more complex piping design to optimize overall operation.

[3] Technical information located at Sanden's website under the header "Technical Information Booklet": https://www.sandenwaterheater.com/for-professionals/

- The equipment is expensive compared to other heat pumps. However, other heat pumps currently can't perform year-round without supplemental heat, which can be expensive and difficult to integrate.

The DHW plant sizing calculations for the sample LaGuardia Houses building determined that the current load (no information was collected on faucet flow rates and other in-apartment conditions) would require a plant with 32 Sanden SANCO2 heat pumps and 1,000 gallons of DHW storage. The Vladeck Houses sample building would require 24 Sanden SANCO2 heat pumps and 1,000 gallons of DHW storage. To complete the installation the units would be installed on concrete pads on the lawn outside of the mechanical room. At LaGuardia Houses the pad would need to be 20' x 10.5' in order to accommodate the heat pumps in 4 rows by 4 columns, double-stacked. At Vladeck Houses the pad would need to be 20' x 7.75' in order to accommodate the heat pumps in 3 rows by 4 columns, double-stacked. DHW storage tanks would be installed in the mechanical room close to the DHW supply and return piping.

Electrical service must be provided to the heat pumps, and DHW piping must be run between the heat pumps and the mechanical rooms. This piping must be buried in a sleeve or trench to protect against corrosion. In the mechanical rooms new DHW mixing valves and recirculation pumps would be installed to maintain a consistent DHW temperature and allow the storage tanks to charge.

Plant Schematics

The following schematic (Figure F6) is from the Sanden technical manual and illustrates a basic design. The heat pump is most efficient when supplied with the coldest water possible, which the piping arrangement is designed to achieve by maintaining temperature stratification within the storage tank. The bottom of the tank is kept at a low temperature by supplying it with cold make-up water. At the top of the tank, hot water is supplied by the heat pump, as well as drawn off to supply DHW to the building. With minimal mixing occurring within the tank, the top of the tank stays hotter than the bottom. As the heat pump charges the tank, eventually the bottom of the tank will heat up to the selected setpoint, at which the tank will be fully charged, and the heat pump cycles off.

Capacity can be increased by designing a system with multiple heat pumps connected to either a larger storage tank or multiple storage tanks; the same design principles still apply. Since the heat pumps should be supplied with the coldest water possible, they should be piped in parallel, not in series. For this design, the tanks are assumed to be kept at the maximum capacity that the heat pumps can output, minimizing storage volume.

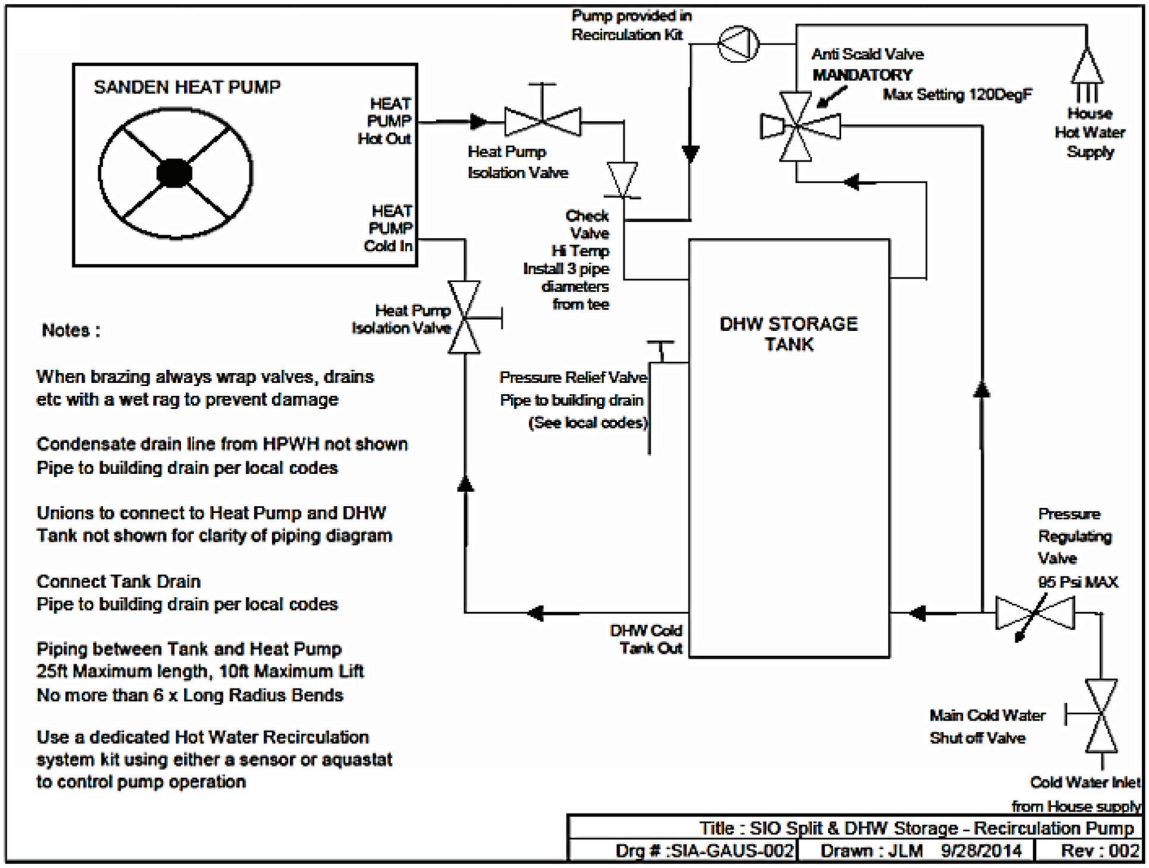


Figure F6. Basic Heat Pump and Storage Tank Schematic, from Sanden technical manual

When multiple storage tanks are used, the best design is to pipe them in series. Water is drawn from the bottom of one tank and supplied to the top of the next, as shown in the following schematic (Figure F7). This approach maintains temperature stratification within each tank, as well as between tanks.

Additional components include a mixing valve and recirculation pump, which are standard elements of a DHW system. A mixing valve is necessary because the water temperature in the storage tank will be higher than is safe to deliver to fixtures. The mixing valve maintains an appropriate DHW supply temperature of about 125°F. The recirculation pump is designed to maintain a minimum level of flow in the DHW piping to avoid inconsistent temperatures, and to reduce water waste.

Plant Siting

Air-source heat pumps must be installed with sufficient ventilation for efficient operation. Typically, this is achieved by installing units outdoors, although it is possible to design an indoor installation. At NYCHA properties, potential outdoor installation locations include on-grade, mounted to the building exterior, on a lower roof if there

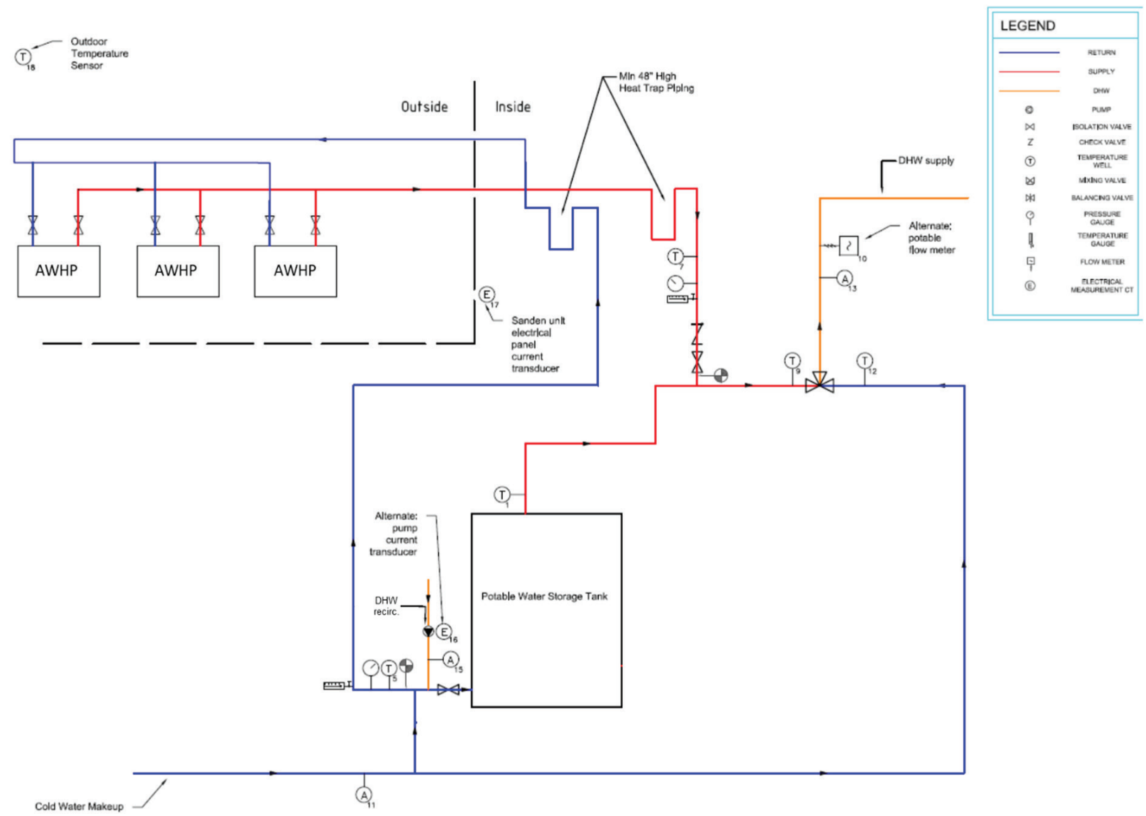


Figure F7. Example of heat pump and storage tank design

is a commercial space or other area connected to the building, or on the main building roof. Indoor installations in basement mechanical rooms are possible but must overcome additional design constraints.

Storage tanks should be installed inside mechanical rooms near the DHW supply and return piping. Locating heat pumps and storage tanks as close as possible to each other is a best practice to reduce piping costs and pumping requirements. Design considerations for various possible heat pump locations are described below:

On-Grade Installation

Installing heat pumps in a ground level lawn area is generally the simplest location. Figure F7 shows heat pump outdoor units installed on the lawn at Vladeck Houses. These are outdoor units for a variable refrigerant flow (VRF) heat pump system providing heating and cooling to community services rooms in the adjacent building's basement. These are larger heat pumps than the Sanden units, but generally exemplify what a ground-based heat pump plant could look like at a NYCHA campus development. The DHW heat pumps selected for this report are much smaller and do not require as much space per heat pump. The heat pumps would be installed on a concrete pad above the

Figure F8. Heat pump outdoor units on the lawn at Vladeck Houses serving non-residential community spaces

snow line. To minimize the footprint, units can be stacked with an 18” vertical clearance between units. To allow for adequate airflow, minimum clearance must be 6” behind and 12” in front of each unit. Required clearances are illustrated below:

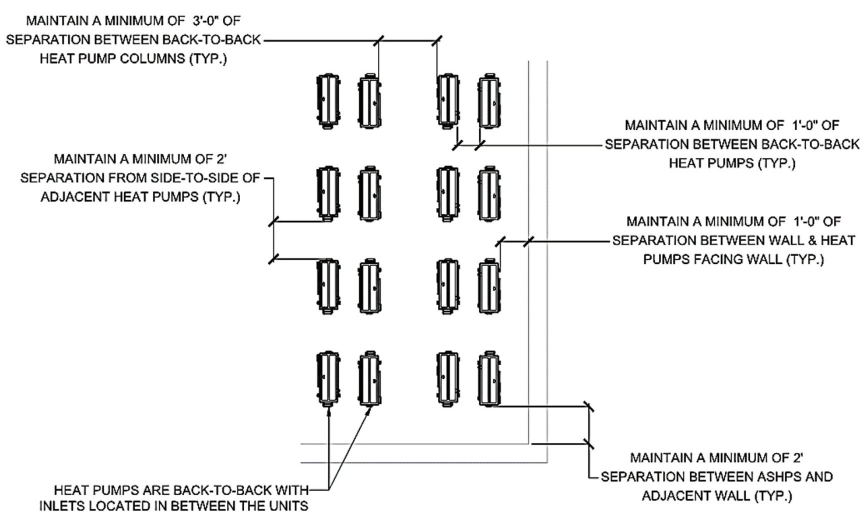


Figure F9. Sanden required clearances

During the winter, condensate will form ice on the heat pump coil. Ice on the coil can be melted by operating the heat pump in defrost mode. Both conditions will generate external condensate that must be safely drained away from the units. A condensate drain may be necessary to prevent water from pooling and/or ice from forming in areas where it could become a hazard.

Units should be installed above the normal snow line and in locations where they are unlikely to become covered by banked snow. Electric heat tracing, under the insulation, is required to provide freeze protection on any exterior water lines to and from the heat pumps.

The main advantage of this location is simplicity. DHW pipes from the heat pumps can be kept to a minimum length and do not need to be installed through occupied spaces. The pipes must be buried in either a trench or sleeve to prevent corrosion.

Installing heat pumps on the lawn takes up green space. The impact of this must be evaluated on a case-by-case basis. At Vladeck Houses the heat pumps were installed on a lawn between the backs of two buildings and were partially concealed by trees and bushes. Fencing around the outdoor units prevents tampering and possible damage.

Mounted to Building Exterior

Depending on the number of heat pumps required and the design of the building it may be possible to mount the heat pumps to the exterior wall. The ideal location would be a large area of windowless exterior wall. Clearances between units and service access must be maintained. Installing units as compactly as possible minimizes piping runs and avoids difficult access to high units.

Figure F10. Heat pump outdoor unit mounted to the building exterior at Vladeck Houses

In this approach units can be installed without sacrificing green space, while still minimizing piping runs through occupied spaces. However, not all buildings provide suitable locations, and it could be considered unsightly to install a bank of units on the building exterior.

Installation on a Lower Roof Area

Some NYCHA developments include low-rise commercial spaces or an otherwise-available lower roof area (see Figure F11). Lower roofs could be ideal locations to install outdoor units without occupying green space or affecting the appearance of the building.

Noise is a minimal concern. Each heat pump has a low operating noise level of 37 dB, which is comparable to light rainfall.

One drawback is that it would be necessary to route DHW piping through some occupied space. Depending of the location of the lower roof in relation to the mechanical room, this may or may not pose a challenge and could have a large impact on piping costs. However, where lower roof areas are available the piping costs are likely to be significantly less than for installations on the main roof, especially in high-rise buildings.

Figure F11. Lower roof area at LaGuardia Houses

Installation on the Main Roof

The last outdoor option is to install the heat pumps on the main roof. This area is likely available at nearly every NYCHA building. However, it requires the most extensive piping work. DHW pipes must be routed from the mechanical room to the roof and back. Generally, this would require taking over a corner of the hallway and core drilling through every floor. This is likely to be cost-prohibitive in high-rise buildings.

Indoor Installation

It is possible to install the heat pumps indoors, but this presents important design challenges. As the heat pumps extract heat from the air to produce hot water, they exhaust cold air. Each heat pump unit produces about 1 ton of cooling. This is less of an issue in the summer as the cold air can help provide free cooling to the building. However, in the winter the heat pumps would be drawing heat out of the building, significantly increasing heating costs. To prevent this from being an issue it would be necessary to provide ventilation to an indoor heat pump installation. The airflow configuration of the Sanden units does not lend itself well to direct ducting, so a whole-room ducted ventilation system with a minimum flow rate of 800 CFM per unit might be required. It is also advisable to insulate the space to avoid cooling the rest of the building during the winter.

If an indoor installation can be effectively designed to not over-cool its own space or the rest of the building, it does have the advantage of having the simplest piping arrangement. The heat pumps would likely be installed in a converted storage room adjacent to the mechanical room, and DHW piping would simply have to run between basement spaces.

Energy and Greenhouse Gas Impact

At both LaGuardia Houses and Vladeck Houses it is difficult to determine the exact DHW energy consumption for a specific building. Natural gas steam boilers in a central boiler plant supply steam to all buildings for DHW production. To estimate DHW energy consumption for the studied buildings, natural gas consumption in the central-plant was weather-normalized to estimate the fraction devoted to DHW. The total consumption was then allocated to each building based on the number of apartments.

Table F2. LaGuardia Houses

Annual DHW Data	Current Central Boiler Plant System		Proposed Heat Pump System		
	Building Total	Per Apartment	Building Total	Per Apartment	Savings
Energy Consumption (kBTU/year)	5,021,200	40,493	1,183,500	9,500	76%
GHG Emissions (MT CO_2e/year)	267	2.15	100	0.81	62%

Table F3. Vladeck Houses

Annual DHW Data	Current Central Boiler Plant System		Proposed Heat Pump System		
	Building Total	Per Apartment	Building Total	Per Apartment	Savings
Energy Consumption (kBTU/year)	6,557,900	60,700	1,062,500	9,800	84%
GHG Emissions (MT CO_2e/year)	348	3.22	90	0.83	74%

Assumptions: Natural Gas GHG Coefficient: 0.00005311 tonsCO2e/kBTU
Electricity GHG Coefficient: 0.0000847 tonsCO2e/kBTU (source: NYC LL97)

Savings Discussion

For both buildings, conversion to a heat pump DHW system is expected to result in significant energy and greenhouse gas emissions savings. Heat pumps are very efficient, and electricity is a cleaner energy source than natural gas. The seasonal efficiency of

Vladeck Houses' current DHW system was calculated to be only 33%, while LaGuardia's was 50%. Here's why:

> **Leaks** – Vladeck Houses had a substantial leak of DHW around the mixing valve; LaGuardia did not. It should be noted that simply repairing leaks has the potential to significantly reduce energy costs and greenhouse gas emissions.
>
> **Recirculation** – Vladeck Houses currently has a recirculation pump, while LaGuardia Houses does not. Recirculation, though required by code, incurs a substantial energy penalty, because heat is lost in the distribution piping. Buildings like LaGuardia Houses that do not currently have this penalty will incur it if the DHW system is upgraded.

Peak Day Gas Demand Savings

Conversion to a heat pump DHW system will reduce gas demand and help meet Con Edison's requirements for Non-Pipeline Solutions. The LaGuardia Houses sample building would save 13.8 Dt/day and the Vladeck Houses sample building would save 18.0 Dt/day if converted to heat pump DHW. Neither building is in Con Edison's highest priority zones for gas-efficiency investments. However, installing heat pump DHW in NYCHA developments within the higher-priority zones could make this type of conversion an attractive gas demand savings project.

Design Alternative – Summer Only

A potential alternative could be designed around running the heat pump plant only during the summer, with the winter load continuing to be supplied by the central steam plant. The DHW load is lower in the summer due to the city water being over 20°F warmer than in the winter.[4] This would allow a smaller plant to satisfy the DHW load. This smaller plant could be installed in the building's basement, which would avoid the need to sacrifice outdoor greenspace while simplifying the installation and minimizing costs. Operating the heat pumps only in the summer minimizes the over-cooling problem associated with an indoor installation, while allowing the steam central plant to be turned off in the summer when it is least efficient. Shutting down the central plant in the summer also allows for the opportunity to conduct necessary maintenance without interrupting service to the buildings. In addition, the heat pumps are supplied with much warmer air in the summer than in the winter. Warmer inlet air allows the heat pumps to

[4] Goldner, F. and Price, D. "Domestic Hot Water Loads, System Sizing and Selection for Multifamily Buildings." ACEEE 1994. Discussion of consumption variation on pages 2.107 - 2.108.

operate more efficiently and with greater output than if the system were sized for an NYC winter design day.

At the LaGuardia Houses sample building, a plant with 32 Sanden heat pumps is necessary to provide DHW year-round. If the plant were sized to only operate in the summer, then the load could be met with only 18. Similarly, the summer DHW load at the Vladeck Houses sample building could be met with 14 Sanden heat pumps, compared to the 24 required to operate year-round.

Energy Cost Savings

Installing heat pump DHW systems will in most cases result in utility cost savings; however, the magnitude of the cost savings will be less than the magnitude of energy savings and GHG reductions. While heat pumps are much more efficient, they use a more expensive fuel. Gas and heating oil cost much less than electricity; in New York City, each unit of electricity costs three to six times the equivalent energy units of natural gas.

The cost savings for heat pump DHW systems may increase as heat pump technology improves and electric rate regimes change to reflect public policy priorities. Introduction of time-of-use rates, for example, may greatly improve the operating cost savings of heat pumps. Similar to how an electric vehicle can charge when electricity is least expensive, a heat pump plant can charge a storage tank when electricity is least expensive, as long as the storage tank is sized appropriately.

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