NEW YORK CITY
HOUSING
AUTHORITY

Sheltering Seniors from Extreme Heat

A Study of NYCHA Senior Housing

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LETTER FROM THE EXECUTIVE VICE PRESIDENT

In 2016 the New York City Housing Authority released the *NextGeneration NYCHA Sustainability Agenda*, a commitment to create healthy and comfortable homes for its nearly 400,000 residents that will withstand the challenge of climate change. NYCHA is especially committed to providing safe and resilient housing for vulnerable populations such as children and seniors. It is in the spirit of this commitment that I am proud to present this report.

One of the greatest climate-related challenges that NYCHA will face in the coming years is that of extreme heat: over 100 New Yorkers are killed each year from heat stroke and other heat-related threats, and climate change is likely to increase this threat in the future. Seniors are especially vulnerable to heat-related climate threats. In addition, increased electric load during heat waves may lead to brownouts and blackouts, putting further stress on a building's residents and cooling systems.

Sheltering in place is a strategy to mitigate heat risk among vulnerable populations by allowing them to remain comfortably in their own homes during a heat wave or blackout. The studies commissioned by NYCHA identify physical and strategic improvements that would allow residents of NYCHA senior housing to shelter in place and provides both short-term and long-term recommendations.

Sheltering Seniors from Extreme Heat builds on NYCHA's *NextGeneration Sustainability Agenda* by incorporating climate change resiliency into capital planning and design. This document will help guide policy and planning at NYCHA as we rebuild and prepare for the challenges that a changing climate will bring, and will ensure that some of the City's most heat-vulnerable populations will be kept comfortable and safe.

Deborah J. Goddard

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EXECUTIVE SUMMARY

Extreme heat kills. Every year, extreme heat in New York City results, on average, in over 450 emergency room visits, 150 hospital admissions, and the deaths of 115 New Yorkers from heat stroke and heat-related exacerbation of chronic health problems. Without preventative planning, climate change will result in more heat-related illness and death as the average temperatures increase, along with increased frequency, intensity, and duration of heat waves and hot days in New York City.

Among heat-vulnerable populations, seniors are at particularly high risk. Seniors spend approximately 90% of their time indoors, are often socially isolated and afflicted with health issues, and are less likely than other groups to be able to travel to local cooling centers.

NYCHA wants to be ready. NYCHA currently houses approximately 62,000 residents who are 65 years or older— the fastest growing age group among NYCHA's population. Eight-thousand of these seniors live in NYCHA's 42 senior-only developments. NYCHA is interested in developing a shelter in place strategy for all its senior residents during extreme heat events. As a starting point, NYCHA asked Arup to assess what physical retrofits to its senior developments could ensure safe indoor air temperatures even during a city-wide or localized blackout. Arup specifically examined:

Shelter in place means that senior residents will take refuge in their own homes during a summer blackout until electricity is restored.

1. the impacts of different building envelopes on indoor air temperature during a heat wave or extreme heat event under blackout conditions
2. the costs and benefits of installing either 100% or critical systems electricity backup generation

NYCHA also commissioned Arup to study the feasibility of heat pump heating and cooling, one of two cooling strategies that NYCHA is piloting.

Upgrading building envelopes will not be enough. In the first part of the study, Arup modeled indoor air temperature in two hypothetical apartments representative of NYCHA's senior housing. In both scenarios, apartments would get dangerously hot during a heat wave or extreme heat event in the absence of air conditioning. Two key observations were made:

- The temperature inside remains higher than the outside.
- Indoor heat builds up and temperature rises over time.

The models indicate that indoor air temperatures can be up to 6°F hotter than outdoor temperatures. This means when the outdoor temperature is 96°F, the inside of a resident's apartment could be 102°F. Upgrading the existing facade to meet or exceed the current code insulation, installing high performance windows, and air sealing could reduce the temperature differential to 3°F.

Furthermore, adding indoor or outdoor shading to a high-performance façade could keep indoor temperatures slightly below peak outdoor temperatures. Nevertheless, the temperature models suggest that providing reliable air conditioning will be a critical intervention to protect NYCHA's seniors in the short-term.

Power backup is essential. In the second part of the study, Arup assessed the installation of generator backed-up air conditioning in senior housing to allow for sheltering in place. Two scenarios—100% backup and critical systems backup— are detailed. Full-site backup is the preferred alternative as it offers better comfort for the residents and simple electrical infrastructure upgrades with minimal disruption to residents.

NYCHA is already testing solutions. NYCHA is piloting two cooling strategies and implementing full-site backup. The smart AC pilot at Meltzer Tower tests the feasibility and efficacy of providing a cooling solution based on window air conditioners that are networked into a centralized control system. The heat pump pilot at Fort Independence does the same for a technology that provides both cooling and heating, which may be a good solution for developments that are pending heating plant replacements in the near- to mid-term. Finally, NYCHA is using FEMA funding at 32 Sandy-affected developments to provide full-site, 100% back-up power, which will be networked into a demand-response control system.

INTRODUCTION

NYCHA is New York City's largest landlord, with 326 public housing developments that are home to some 390,000 New Yorkers. Since Superstorm Sandy, NYCHA has been planning ahead for future climate impacts. Within NYCHA's $3 billion Sandy recovery program, much of this climate adaptation work is focused on avoiding future damage from coastal floods and storm surges. Design innovations include elevating the ground level around entrances, flood barriers—passive, deployable, and automatic—and raising heating plants above flood level. NYCHA is also providing 100% islandable electric back-up for Sandy developments. Beyond the Sandy portfolio, NYCHA has partnered with DEP to test "couldburst" green infrastructure for stormwater management for high-intensity rain events, which are expected to become more frequent in coming years. A pilot is currently in design for South Jamaica Houses in Queens.

Among the future climate risks, one of the most concerning is extreme heat: hotter summers, frequent and prolonged heat waves, and higher peak temperatures. Locational and socioeconomic factors suggest that NYCHA residents, particularly senior residents, will be at high risk of adverse health impacts.

Summers are getting hotter and more deadly

Heat waves are defined as three or more consecutive days with maximum temperatures at or above 90°F. Extreme heat events are periods when the heat index exceeds 100°F.

New York City experiences at least two heat waves every year and multiple days when the temperature exceeds 90°F. The City is particularly vulnerable to extreme heat due to its dense urban fabric. Increased temperatures are likely to become more of a problem because of climate change and densification of neighborhoods, which exacerbates the urban heat island effect. The urban heat island effect is caused by the thermal properties of urban materials, which absorb and store radiation during the day and release it as heat at night, resulting in evening temperatures that are many degrees higher than rural outliers. In New York City, this difference is on average 7°F but can reach as high as 10-20°F.

New York City experienced twenty-one heat waves between 2000 - 2006, six of which lasted five or more days; the second heat wave of 2006 was the most severe among these, lasting 10 days with maximum temperatures exceeding 100°F for three days[1]. In 2011, 2013, and 2016 New York City saw additional, record breaking heat waves where extreme weather lasted up to ten days.

The New York City Panel on Climate Change predicts that by the 2050s, mean average temperatures will increase between 4 and 5.7 °F; by the 2080s, heat waves will triple from the pre-2000 baseline of two per year to six per year.[2]

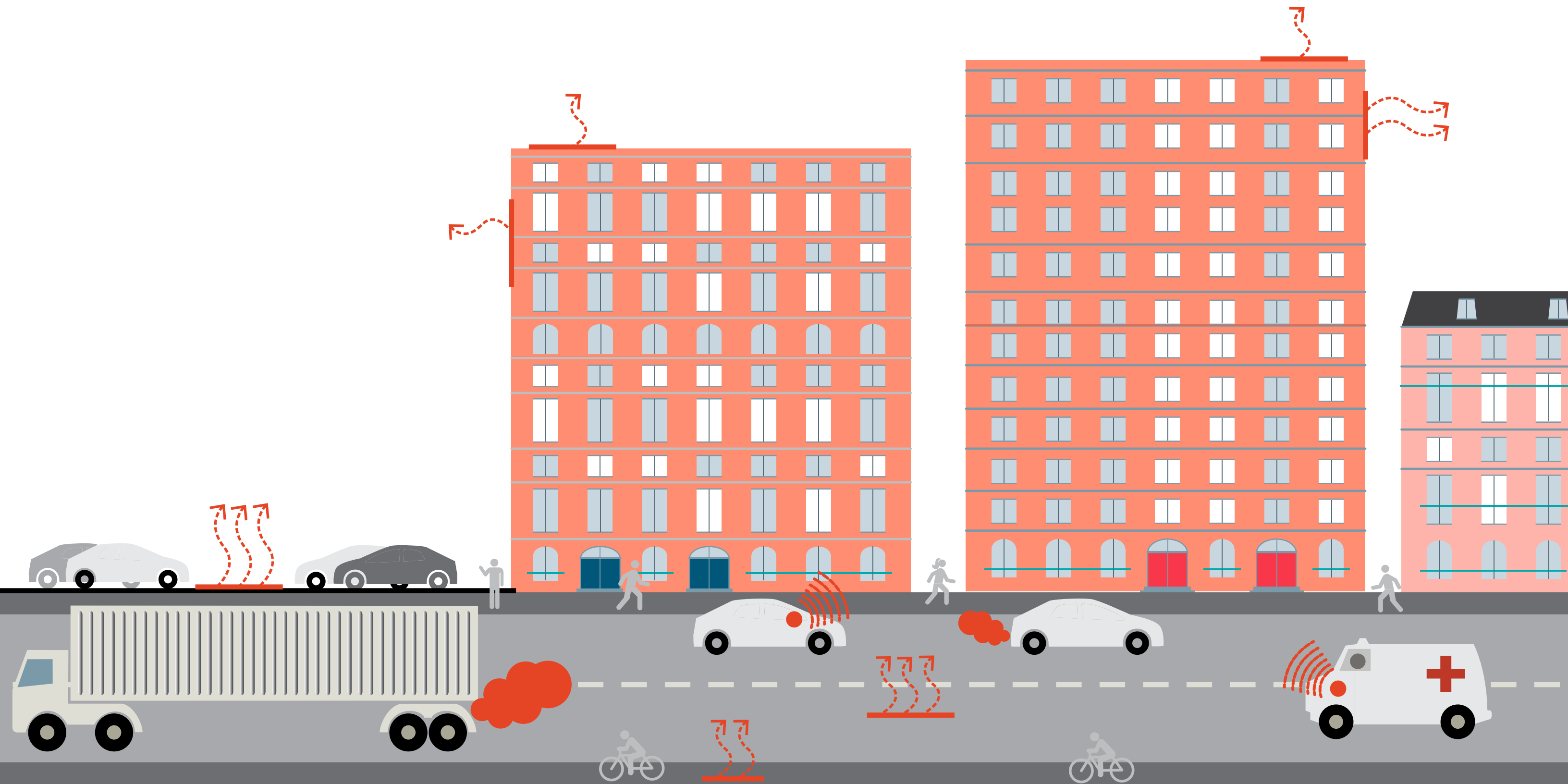
Heat waves kill more people in the United States annually than all other natural disasters combined.[3] This also holds true in NYC. Between 2000 and 2012, New York City suffered 162 heat-related deaths, 70 of which occurred during the heat waves of 2006 and 2011. These numbers, however, understate the true costs of heat events. NYC DOH estimates that during those same years, an annual average of 93 deaths could be attributed to heat exacerbated health conditions— known as "excess deaths."[4] Since 2000, heat events have also sent thousands of New Yorkers to local hospitals, resulting in an estimated 450 emergency room visits and 150 hospital intakes annually.[5]

NYCHA's senior residents are at elevated risk

Comprising approximately 17% of NYCHA's residents, people aged 65 and older are the fastest growing age group among NYCHA's population.[6] Eight-thousand of these 65,000 seniors live in 61 senior-only buildings, which are distributed across 41 NYCHA developments. Thirty-seven percent of NYCHA families have a head of household that is 62 years or older.[7]

Older adults (age > 65) are more likely to suffer from one or more of the risk factors associated with heat stress related illnesses. These risk factors include chronic medical conditions, such as heart disease or obesity; the use of medications that alter the body's cooling mechanisms; social isolation; and limited mobility. According to a 2011 study by NYC DOH, rates of certain indicators of poor health are elevated among NYCHA's senior population when compared to New York City's senior population at large. For example,

Fig. 1: Heat gain sources in the built environment

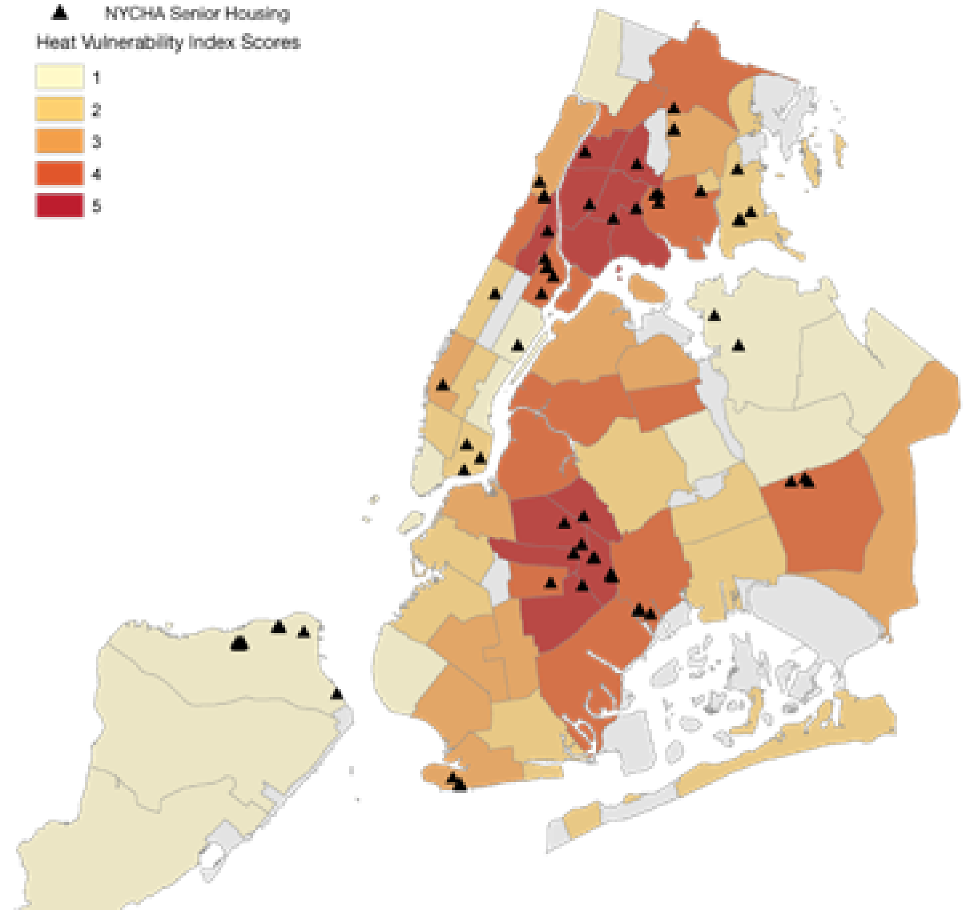


29% of NYCHA senior residents report limitations in their ability to perform basic activities, 37% percent have diabetes, and 15% are smokers.[8]

Although New York City seniors are particularly vulnerable to heat related illness and death, compared to the rest of the population, this age group is less aware of heat warnings; is more likely to stay indoors during heat waves; and is more resistant to using air conditioning, for reasons related to comfort, cost, and personal preference.[9] Indeed, NYC DOH found that eight (33%) of the 24 heat-related deaths during the 2013 heat wave were of individuals 65 and over. Furthermore, two-thirds of the total deaths had an onset of illness at home[10].

NYCHA housing is located predominantly in heat vulnerable neighborhoods. New York City publishes a Heat Vulnerability Index (HVI) map that identifies neighborhoods that are at risk during extreme heat. Each neighborhood receives a score from 1 (lowest risk) to 5 (highest risk) based on results from a

Fig.2: 70% of NYCHA senior housing is located in high-scoring neighborhoods



Data Sources: NYC Environment and Health portal. Accessed http://a816-dohbesp.nyc.gov/IndicatorPublic/VisualizationData.aspx?id=2191,4466a0,100,Map,Score,2010 at statistical model that uses social and environmental factors to estimate risk of heat- related death across NYC neighborhoods. Seventy-percent of NYCHA's senior housing is located within high-scoring neighborhoods.

How hot is too hot?

Unfortunately, there is very little research on thermal comfort among vulnerable people, and there is no universally accepted upper threshold for tolerable or safe indoor air temperatures. Nevertheless, some organizations have established policies that provide useful loose guides. For example, under federal regulations, long-term care facilities certified after 1991 must maintain a temperature range of 71 – 81°F. New York State's Department of Health regulates nursing homes throughout the state and mandates that nursing homes maintain comfortable temperatures that do not exceed 80°F. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) recommends 79°F as an upper temperature threshold for comfort.

Sheltering in place

Post-disaster research has shown that seniors can suffer adverse health impacts from mere displacement from their homes, and many are reluctant to evacuate to safe shelter for a variety of reasons ranging from fear of break-ins to the need to access their localized support and social networks. Although NYCHA will always follow any emergency orders as they are issued by the City, best practices in the field and NYCHA's past experience suggest that strategies that allow seniors to stay in their apartments safely are preferable to those that dislocate them for any period of time.

The recommended mitigant for high heat is mechanical cooling – air conditioning; however, unlike the provision of heat in winter, providing cooling in summer is not yet an expected or required landlord responsibility in New York City. New York City's administrative codes provide wintertime minimum indoor temperatures. No equivalent laws stipulate summertime maximum indoor temperatures. Even in market-rate rental housing, landlord-provided air conditioning is uncommon. However, as summers get hotter and the attendant health impacts begin to be felt, the norms for air conditioning may change.

Many public housing authorities across the country – including in subtropical Florida – have argued that they are prohibited from providing air conditioning. In 2015, NYCHA began working with the New York City regional office of HUD to understand the regulatory limitations of providing air conditioning in NYCHA housing. Public housing authorities may have received past guidance that discouraged providing cooling, but HUD consultants working on NYCHA's behalf found no regulatory prohibition.

With the regulatory questions answered, NYCHA began to plan pilots for two cooling technologies: window air conditioners and heat pumps. Although window air conditioners were displaced by ducted central cooling in many parts of the country, they are the prevailing cooling method throughout New York City and the only method currently available to NYCHA residents. Ductless Air Source Heat Pumps (ASHPs), a 1980's invention now ubiquitous in Europe and Asia, is a promising alternative to ducted central cooling systems in that they are more easily retrofitted into the low-ceilinged, mid-century buildings characteristic of NYCHA's portfolio. ASHPs also provide heating, which may make it a good solution for developments slated to receive heating plant replacements.

To inform a long-term approach to cooling, NYCHA engaged Arup to explore two questions related to sheltering seniors from extreme heat:

1. How important is the building enclosure relative to mechanical cooling? If there is a resource tradeoff between investing in a high-performance enclosure and new mechanical cooling, would a new high-performance envelope by itself suffice to provide safe indoor temperatures during high heat events?
2. Is there a cost-efficient alternative to full-load electrical backup? Mechanical cooling depends on having electricity. High cooling demand during summer heat events may result in blackouts or brownouts. To ensure that residents may shelter in place, NYCHA's cooling strategy would need to account for grid unavailability. Master metered buildings, like most NYCHA buildings, typically have high electric loads, so full-load backup entails providing more electricity than is needed for critical systems.

NYCHA also engaged Arup to perform a feasibility and design analysis for a heat pump pilot project.

Characteristics of NYCHA's senior housing

NYCHA's senior housing is located in all five boroughs, but forms clusters in Central Brooklyn, Upper and Lower Manhattan, and the Bronx. Approximately 40% of these buildings are more than one mile from a local cooling center.

The senior housing portfolio consists primarily of multi-family houses, the bulk of which were built prior to 1980. The oldest senior development was constructed in 1962. The newest dates to 1994. All the buildings have masonry walls with flat, built-up roofs. The senior housing portfolio can be broadly categorized into three types based on number of stories: low-rise (less than six stories), mid-rise (seven to twelve stories), and high-rise (thirteen or more stories).

Low-rise buildings are found across all five boroughs but are concentrated in Staten Island. Low-rise buildings account for 19% of the total senior housing portfolio by area. The mid-rise and high-rise buildings together make up 81% of the total portfolio by area.

The portfolio can be broadly categorized into master-planned developments and scattered sites with single buildings. Seventy-nine percent of the buildings are over 100,000 square ft.

The majority of senior buildings are steam heated in cold months. NYCHA does not provide cooling to its residents. NYCHA residents who want air conditioning must sign an appliance agreement, which permits them to install up to two window, through-wall, or window-wall units. Once signed, senior residents are responsible for installation and maintenance, in addition to a monthly $8 surcharge fee per unit. NYCHA is responsible for paying the electric bill. Some senior residents choose not to install air conditioners for varied reasons, such as cost, medical conditions, or personal preference.

Notes

[1] Source: https://www1.nyc.gov/assets/em/downloads/pdf/hazard_mitigation/nycs_risk_landscape_a_guide_to_hazard_mitigation_final.pdf

[2] Source: https://nyaspubs.onlinelibrary.wiley.com/toc/17496632/1336/1

[3] Source: https://www1.nyc.gov/assets/doh/downloads/pdf/epi/databrief47.pdf

[4] Ibid

[5] Source: https://www1.nyc.gov/assets/em/downloads/pdf/hazard_mitigation/nycs_risk_landscape_a_guide_to_hazard_mitigation_final.pdf

[6] Source: https://www1.nyc.gov/assets/nycha/downloads/pdf/senior-report-nycha.pdf

[7] Source: https://www1.nyc.gov/assets/nycha/downloads/pdf/res_data.pdf

[8] https://www1.nyc.gov/assets/nycha/downloads/pdf/senior-report-nycha.pdf

[9] Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4074319/

[10] Source: https://www1.nyc.gov/assets/doh/downloads/pdf/epi/databrief47.pdf

AIR CONDITIONING PILOT PROJECTS

MELTZER TOWER
SMART WINDOW AIR CONDITIONERS

Objective

With the Meltzer Tower pilot project, NYCHA will assess whether the installation of high efficiency, networked (aka “smart”) air conditioners in senior housing—at no cost to tenants—can be and economic way to ensure that every apartment in a senior designated building maintains safe temperatures during a heat wave or extreme heat event. Networked air conditioners can be centrally controlled during a heat wave to ensure residents’ rooms remain at a comfortable temperature while minimizing peak energy usage and costs to NYCHA. The pilot will also assess whether a voluntary air conditioning program can be designed to elicit participation rates close to 100%.

Dates

Spring 2019 – Winter 2020

Building selection and characteristics

NYCHA chose the senior-only building Meltzer Tower in Lower Manhattan as the site of its smart AC pilot because it is a standalone building with one-bedroom and studio units of approximately equal square footage. The consistency among units simplified calculations relating to the size and quantity of required air conditioners. Most importantly, the apartments already have dedicated appliance outlets in the living rooms, so NYCHA contractors can install the air conditioners on existing breakers without costly electrical modifications.

Implementation

All current residents will receive the opportunity to swap their existing window air conditioners for new NYCHA-owned smart AC units at no charge, up to the maximum allowed number for their apartment. Participants who do not currently have ACs will receive one. Pilot participants will be exempt from the standard monthly air conditioning surcharge of $8 per air conditioner, and will have the choice of disposing of their old AC units or having NYCHA remove them; in no case will they be allowed to be re-installed in participating apartments. New smart AC units will be installed by a NYCHA contractor, who will ensure that installation meet highest safety standards and strengthen compliance with Local Law 11. Future installations of resident-owned AC units will not be permitted in participating apartments, and residents who have fewer than the maximum number of allowed air conditioners may request additional AC units from NYCHA. The privileges and responsibilities of participation will be memorialized in a side agreement to the lease. Participation in the pilot is voluntary for current residents.

For vacant units, NYCHA will install smart ACs during apartment turnover and new tenants will receive the ACs as Authority-owned equipment along with their refrigerator. New leases will prohibit the installation of resident-owned AC units.

The new smart AC units will be wi-fi enabled and connected to a network that will be installed as part of the pilot. Once networked, the ACs units' condensers will be managed by centralized control software to optimize energy efficiency. NYCHA also plans to participate in utility-sponsored demand response programs to offset the on-going pilot costs.

Residents will have full control over the temperature settings during normal operation. During dangerous heat waves or high-heat events, NYCHA's control software will ensure that all AC units are turned on and providing cooling to maintain comfortable indoor temperatures.

In April 2019, NYCHA will competitively procure a vendor for a three- year contract to supply and install new smart AC units and recycle old ones on a rolling basis as new tenants join the program. Once selected, the contractor and NYCHA will begin formal tenant meetings and informational sessions. The first wave of installations is expected in early June 2019. During this time, building staff will receive training for air conditioner maintenance. NYCHA will list a separate solicitation at the end of August 2019 for demand management services.

Limitations

While the new smart window ACs will be high-efficiency, Energy Star-approved units, all window ACs inherently create opportunities for air infiltration, which is a primary source of energy loss in winter. To the extent that the pilot will increase the number of AC units, the wintertime heating energy loss may increase. NYCHA will minimize this effect by properly air sealing each unit into the window.

Window AC units also present some disadvantages compared to other high-efficiency centralized systems like air source heat pumps. First, proper installation with brackets greatly reduce, but does not eliminate Local Law 11 risk, where as heat pump systems with roof or ground-mounted condensing units eliminate the Local Law 11 risk entirely. Secondly, because the condensing unit is integral to the window AC, the smart AC will be louder when in operation than a heat pump air handling unit, which is nearly silent. Residents who object to the noise may therefore still choose to underutilize the AC units.

Finally, because window ACs may be removed with the right tools, there is some small risk of lossage of AC units.

Evaluation

In November 2019 NYCHA will comprehensively evaluate the pilot. NYCHA will assess several metrics to determine the pilot's successes, challenges, and any required recalibrations. First, NYCHA will compare electricity costs during the pilot to usage and cost data from the previous three years to see if the program met its goal of being cost neutral (or near cost neutral). Second, NYCHA will evaluate voluntary enrollement against the goal of >90% participation, and determine the reasons for participation and non-participation through resident interviews and surveys. Finally, NYCHA will collect qualitative data from NYCHA staff and contractors throughout the pilot to determine ease of implementation and operations, and from residents to understand how well the pilot met their needs and expectations.The results of this evaluation will inform the expansion of the program to other senior buildings in NYCHA's portfolio.

Fort Independence Houses
Air Source Heat Pumps

Objective

Heat pumps are a high-efficiency heating and cooling technology that can provide central cooling to senior residents and replace energy intensive steam/ hydronic heating systems. With the Fort Independence heat pump pilot, NYCHA seeks to acquire knowledge of the technical and legal nuances of heat pump technology to ensure effective installation, operation, and maintenance; assess the efficacy and convenience of the system in providing reliable heating and cooling; and compare the efficiency of heat pump heating and cooling to the status quo (i.e. central hydronic heating and resident owned and operated air conditioners).

Dates

Spring 2019 – Winter 2020

Building selection and characteristics

Located in the North Bronx, Fort Independence is a 21-story building with 344 units. Fort Independence was recommended as the site of its heat pump pilot project because the building was one of only five in NYCHA's portfolio that has an interval electric meter — a digital meter that collects usage data every 15 minutes—as well as an independent HVAC system (meaning it is not part of a master planned campus and therefore has its own gas meter and boiler). These characteristics allowed NYCHA to assess whether additional load could be supported and observe changes in energy consumption after heat pump installation. At the time of the feasibility analysis, the building also had excess electric capacity conveniently located near the roof where heat pump condensers will be installed. Fort Independence is not a senior-only building (although it does house the Fort Independence Senior Center), but ultimately technical considerations severely limited acceptable sites for the pilot.

Implementation

NYCHA will install a commercial variant refrigerant flow (VRF) air source heat pump system to serve seven of the 20 apartments on the top floor of Fort Independence. This particular type of heat pump delivers the benefits of heat pump efficiency without significant disruption to residents. NYCHA will mount the outdoor condensers on the building roof and run refrigerant lines through the roof, above the hallway ceiling, and into indoor, ductless wall units with individual zone control that are mounted on the living and bedroom walls. NYCHA will remove any existing, resident-owned air conditioners from the seven pilot units and install isolation valves on the existing heating systems, which can be reversed easily if necessary.

The heat pump will provide heating and cooling and allow NYCHA to compare energy usage and resident satisfaction in the pilot apartments to the thirteen "control" apartments that remain on the conventional heating and cooling systems. To enable a comparison of energy demand, NYCHA has metered all the top floor units for apartment level electric consumption. Each participating apartment will also be outfitted with a thermostat that will read back temperatures to a centralized control system. This control system will link the condenser units and allow NYCHA to set indoor temperatures from a single access point, ensuring adequate cooling during a heat wave.

As of April 2019, the RFQ for a contractor to install and maintain the system for five years is out to bid. NYCHA expects to have a contractor in place by early May 2019 and complete installation in six to eight weeks.

Limitations

Because the pilot will only affect seven out of the building's 340 apartments, the existing hydronic boiler will remain the primary source of heating and no observable reduction in gas consumption is expected. Additionally, because every building is different, NYCHA does not expect to develop a universally-applicable design. Each retrofit system will have to be designed to meet each building's specific needs and limitations.

Evaluation and Next Steps

NYCHA will collect one year of data and conduct an evaluation of the pilot by winter 2020. Using both quantitative data of costs and energy usage and qualitative data from resident and contractor interviews and surveys, NYCHA will assess 1. the effectiveness of the designed system in keeping participating apartments cool in the summer and warm in winter; 2. the cost of installation per unit; 3. the convenience of the system for residents; 4. the annual maintenance requirements and efficiency of using third party managers; and 5. whether or not the system reduced energy usage and costs when compared to the control apartments. The findings will inform the planning of future ASHP projects.

TECHNICAL STUDIES

PART I: Building Envelope and Heat Stress

NYCHA commissioned Arup to assess the effect of building envelope on indoor air temperatures in NYCHA's senior housing. Arup modeled two apartment types representative of the senior housing stock and examined whether a new high performance façade alone could provide safe indoor air temperatures during heat waves or extreme heat events— or whether air conditioning would also be necessary to keep residents safe. Arup also explored the benefits and costs of a combined strategy, including envelope upgrading and air conditioner installation.

How hot does a senior apartment get during very hot weather?

Building enclosure construction plays a critical role in the external gains associated with a building's indoor space. Older buildings with minimal insulation gain heat faster than newer ones, but also lose heat quickly. Internal gains from cooking and other equipment add to the space heat gain.

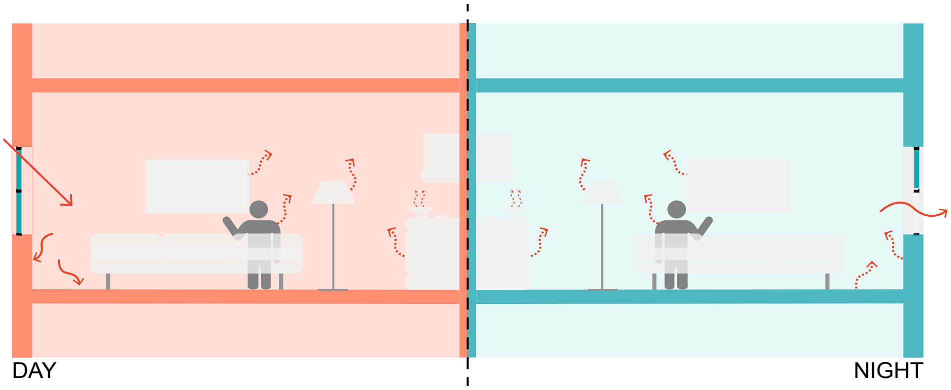


Fig. 3: Apartment internal and external gains

An apartment's location within a building also matters. For example, a top floor, corner apartment with poorly insulated walls/roof and unshaded south and west facing windows could potentially gain heat faster than a center floor apartment. On the other hand, center floor apartments with a single exposure do not have the opportunity to cool down using cross-ventilation.

To study the effects of conventional and high-performance building enclosures on indoor air temperatures at senior residences, Arup examined two cases:

» A corner apartment: an apartment located on the top floor corner with three exposures - the roof and two exterior walls facing the south and the west.

» A center apartment: an apartment located in the center of a building with a single exposure - an exterior wall facing the south.

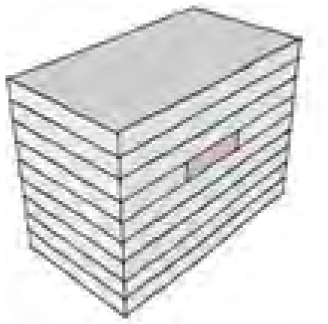


Fig. 4: Center apartment

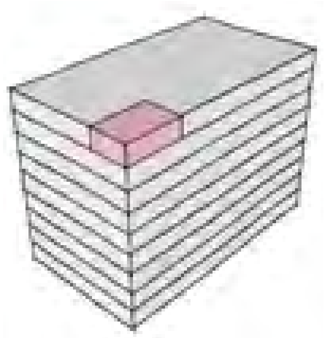


Fig. 5: Corner apartment

Three different facade conditions were simulated:

» Existing facade (represents existing conditions at the representative buildings surveyed for this study - refer to appendix A)

» 2016 New York City Energy Conservation Construction Code (NYCECC) compliant facade

» High performance facade (higher efficiency than 2016 NYCECC)

The study applied two different extreme weather profiles. One represents a heat wave (three or more consecutive days where maximum temperatures exceed 90°F) and the other represents a record-breaking extreme heat event. The first profile corresponds to a heat wave that lasted nine days, from July 27th to August 5th, 2006, causing 40 heat-related deaths in New York City. The model applied the six-day time period between July 29th and August 3rd, which includes the three warmest consecutive days of the heat wave. During these six days, the outdoor temperature was above 86°F for 50 hours and above 93°F for 14 hours.[10]

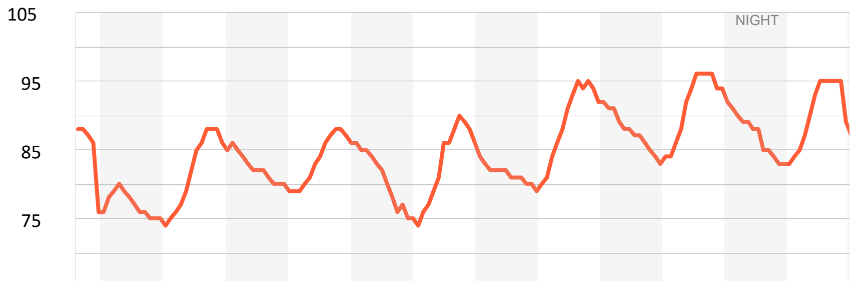


Fig. 6: Outdoor temperature profile 1

The second weather profile corresponds to the time period between July 20th - 26th, 2011 with record breaking temperatures. The highest temperature ever recorded at Central Park (103°F) occurred during this period on July 22nd. This scenario is representative of an extreme heat event, not a heat wave, because on previous and subsequent days temperatures were as low as 68°F.

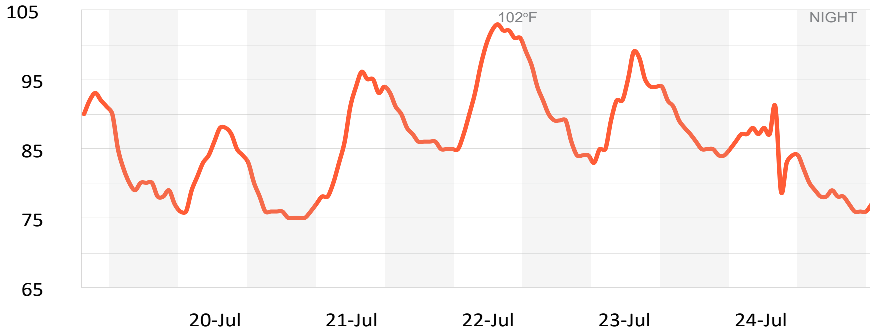


Fig. 7: Outdoor temperature profile 2

Figures 8-10 show the modeled indoor air temperatures in the corner apartment with the three different facades. In the case of the existing façade, when outdoor temperatures peaked, indoor air temperatures were 6°F higher. That is, when it was 98°F outside, the corner apartment heated to 104°F. Conditions under the code façade were moderately improved, but indoor temperatures still exceeded the outdoor peak by 3°F. The high performance façade performed no better than the code façade, and in fact resulted in slightly warmer indoor temperatures because of the increased insulation. In all three cases, in the absence of air conditioning, the corner apartment reached dangerously high temperatures that consistently exceeded those of the outdoors.

The existing façade performed similarly with the center apartment as with the corner one. When outdoor temperatures peaked, the center apartment's indoor temperature was 6°F higher. The code and high-performance facades kept temperatures in the center apartment slightly below those in the corner apartment, particularly in the first few days of heat. But again, on average, indoor temperatures remained 3°F lower in the center apartment with the code and high performance façade than with the existing facade. As seen with the corner apartment. the high performance façade performed no better than the code façade in moderating the center apartment's indoor temperature.

The addition of shading to the exterior (1.7 meter extensions) and interior of the existing façade and the high performance façade reduced temperatures in the corner and center apartments by an average of 3°F. The high performance façade with shading kept indoor temperatures equal to- or several degrees lower than the peak daily outdoor temperature.

Corner Apartment

Existing facade

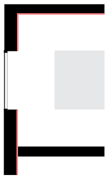
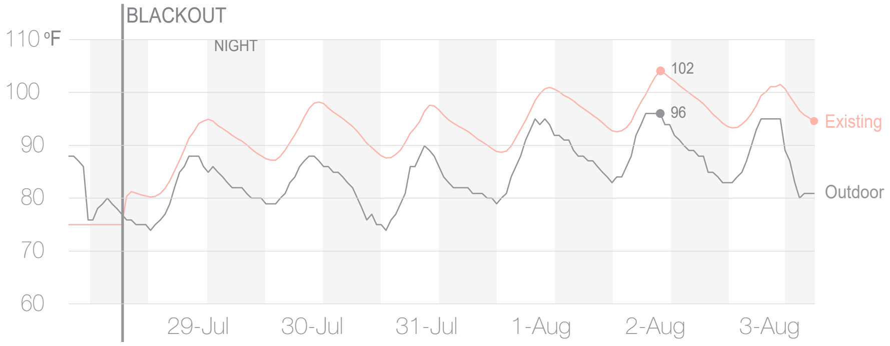


Fig. 8: Corner apartment - existing facade temperature profile



The indoor temperature in the existing apartment is 6°F higher than the outdoor temperature during the peak.

2016 NYCECC compliant facade

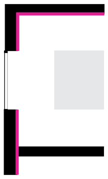
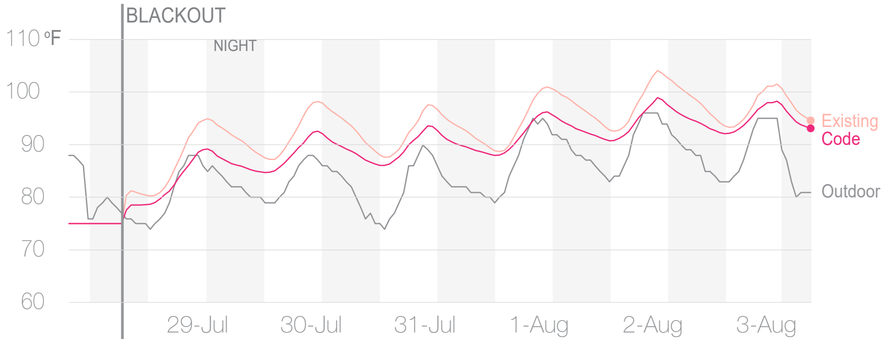


Fig. 9: Corner apartment - 2016 NYCECC compliant facade temperature profile



The code facade keeps the room cooler than the existing facade by 3°F.

High performance facade

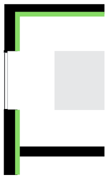
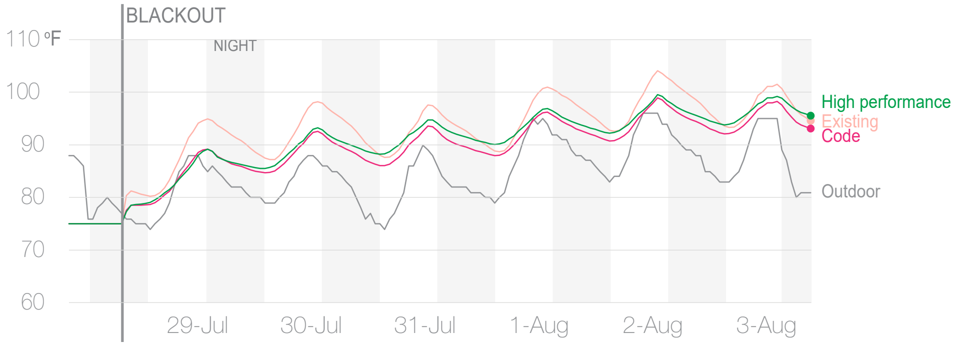


Fig. 10: Corner apartment - high performance facade temperature profile



The high performance facade tracks the code facade temperature closely. But it remains a bit warmer than the code due to higher levels of insulation that restrict indoor heat from dissipating.

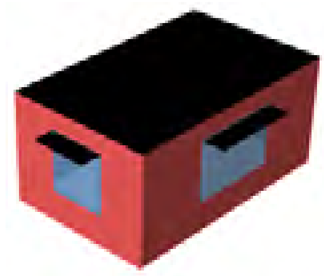


Fig. 11: Model view of corner apartment with external shading

Shading

Additionally, the effect of interior (e.g. curtains) and exterior projected shading was also studied. Exterior shadings extended approximately 1.7 ft from the facade. To bookend the results, only the 'Existing' facade and the high performance case were simulated with both forms of shading.

Existing facade with internal + external shading

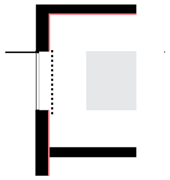
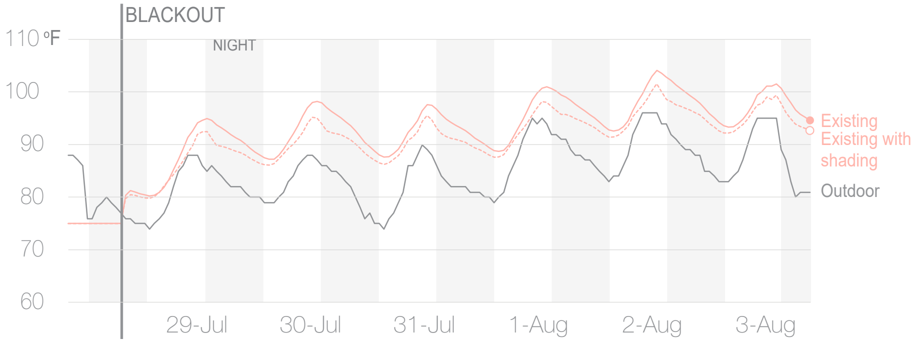


Fig. 12: Corner apartment - existing facade temperature profile



The indoor temperature with shading is on an average 3°F cooler than the facade without shading.

High performance facade with internal + external shading

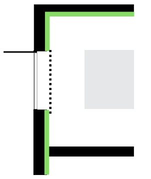
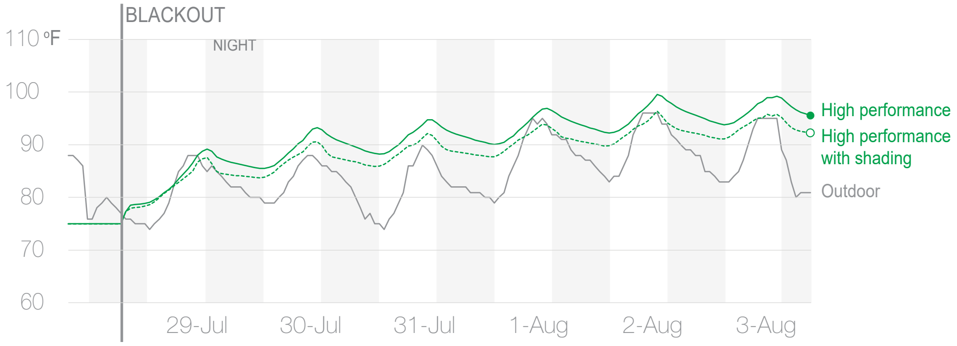


Fig. 13: Corner apartment - existing facade temperature profile

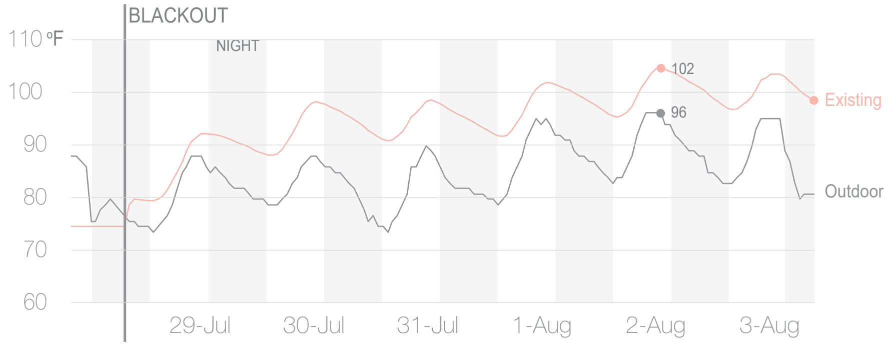


Similar to the existing facade with shading, the high performance facade with shading is on an average 3°F cooler than the facade without shading.

Center Apartment

Existing facade

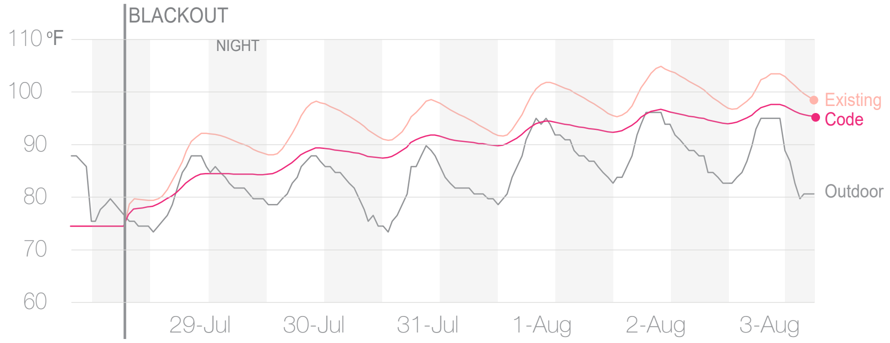
Fig. 14: Center apartment - existing facade temperature profile



The indoor temperature in the existing apartment is 6°F higher than the outdoor temperature during the peak.

2016 NYCECC compliant facade

Fig. 15: Corner apartment - 2016 NYCECC-compliant facade temperature profile



The code facade keeps the room cooler than the existing facade by 3°F.

High performance facade

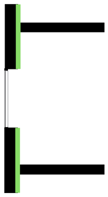
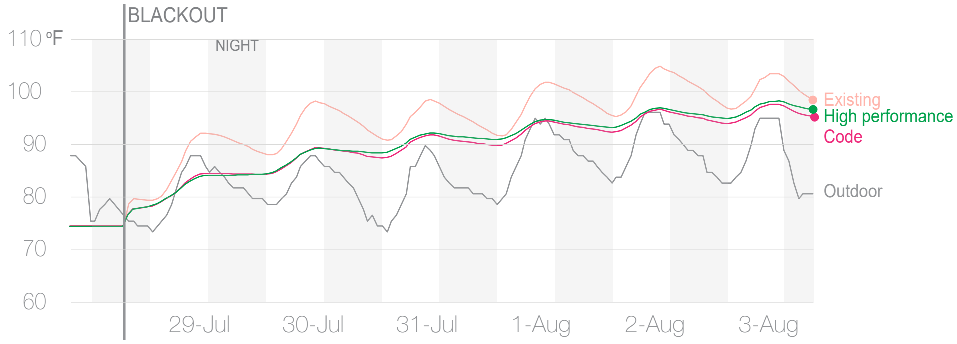


Fig. 16: Center apartment - high performance facade temperature profile



The high performance facade tracks the code facade temperature closely.

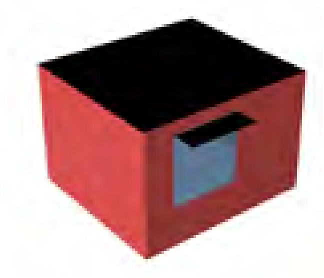


Fig. 17: Model view of center apartment

Shading

Additionally, the effect of interior (e.g. curtains) and exterior projected shading was also studied. Exterior shadings extended approximately 1.7 ft from the facade. To bookend the results, only the 'Existing' facade and the high performance case were simulated with both forms of shading.

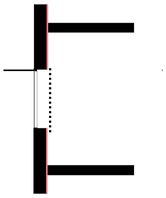
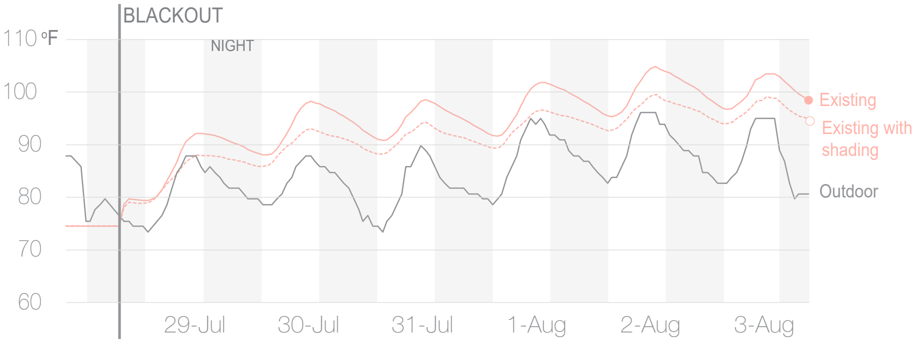


Fig. 18: Center apartment - existing facade temperature profile

Existing facade with internal + external shading



The indoor temperature with shading is on an average 3°F cooler than the facade without shading.

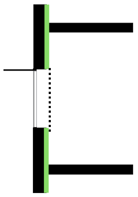
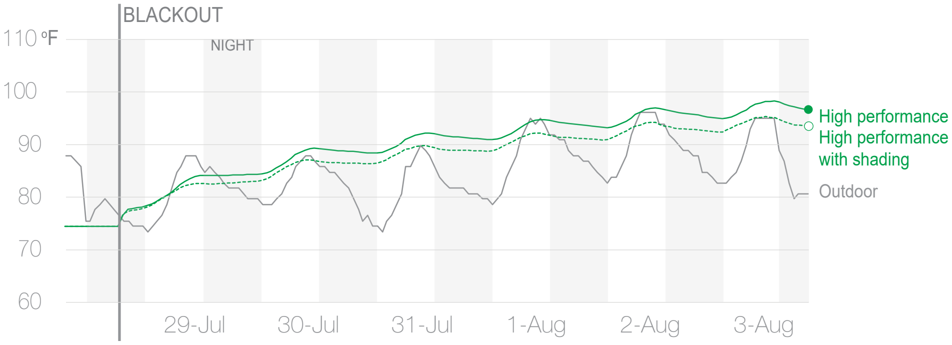


Fig. 19: Center apartment - existing facade temperature profile

High performance facade with internal + external shading



Similar to the existing facade with shading, the high performance face with shading is on an average 3°F cooler than the facade without shading.

Study limitations

All models assume that apartment windows are closed because the opening or closing of windows depends on resident behavior and is difficult to accurately account for in simulations. However, the opening of windows plays a critical role in relieving heat stress and the use of appropriate ventilation strategies for cooling (e.g. opening windows at night, to release warm air and draw in cool air) would likely moderate the predicted indoor temperatures.

2016 NYCECC compliant versus the high performance façade

Results showed that the indoor temperatures were similar in both the 2016 NYCECC-compliant (i.e. "code façade") case and the high performance case when the air-conditioning is turned off. There are two primary reasons for this. First, the window standards for NYCECC are difficult to improve upon without resorting to very costly measures. As a result, under the code and high performance facades, indoor conditions evolve similarly on the first day of the heat wave. Second, the additional insulation in the high performance facade impedes the escape of heat from the interior to the cooler environment at night. The effect of this can be seen during the night, as the temperature of the 2016 NYCECC-compliant case drops faster than in the high performance case. Indeed, the benefits of a "leakier" façade during high heat events are most evident in the existing façade models. Apartments with these facades experience the fastest and largest temperature drops at night because their high infiltration rates allow greater air exchange with the cooler, outdoor evening air.

This situation, where the thermal insulation and infiltration rates are sometimes beneficial and other times detrimental, coupled with the transient nature of the building thermal mass and outdoor conditions, suggest the existence of an optimum level of insulation and infiltration. Of the conditions explored in this study, the 2016 NYCECC-compliant facade is best at this trade-off.

Study takeaway: Façade upgrades alone will not ensure safe indoor temperatures

In all cases without shading, the daily indoor temperature within the modeled apartments builds up over time and remains higher than outdoor temperatures during a blackout. Under status quo conditions (existing façade, no shading) when outdoor temperatures peak at 96°F, the indoor temperature reaches 104°F—6 °F higher than the outside. The addition of external shading reduces this differential by 3°F. Under shaded conditions, temperatures in apartments with an energy efficient facade dip below outdoor temperatures for several hours a day. Nevertheless, by day four of the modeled heat wave, the indoor air temperature of an apartment with a shaded, high-performance façade remains above 90°F both day and night.

Taken together the study results suggest that an energy efficient envelope is inadequate to ensure that NYCHA's senior residents can reside safely indoors during a heat wave. Based on these findings, air conditioning will be a necessary intervention for NYCHA senior housing.

Air conditioner sizing and energy savings

As would be expected, an analysis of air conditioning sizing and energy savings demonstrated that apartments with the existing façade would require larger air conditioners for cooling than apartments with more energy efficient facades. For example, the high performance facade with shading requires the smallest AC unit (0.17 tons), while the existing facade requires a 0.8 ton unit—a substantial increase due to increased gains and higher infiltration.

The cooling advantages of the "leakier" NYECCC-compliant envelope (discussed above) disappear when air conditioning is introduced. Although both the code compliant and high performance facade performed similarly during a heat wave, the 2016 NYCECC-compliant facade requires a larger air conditioning unit to keep the space under comfortable conditions. The additional insulation of the high performance facade results in higher energy savings.

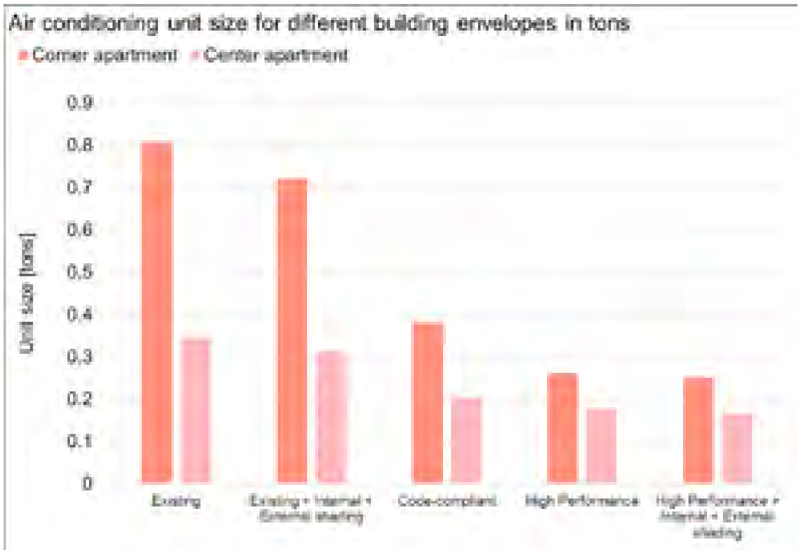


Fig. 20: Air conditioning unit size for different building facades

The cost of upgrading an existing facade to 2016 NYCECC-compliant and high performance requirements, as well as the installation of external shading and window ACs are presented below. As expected, the high performance facade costs slightly more than the 2016 NYCECC compliant facade.

See Exhibit C for details of the cost estimate.

Corner Apartment

	'16 NYCECC Compliant	High Performance	Change ($)	Change (%)
Facade upgrade	$50,760	$57,000	$6,240	12.3%
Addition of shading (internal and external)	$5,710	$5,710	$-	0.0%
Window AC installation (2 per apartment)	$1,150	$1,150	$-	0.0%
Total	$57,620	$63,860	$6,240	10.8%

Center Apartment

	'16 NYCECC Compliant	High Performance	Change ($)	Change (%)
Facade upgrade	$37,340	$41,570	$4,230	11.3%
Addition of shading (internal and external)	$5,710	$5,710	$-	0.0%
Window AC installation (2 per apartment)	$1,150	$1,150	$-	0.0%
Total	$44,200	$48,430	$4,230	9.6%

PART II: Generator Backup

Upgrading NYCHA senior housing facades alone will not result in safe indoor air temperatures during a heatwave; mechanical cooling— air conditioners— will be required. Mechanical cooling is impossible under blackout conditions unless some form of backup generation is available on site. As of 2019, NYCHA has already begun implementing full-site backup power for 32 of its Sandy impacted developments. NYCHA asked Arup to examine the tradeoffs between providing 100% backup power (as in its Sandy developments) or limiting on-site generation to the less resource intensive backup of critical systems only.

Summary of backup options

There are no mandates that require whole building backup; powering critical systems during a blackout would still allow seniors to safely shelter in place during a heat wave. In this section, the costs and benefits of two scenarios are assessed:

- **100% backup:** Provides generator backup power to continue uninterrupted building operations (including active cooling) during a black-out scenario.
- **Critical systems backup:** Provides generator backup power to continue emergency and critical building operations. Emergency systems vary by building type but they typically include emergency lighting, fire suppression pumps, elevator components, and fire alarm systems. In addition, the following critical systems can be added to the emergency backup system: emergency outlets to charge cell phones (in common areas), fans and pumps for heating/ cooling systems, and water booster pumps to deliver potable water to upper floors.

Natural gas generators are NYCHA's preferred backup power system and have already been successfully installed on NYCHA's Sandy-affected developments. Provided the gas supply is intact, these generators can run for as long as needed. The following models assume backup generation in both cases is powered by natural gas. Appendix B documents the considerations for electrical infrastructure, calculation methodology, and applicable regulations.

Providing 100% backup

In a 100% backup scenario, generators allow all normal building operations to remain in service with only a short interruption. The greatest advantage of this approach is the elimination of any inconvenience to building occupants. In order to size and compare costs of this form of backup generation, Arup conducted site visits to six representative senior developments (outlined in exhibit A). Peak meter readings were not available, so the site load for the smallest and largest sites was estimated to be 80% of the building service size. The peak demand is projected to be much lower than this but would need to be confirmed with metered data prior to implementation. No demand factors—which could be used to further reduce the generator's size—were applied to the calculation. For these reasons, the generator loading was allowed to reach higher levels, forming a conservative estimate of generator size:

100% backup	Minimum	Maximum
Site service size (A)	1600 at 208 V	2400 at 208 V
Site load (kVA)	461	692
Number of generators	1	2
Generator Size (kW)	500	350
Generator Size (kVA)	625	438
Generator loading	74%	79%

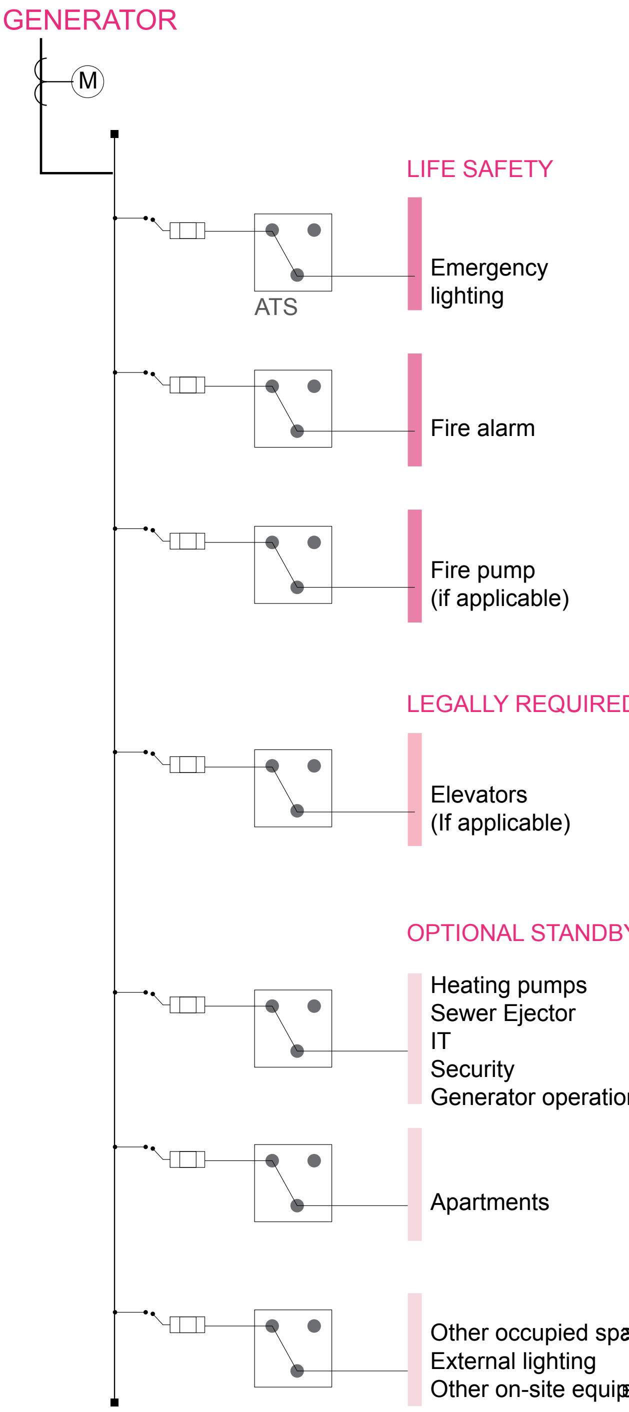


Fig. 21: 100% backup generator wiring diagram

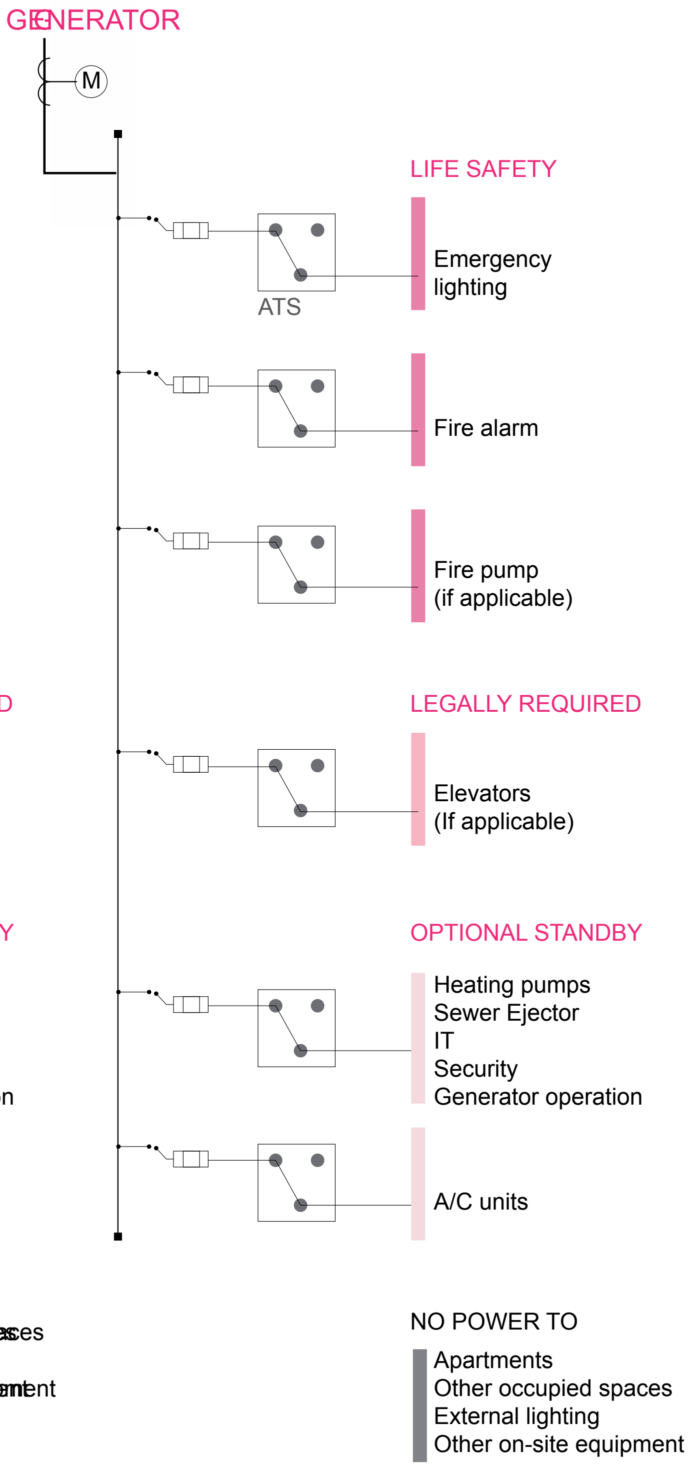


Fig. 22: Partial backup generator wiring digram

Providing critical systems backup

Critical systems backup powers the minimum emergency equipment. To determine a preliminary size for the generator in the absence of metered data, the load is assumed to be the entire building's load minus the apartment load. On average, the load in the apartments of the six representative buildings is 2.73kW. This analysis assumes that this load times the number of apartments represents 80% of a building's load.

The approximation of the apartment load shown does not include the AC units which will need to be on a dedicated distribution.

The backup of only life-saving equipment has the advantage of reducing the generator size and related energy costs. However, the required electrical infrastructure upgrade is similar to the full site backup scenario, and in the event of a longer blackout, the building's residents will be left with no power for the blackout's duration. The following table is again based on the six representative buildings:

Partial backup	**Minimum**	**Maximum**
Site service size (A)	1600 at 208 V	2400 at 208 V
Site load (kVA)	255	345
Number of generators	1	1
Generator Size (kW)	250	350
Generator Size (kVA)	313	438
Generator loading	82%	79%

Adding air conditioning units to both scenarios

The experiences of other developments that have already installed backup generation suggests that both the 100% and critical system back-up generators sized in the scenarios above could easily support additional load from air conditioning units. For example, at the Red Hook developments the readings showed that, on average, metered demand was roughly 44% of the installed generator (being already 80% of the service size); the highest building demand was 75% of the generator size. When surveying the Baruch House service end boxes, Arup noted that there were consistently fewer ConEd sets than NYCHA owned sets (roughly 50% or fewer) at all 18 sites. Finally, when Arup surveyed metered data at other NYCHA sites, peak demand over the course of two years was equal to roughly 50% of the site's service.

How much would each cost?

The cost estimate is a rough order of magnitude. The accuracy range of this estimate has been determined to be -25% and +50%. The accuracy range is a gauge of likely bid prices if the project was issued to tender at this current stage.

See Exhibit C for details of the cost estimate.

Recommendation

Generator location	Critical System Backup	100% Backup	Change $	Change %
On the ground	$333,000	$396,000	$63,000	18.9%
Generator on roof, electrical ground	$444,000	$562,000	$118,000	26.6%
Roof Location	$450,000	$586,000	$136,000	30.2%

Based on this assessment, Arup believes that 100% backup offers better comfort for the residents and a simpler electrical infrastructure upgrade to offset the price for larger generator.

Collection of metered readings before initiating installation would allow a better sizing of the new system, and likely result in lower costs for the 100% backup scenario.

PART III: Heat Pump Feasibility

NYCHA commissioned Arup to examine the feasibility of retrofitting a building with an electric air-source heat pump system to be used for heating and cooling. Arup also led the selection of a building for a pilot project.

Fort Independence is the recommended building for a pilot project

Fort Independence is the recommended building for an air-source heat pump pilot installation. A portfolio-level analysis including site visits were used to select this building from among others in NYCHA's portfolio. The retrofit was determined to be structurally, electrically, and mechanically feasible for this building.

A set of selection criteria were applied to NYCHA's large portfolio to identify candidate buildings. The primary filter was the availability of 15-minute interval data, or the electrical consumption of the building every 15 minutes. This data is required to estimate the electrical capacity of a building to determine whether the additional electric load from heat pumps can be supported. Buildings with independent HVAC systems were also preferred so that changes in energy consumption may be observed after the heat pump is installed. Combined, these two criteria identified five potential sites. It is recommended that meters with the capability to measure electrical demand (in at least 15-minute intervals or preferably more frequently) be installed in buildings that will be considered for retrofits in the future. Site visits were conducted at both of the buildings, and both were confirmed to be feasible locations for a heat pump retrofit project.

Fort Independence is the preferred building because its heating system is hydronic, which is easier to retrofit than a steam system. Fort Independence also had spare capacity on electrical panels on the 21st floor, which is much closer to the rooftop outdoor units. Conduit would need to be run from the roof to the basement at Atlantic Terminal.

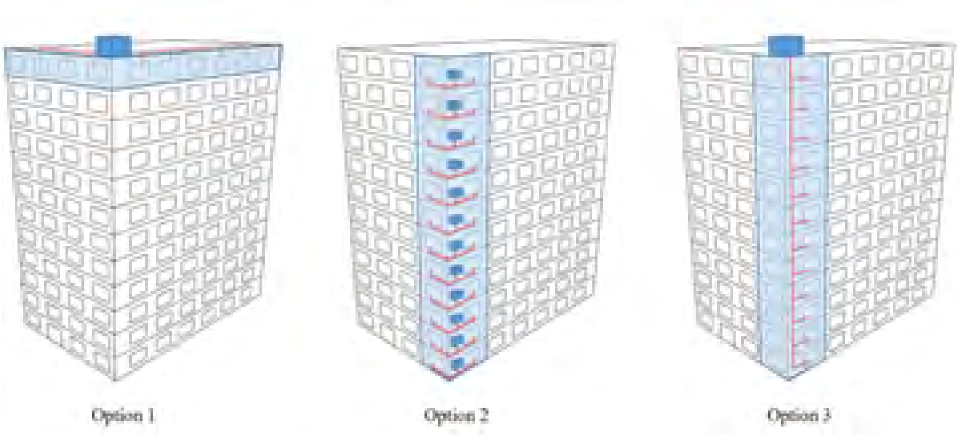
An air-source VRF system is recommended

A non-ducted variable refrigerant flow (VRF) heat pump was selected from the many types available. It is a form of air-source heat pump (ASHP) that uses only refrigerant piping. This offers the benefits of a highly efficient system while minimizing disruptive retrofit activities.

After selecting Fort Independence, different configurations for system layout were considered. Option 1 shown below was chosen as the recommended system.

It is the least intrusive for a retrofit of this scale, and takes advantage of the efficiency benefits of centralizing outdoor units to the maximum extent possible.

The recommended system will provide heating and cooling to seven apartments on the 21st floor. An indoor unit will be mounted on the wall of each living room and bedroom, for a total of 21 indoor units. These will be served by four outdoor units each six refrigerant tons (RT) in capacity. The outdoor units will be mounted on the roof of the building using steel dunnage. The new equipment will be served by a new electrical panel connected to the existing panel on the North side of the 21st floor.



System Layout Options

Two alternate system configurations were considered. Option 2 has seven apartments in a vertical configuration (the same apartment on each of seven floors) served by the VRF system. Each apartment would have one 3-RT outdoor unit connected with three wall-mounted indoor units. Each outdoor unit would be mounted to the façade using a support rack, and connected to a new electrical panel on the 21st floor. Option 3 uses the same technological approach to option 1 but has a vertical configuration. This option would require a significantly more work during installation than Option 1.

Electrified mechanical systems are the way forward

Climate change poses a serious threat to New York City. To respond to this threat, New York has joined many other cities around the world in signing the Paris Agreement, committing to limit the rise in global temperature to well under 2 °C. New York has set an 80 x 50 goal (80% reduction of 2005 emissions by 2050) to act on this commitment.

Buildings are responsible for over 73% of the total energy consumption of the United States. Traditionally, buildings have met demand for space heating and domestic hot water heating with carbon-intensive fuels like fuel oil, diesel, and more recently, natural gas. Heating and cooling technologies that make use of natural gas (e.g. furnaces, boilers, and absorption chillers) alleviate many of the air quality and health concerns associated with diesel and fuel oil. However, to achieve the carbon emission reduction necessary for an 80 x 50 goal, alternatives to natural gas must be implemented.

Air-source heat pumps (ASHP) are one such alternative. An ASHP uses a working fluid to transfer heat between outdoor air and indoor air. They can be run in cooling mode or heating mode, and can sometimes provide both simultaneously (using heat recovery). They are also efficient; depending on the outdoor temperature, a heat pump can achieve a coefficient of performance (COP) of 3 to 4, meaning the thermal energy delivered is 3 to 4 times the electrical energy consumed. They are powered with electricity.

Heat pumps are part of a broader effort to electrify the buildings and transportation sectors. Electricity is a much more versatile form of energy. Its source can be a variety of renewable resources, from solar panels or batteries atop the roof of the same building to offshore wind turbines hundreds of miles away. Energy generation in dense areas like New York City is a challenge, and electricity extends the available selection of technology options.

Older buildings, the majority of New York City's building stock, are less efficient, and generally meet their thermal energy demands with more carbon-intensive technology. The result is a stock of buildings that may still be in use for decades, but are performing far below today's energy and sustainability standards. If New York City is to realize its carbon reduction goals, many of these buildings will need to be upgraded. Upgrading to electric systems will allow emissions to drop to zero as the grid is transitioned to renewable energy.

The goal of this study is to select a building in NYCHA's portfolio for which it is feasible to install a heat pump. This project will be used to assess the feasibility of retrofitting existing buildings with electric systems.

Heat pumps are carbon friendly and more efficient

Heat pumps come in three primary forms: air-source, water-source, and ground-source, distinguished by the medium with which heat is exchanged. Ground-source heat pumps could also be widely used in New York City, but are best used in new construction. They require open land area for drilling or excavating, which is much easier to accomplish before a building is built.

Water-source heat pumps require a body of water with which to exchange heat. This can be done with a water body (e.g. a lake or river) or with an adapted cooling tower (winterized or one that uses glycol). Air-source heat pumps (ASHP) are the most versatile. They are more modular and can be implemented without as much infrastructure. They are readily adapted to retrofit applications.

An advanced type of ASHP is called variable refrigerant flow (VRF) technology, which allows the refrigerant flow to vary using variable frequency drives and electronic expansion valves, increasing system efficiency. A non-ducted VRF is recommended on this project.

Considerations for a heat pump retrofit

There are a number of basic layouts appropriate for a heat pump pilot retrofit, shown in the figure. Option 1 centralizes outdoor units on the roof, and serves apartments on the top floor. Option 2 is decentralized; each apartment is served by a smaller outdoor unit mounted to the façade. Option 3 also locates outdoor units on the roof, but drops vertically to serve the same apartment on a number of floors.

If NYCHA is to pursue a whole building retrofit, any of these options can be used. For this pilot installation, Option 1 is recommended. This will be the least intrusive, while still taking advantage of the efficiency benefits of a centralized system.

Retrofitting an ASHP system of this type involves a number of steps:

- Existing heating system must be decommissioned by disconnecting and removing radiators and capping the distribution system
- Heating set points for boilers must be adjusted downwards (if apartments converted make up a substantial portion of the total building)
- Outdoor units must be mounted on roof using dunnage
- Indoor units must be mounted on apartment walls or floors
- Outdoor units must be connected to an electrical panel with sufficient capacity; if that capacity is not present on an existing panel, a new one must be installed
- Holes for refrigerant pipes must be cored through roof slab and waterproofed/sealed
- Refrigerant pipes must be installed between outdoor units and indoor units, affecting both apartments and common corridor spaces
- Pipework to collect indoor unit condensate must be installed

- Equipment used to meter the energy consumed by heat pumps must be installed (optional; only observable if apartments make up large enough portion of total building)

Key factors in selecting a building

A heat pump can be installed in almost any existing building. However, some building characteristics are more conducive to a heat pump retrofit. The table in Exhibit E shows characteristics and parameters that could be used to select buildings for retrofit suitability. In this study, building selection was driven primarily by the availability of meter data.

Upgrading a building's electrical service would dramatically increase the costs of retrofitting a heat pump system. Buildings that have enough capacity to support these new loads should be prioritized, and ones that have open space on existing panels are even better. To know whether that capacity exists, 15-minute interval meter data must be available (preferably a few years' worth) to determine the building's peak demand for electricity. This is the only way to know that the building can support more electrical load.

Conceptual System Layout

The recommended layout serves seven apartments on the 21st floor. Four outdoor units mounted to the roof serve 21 indoor units, which are mounted to the walls of each bedroom and living room in the apartments served. This layout is advantageous for a pilot retrofit because it is the least disruptive, since the majority of the piping would be located above the roof, saving some disruption to the common hallway spaces. Electrical conduit and refrigerant piping can be fed through a cored hole in the roof. The holes are then sealed and insulated.

An alternative layout is also presented, which serves a stack of seven apartments vertically. Each apartment has one outdoor unit and three indoor units. This is also a feasible layout.

Not presented is a layout in which each vertical stack of apartments is served by a centralized heat pump on the roof. Although this type of system could be made to work for a small number of units, it would likely not be feasible for many of NYCHA's buildings. The New York City Building Code limits on the amount of refrigerant that may serve a given volume of space in an apartment. The room size in Fort Independence limits that refrigerant to an amount that can serve roughly six rooms. Because NYCHA's buildings are generally taller than six stories, this approach is not recommended.

Mechanical

The heating and cooling loads were estimated using the energy models developed for the study of heat stress mitigation in NYCHA senior housing. Those loads were taken and scaled to each room served by an indoor unit based upon area and position in the building. The peak cooling loads for each room ranged from 0.35 refrigerant tons (RT) to 0.95 RT. Peak heating loads stretched from 6,300 Btu/h to 17,600 Btu/h.

Each room was assigned a wall-mounted indoor unit sized to the greater of the heating and cooling demand. Indoor unit sizes included 0.5 RT, 0.75 RT, 1.0 RT, and 1.5 RT. Layout is shown below.

Although the 21 selected indoor units could be served by one 18 RT outdoor unit, four outdoor units were instead sized to six RT each. The New York City code imposes a refrigerant concentration limit (RCL) of 26 lbs per 1000 cubic feet of space served. The smallest room served is about 130 square feet, which places a limit of 27.3 lbs on system refrigerant. This imposes a maximum outdoor unit size of 6.8 RT.

Option 1 System Layout

The alternative option would serve a vertical stack of seven apartments, rather than seven apartments on one floor. One floor of this arrangement is shown below.

The outdoor units in this case would be mounted to the façade. Indoor units would still be mounted to the wall, and would have the capacities shown.

Option 2 System Layout

Refrigerant piping can be distributed via two primary strategies. The roof could be penetrated in one place and pipes could be distributed via the indoor ceiling. This would require disruption of the common corridor to run the piping. Alternatively, the roof could be penetrated above each apartment with piping running above the roof. This would require waterproofing for the penetrations, could complicate maintenance, and may impact the durability of the exposed piping. A single penetration is recommended.

The condensate from the indoor units must also be collected and disposed of. The simplest way to achieve this would be to allow the condensate to drain via gravity outside of the façade. This will likely be the most appropriate solution for Option 2. Another solution would be to pump it to a sink in a janitor’s closet. Drawings indicate that there is one located on the 21st floor near the electrical panel on the South side of the building. This solution would be appropriate for Option 1.

Some supply risers in the hydronic heating system serve multiple apartments on each floor. Likewise, some return risers accept water from multiple apartments. The apartments chosen for the heat pump system were chosen such that the radiators removed do not inhibit the supply of hot water to adjacent apartments.

After disrupting the supply of heat to the apartments served, the output at the boiler should be adjusted downwards. Because the Fort Independence pilot will involve only a small number of apartments, this adjustment will not be necessary.

Electrical

From an electrical infrastructure upgrade perspective, the two presented options differ only in the number of outdoor heat pump units that require a connection. Regardless of the set-up and number of units, the addition of heat pumps will require the installation of one or two new panels (depending on readings).

The location of the apartments served has no bearing on the electrical solution. In all options, the intent is to supply the indoor units directly from each apartment's dedicated panel.

The number of outdoor units varies from (4) six-ton units in option 1 to (7) three-ton units in option 2. The load and electrical distribution design will differ as follows:

- (4) six-ton units have a rated load of 15.7A each or roughly 5.7kVA. These require individual 35A, 208V 3P breakers
- (7) three-ton units have a rated load of 17.6A each or roughly 3.7kVA. These require individual 30A, 208V 1P breakers.

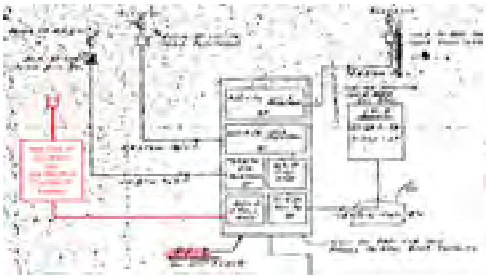
Both options will require the addition of a new panel.

PP-1 and PP-2 are the two existing panels identified for the connection given their location and availability. The selection of the preferred panel as a supply point will mainly be conditional to the panel's current loading. Readings on both panels are necessary in order to determine if one is more heavily loaded than the other.

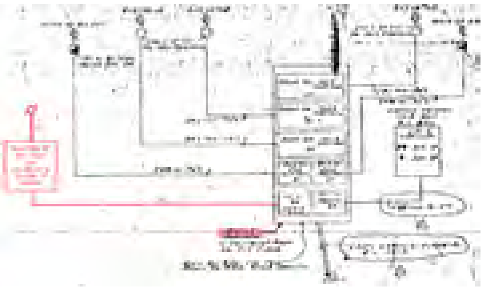
The available 100A, 3P breaker shall be used in both cases to supply the new sub-panel. From the visual inspection, there seemed to be enough space in the PP-2 electrical room for the new panel, but another location could be necessary given that the PP-1 closet had little wall space available.

In the event that both panels have availability, the closer proximity to the new heat pumps depending on the option will be prioritized. Whereas if both panels are substantially loaded, it is possible to install (2) two sub-panels and divide the load evenly. Ultimately, the readings will dictate the better course of action. There is a possibility that both panels are too heavily loaded which would require the increase of the fused disconnect along with the associated feeder and the replacement of that panel.

The single line diagram would be similar in all options; involving a new sub-panel for either PP-1 or PP-2, or both.

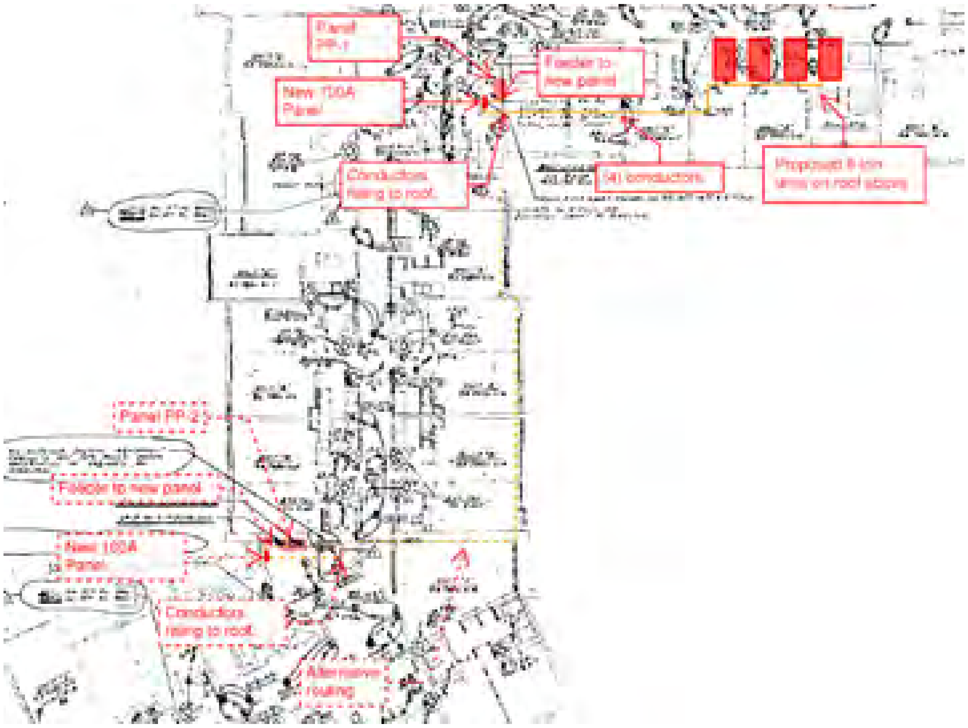


Single Line Diagram for PP-2



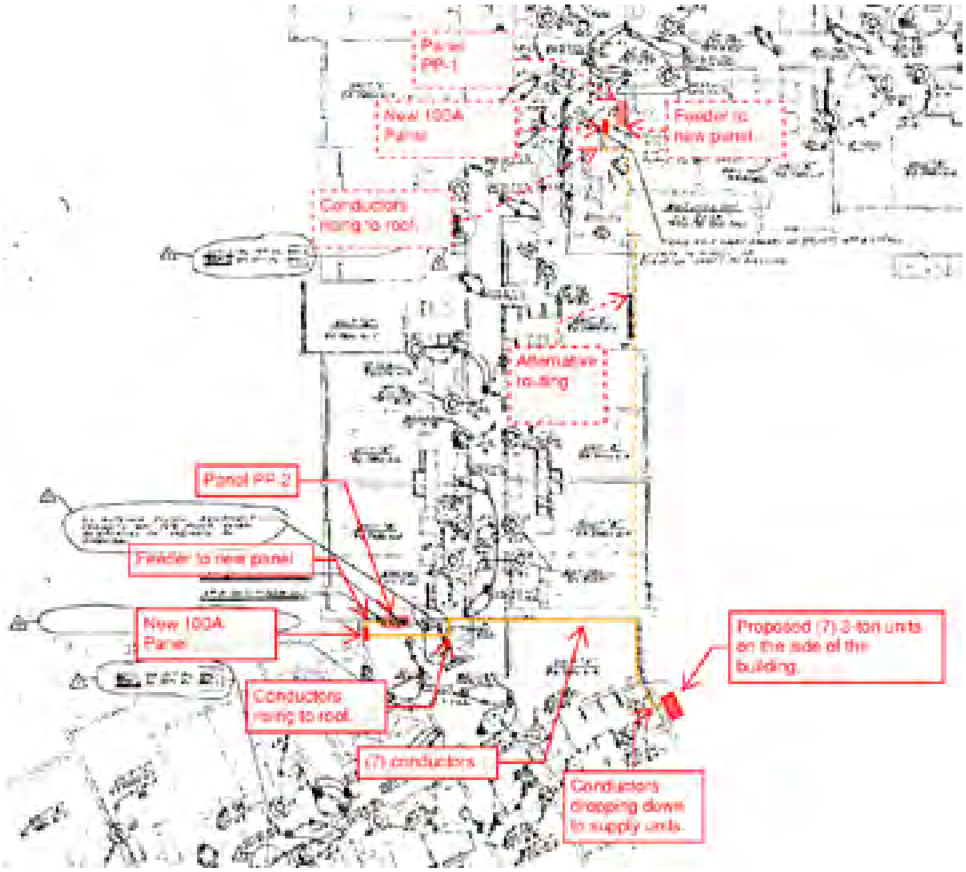
Single Line Diagram for PP-1

For options where (4) six-ton units are serving apartments on a single floor, PP-1 is the preferred connection point due to proximity as shown below. An alternative routing is shown from PP-2.



(4) six-ton units layout

On another hand, PP-2 is the preferred connection point when (7) three-ton units are serving identical apartments on different floors.



(7) three-ton units layout

The number of indoor units per apartment varies from 2-4 depending on the space layout, with an average of 3 units throughout. The size of the units also differs within an apartment, but from an electrical load perspective, all the units have a similar usage. Using a value of 0.5A @ 208V per unit, this would represent 1.5A or 315VA (~250W) per apartment.

From the apartments surveyed during the site visit, many already had an A/C connected to dedicated outlets near the windows. This correlates with a multitude of past projects in NYCHA buildings that added a dedicated supply for commercial AC units in apartments. Based on these, we can assume a planned minimum usage of 2kW at 120V. This can be further validated by the single pole dedicated 20A circuit for the AC units in the apartments, as seen during the site visit.

Whereas the load is considerably lower (down from 2kW to 250W), the circuit cannot be reused and must be replaced due to the operating voltage for the indoor units. The original breaker – or fuse – can be reused, but a second one adjacent to it must be added to create the 208V required. On top of the location of the existing outlet, the new circuit must extend to the new planned indoor units placements. The panels in the apartments are rated 50 or 60A, 120/208V, 2P and offer the required space for the installation of indoor units combined with the possibility to reuse an existing circuit, as seen below.

Typical Unit Panel

Because the indoor units are 208V, two single circuits must be replaced with one double circuit. This is straightforward if the panels are in good condition, and based on observations during site visits, they were. However, if it is found that a panel is not in good condition, it may need to be replaced.

Load unbalancing due to an addition affecting only panels on a single riser is not a consideration given the low overall extra load (1.8kW) and actual reduction form the existing AC system.

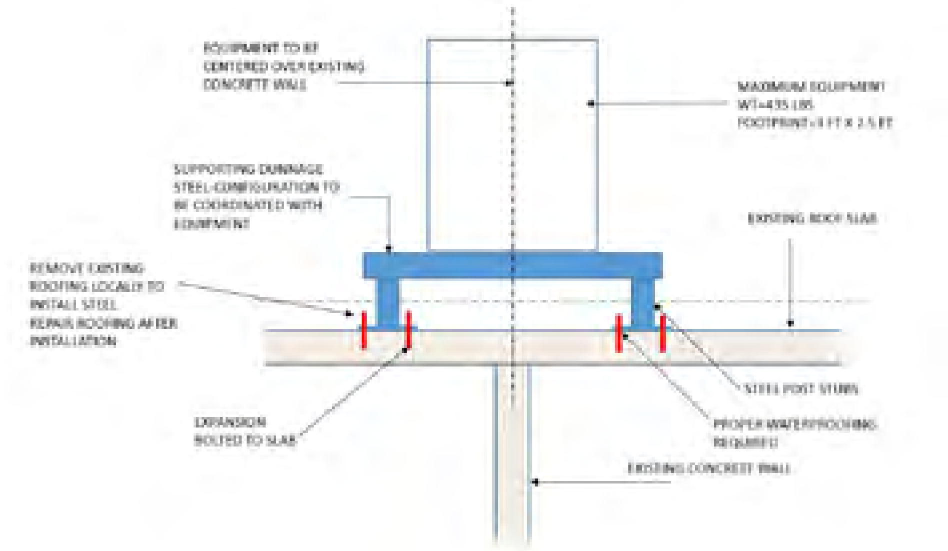
Whereas both options represent a similar load, opting for four (4) larger units not only slightly reduces the electrical burden – 23kVA total vs 26kVA for the seven (7) smaller units – on the system, but is also a solution requiring a smaller amount of new electrical distribution equipment; ultimately being a more electrically efficient solution in conditioning the 7 units.

Overall, considering the option representing the largest load, the total additional load to the building is roughly 26kVA (or ~ 20kW), resulting in only a small increase of the site’s usage which has a peak record of 672kW. This increase will likely be reduced in the summer months assuming that the current AC units will be effectively replaced by a centralized system.

Structural

The outdoor units are the primary structural concern in the recommended system. The indoor unit components of an ASHP are usually both smaller and lighter than a normal air conditioning unit. They may be mounted on the floor or on the wall (using studs) with little concern.

The four outdoor units in the recommended system each weigh 435 lbs. That load must be distributed using steel dunnage. The raised supports will also protect the units from accumulated rain and snow, and will need to be higher than the design snow drift height. Figure 35 shows a layout of this system. Units must be placed atop the dunnage centered over a concrete wall. The dunnage must rest directly on the concrete slab, and should be secured in place with expansion bolts. Sizing of dunnage should be part of a later design effort.



Steel Dunnage for Roof-Mounted Outdoor Units

If Option 2 were to be pursued, a support rack would be needed to support each of the outdoor units mounted to the façade. A sample rack of this kind is shown below. Because each of these outdoor units is 283 lbs, additional support for the masonry walls may also be needed. In this case, reinforcing steel vertically spanning between floors must be mounted to the façade and tied into each floor slab. Electrical conduit and/or refrigerant piping attached to the exterior of a building could also impose additional loads on the façade. If the building is tall enough, the weight of the conduit will be too great to be self-supported. In this case, an intermediate support would need to be installed and tied into the façade.

Support Rack for Facade-Mounted Outdoor Units

Solar and Battery Storage

The feasibility of powering the new electrical loads from the outdoor units using solar photovoltaic (PV) combined with lithium ion battery storage (solar + storage) was explored. If the side of the roof not occupied by the heat pump is used for solar panels, a maximum of about 218 panels can be installed. This corresponds to a peak output of 72 kW. Figure 37 shows the layout. For comparison, the heat pumps have a peak electric demand of about 22 kW in heating.

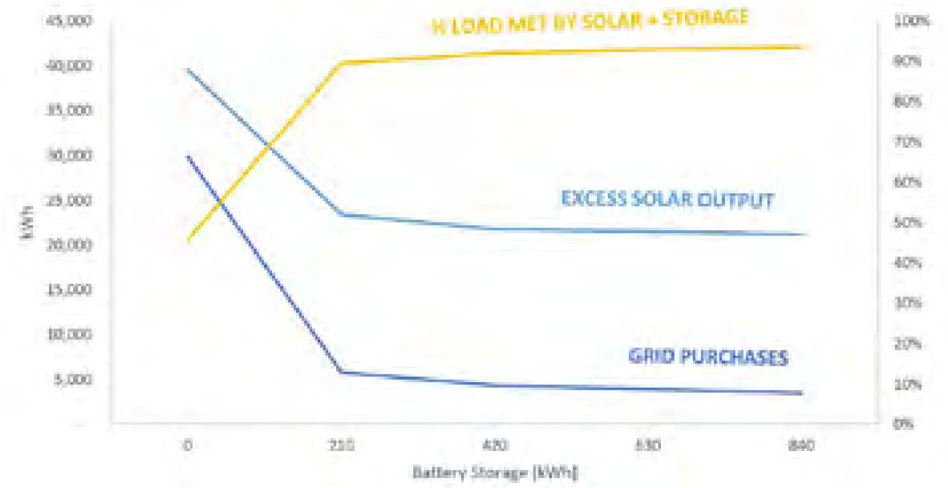
Fort Independence Solar PV Potential

An analysis conducted with HOMER, a software tool developed by the Department of Energy, predicted a total annual energy output of about 86 MWh from the solar panels. This output is variable; the panels have a high output during sunny daytime hours, some output on cloudy days, and no output at night.

The heat pumps are conservatively estimated (via a simplistic model) to require only 55 MWh of power. However, the variability of the solar resource misaligns the output and load for much of the time. Only 27 MWh of the total 86 MWh produced can be used by the heat pumps directly.

This problem can be addressed by using energy storage, by connecting the system to the grid, or both. Energy storage in the form of lithium ion batteries allows excess electricity produced by the solar array to be stored and later discharged when the panels are not producing. To have a grid-independent system, the batteries must be sized large enough to serve peak heating demand during cold and cloudy (low solar output) periods. The results of the HOMER analysis show that approximately 3.1 MWh, or 15 individual 210-kWh units, of battery storage would be needed. This is a very large amount of storage. These units are expensive, and each weighs 2,650 lbs (preventing them from being placed on the roof). Further, the cold and cloudy periods in which the batteries are most likely to be depleted coincide with the periods where a loss of heating would be most detrimental to residents. A grid-independent system is not advised.

A grid-connected system could be combined with a smaller amount of storage. As shown in Figure 38, most of the benefits of battery storage come initially, requiring only a small amount. Just one 210-kWh battery unit allows output from the solar panel to meet 89% of the heat pump load (from 46% with no storage). After that, the marginal improvements are small. If battery storage is desired, no more than 210 kWh is recommended.



Additional Load Served with Battery Storage

Installing a solar array would further help to meet New York City's carbon goals by supplying new electric loads with renewable sources. However, it must be noted that the installation could be electrically complex, particularly if batteries are included. The details of electrical connection and inverter placement would be determined in a more in-depth design effort. If a solar + storage system is to be further pursued, the utility should be engaged. The cost-effectiveness of installing solar + storage will rely on the compensation scheme for excess generation, and the extent of the electrical work needed to connect the system.

Conclusion

The NYCHA portfolio contains many buildings that could be suitable candidates for electrification. A full assessment of their suitability includes a determination of available electrical capacity, which requires a meter that measures electrical demand in 15-minute intervals. Few standalone buildings had this information; of those buildings, Fort Independence and Atlantic Terminal were determined to be good candidates. If NYCHA is to pursue electrification on a larger scale in the future, it is recommended that new interval meters be widely installed.

Fort Independence is the recommended building. It has a hydronic heating system, a longer period of available meter data, and panels with spare capacity located in close proximity to the roof. That said, the challenges associated with Atlantic Terminal could be overcome if desired.

The recommended system type is a roof-mounted non-ducted variable refrigerant flow system. This is an efficient technology that modulates the refrigerant cycled through the system to avoid wasted energy. Other technologies include standard multi-split heat pumps (refrigerant-based without the ability to vary the flow of refrigerant) or packaged terminal air conditioner (PTAC) units. These are less efficient, but viable and electric.

The recommended system layout is a group of four outdoor units mounted on the roof that serve seven apartments on the 21st floor. This allows for the centralization of outdoor units to the maximum extent feasible (subject to code-mandated Refrigerant Concentration Limits). It also minimizes the disruptiveness of retrofit construction activities. An alternative layout is also feasible, in which each of seven vertically-arranged apartments is served by one smaller, façade-mounted outdoor unit.

Exhibit A: Simulation Methodology

For this study, computer models of typical rooms in NYCHA's Mary Mcleod Bethune Gardens building were simulated. The software used was EnergyPlus, a building simulator developed by the US Department of Energy.

Two different room geometries were considered and are referred to as "Scenario 1" and "Scenario 2". In Scenario 1 the room is in an apartment located in a corner of the uppermost floor of the building, so the roof and two walls of the room are exposed to outdoor conditions.

In Scenario 2 the room is on an intermediate floor and with only one of its walls exposed to the outdoor environment. Windows cover approximately 20% of the wall area, which is typically the case in NYCHA buildings. The dimensions of the rooms are based on those of actual senior housing buildings and can be found in the next section.

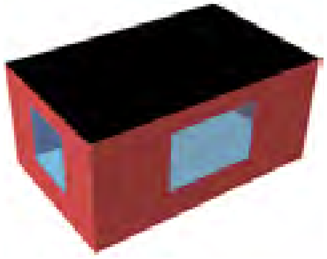


Fig. 29: Scenario 1 - corner apartment model

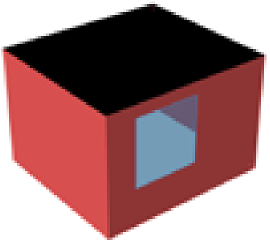


Fig. 30: Scenario 2 - center apartment model

Occupants of south-facing apartments are under increased risk of heat-related illness because of the higher amount of solar energy entering the room through south-facing walls. For this reason, the exterior wall of the room of Scenario 2, as well as the largest wall of Scenario 1, is oriented facing south in the simulations.

Three different facade conditions were simulated:

1. Existing facade (represents existing conditions at the representative buildings surveyed for this study - refer to appendix A)
2. 2016 NYCECC compliant facade
3. High performance facade (better than 2016 NYCECC)

Additionally, the effect of interior (e.g. curtains) and exterior projected shading was also studied (see Figure X). Exterior shadings extended approximately 1.7 ft from the facade. The existing facade and the high performance one were simulated again with both forms of shading.The relevant thermal properties of each facade condition are summarized below..

Two-dimensional finite element models of the current facade in Bethune Gardens were used to determine these values for NYCHA’s current building stock. Bethune Garden is a relatively old building so its facade performance is expected to be below that of a newer building that complies with current–and more stringent–energy and construction standards.

Calculation Assumptions

Existing facade constructions are listed in the table below. Interior partitions were assumed to be adiabatic with no appreciable thermal mass. Floor refers to uninsulated slab between apartments. Infiltration is assumed to be 0.3 cfm/ft2 of floor area.

U-value (BTU/hrft2F)	Density (lb/ft3)	Heat capacity (BTU/lbF)	Solar absorptivity	Thermal emissivity	
Exterior Wall	0.92	140	0.21	0.7	0.9
Roof	0.15	140	0.21	0.7	0.9
Floor	1.48	140	0.21	0.7	0.9

	U-value (BTU/hrft2F)	SHGC	VT
Windows (including frame)	1.23	0.78	0.9

2016 NYCECC compliant facade constructions are listed in the table below. Infiltration is assumed to be 0.14 cfm/ft2 of floor area.

The fenestration U-value for the 2016 NYCECC compliant case is really low. It approximately corresponds to a double glazing low e=0.10 coating with a 13 mm argon space insulated fiberglass or vinyl frame.

U-value (BTU/hrft2F)	Density (lb/ft3)	Heat capacity (BTU/lbF)	Solar absorptivity	Thermal emissivity	
Exterior Wall	0.060	140	0.21	0.7	0.9
Roof	0.026	140	0.21	0.7	0.9
Floor	1.48	140	0.21	0.7	0.9

	U-value (BTU/hrft2F)	SHGC	VT
Windows (including frame)	0.32	0.78	0.9

High performance facade constructions are listed in the table below. Infiltration is assumed to be 0.02 cfm/ft2 of floor area.

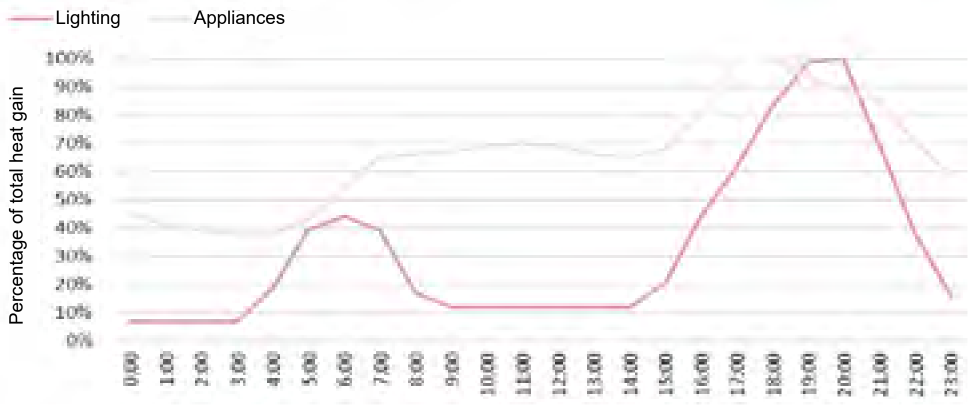
The fenestration U-value approximately corresponds to a triple glazing low e=0.20 coating with a 1/2 in air with a vinyl frame.

U-value (BTU/hrft2F)	**Density (lb/ft3)**	**Heat capacity (BTU/lbF)**	**Solar absorptivity**	**Thermal emissivity**	
Exterior Wall	0.05	140	0.21	0.7	0.9
Roof	0.02	140	0.21	0.3	0.75
Floor	1.48	140	0.21	0.7	0.9

	U-value (BTU/hrft2F)	**SHGC**	**VT**
Windows (including frame)	0.31	0.78	0.9

Schedules

The schedule shows the percentage of the total energy load that the lights and the appliances in the space release into the air in the form of heat. For example, at 6:00 pm the lights that are on in the apartment emit approximately 80% of all the heat that could be released by lighting. In a space with lights of the same wattage this would also mean that 80% of the lights are on at that time.



Typology selection

Based on the portfolio analysis, two predominant typologies were identified: Mid-rise and high-rise buildings that span both pre-1980 and post-1980 vintages. These buildings collectively make-up the bulk of the senior housing portfolio. Buildings that represent these typologies were then short-listed to conduct site-visits. Building selection is detailed out in the next section.

Building Type	Stories (Above Ground)	Area (sf)	Dwelling Units	Number of Buildings	Percent of Total Senior Housing Area
Mid- Rise	**7 to 12**	**1,984,253**	**2,261**	**14**	**33%**
High-Rise	**13+**	**2,935,057**	**3,832**	**21**	**48%**

Representative buildings

Representative buildings were selected based on the following criteria:

- Building height (mid or high rise)
- A mix of both pre-1980 and post-1980
- Proximity to NYCHA cooling centers
- Proximity to other potential sites

Based on the criteria above, six buildings were chosen as representative buildings for the two typologies. The chosen buildings are at least one-mile away from the nearest cooling center. These sites are also in close proximity to other sites which allows for efficient site-visits. The characteristics of the chosen buildings are documented in the table below. Heating systems were not used as a criteria as this study focuses primarily on the summer blackout scenario. However, the heating systems in all the chosen buildings are stand-alone systems with steam boilers with the exception of one building that has a hot water heating system.

After identifying the representative buildings, we acquired the architectural and MEP drawing sets for each of the buildings. These allowed us to perform a desktop study to identify key characteristics in detail prior to visiting the buildings. These characteristics are documented in the table below.

Development	Address	Borough	Area in sf	Dwelling Units	Stories	Vintage	Heating system
Bethune Gardens	1945 Amsterdam Avenue	Manhattan	179,600	210	22	Pre-1980	Steam
Conlon Lihfe Tower	92-33 170th Street	Queens	156,200	216	13	Pre-1980	Steam
International Tower	90-20 170th Street	Queens	134,200	159	10	Post-1980	Hot water
Marshall Plaza	1970 Amsterdam Avenue	Manhattan	143,700	180	13	Post-1980	Steam
Reid Apartments	728 E New York Avenue	Brooklyn	151,250	230	20	Pre-1980	Steam
Thomas Apartments	102 W 91st Street	Manhattan	69,683	87	11	Post-1980	Steam

Exhibit B: Considerations for electrical infrastructure backup

Regulations:

The design criteria needs to meet all the codes and standards outlined in the Regulations section in Appendix B.

Loads:

The installation of a generator automatically requires the separation of the load into three categories:

- Life Safety (LS)
- Legally Required Standby (LRS)
- Optional Standby (OS)

As shown on Fig. 23, these loads need to be physically separated from each other (with the fire alarm additionally having a dedicated supply).

Since the Life Safety and Legally Required Standby loads are prescriptive, the main difference in our two scenarios lies in what we qualify as Optional Standby load. These are noted on the diagram.

Location:

The generator can be located on the rooftop or on the ground.

For ease of installation, we assume that the new generator will be installed on the roof of the buildings. This allows for the generators to be located well above the design flood elevation and out of harm's way of any flooding events. Gas piping and electrical conduits would be routed up the exterior of the building from the ground floor up to the roof level.

The location of the generator needs to be evaluated on a site by site basis.

Enclosure:

The generators will be installed within a weatherproof sound attenuated enclosure. In the situation where multiple smaller generators are operating in parallel, they will be located within one enclosure. The sound attenuating enclosure should reduce the generator noise level to a maximum of 60 dBa when measured 23 feet from the generator enclosure.

Generator sizing:

A rough generator sizing was performed to determine the amount and ratings, but a more in depth analysis for each building is necessary to take into account future metered readings and factors such as starting kVA (sKVA) from motors. This can be 6x-12x the normal full load rating. Gas generators skVA is not as robust as diesel generators and apartment AC loads combined with existing motors can have a large impact on the sizing.

Electrical infrastructure:

The existing electrical distribution in each building will need to be re-wired and much of the current panels replaced. Site visits will confirm the upgrades but a number of considerations must be taken into account:

- New dedicated room for emergency equipment
- The flood elevation line
- Space availability on the roof or near the building
- ConEd fault level
- Number of existing panels and configuration of the distribution
- Proximity of equipment to limit voltage drop

The site conditions, existing distribution and preferred solution (full or partial backup) will determine the extent of the renovation.

Structural considerations:

An evaluation of the roof will be necessary to determine if the building’s structure can support generator with dunnage.

Gas supply

A new gas supply is required for the generator installation. A typical building has a 4” gas supply originating from utility that is broken up into (4-5) 1 ½” gas lines and routed to the apartments.

The utility company will need to be advised of additional gas load requirement from generators. The utility may have to upgrade site gas distribution. And as a result, the existing gas service to each building may need to be upgraded or a new dedicated gas line may need to be installed for the generator.

Calculation methodology

To determine the generator requirements, we first estimated the different building loads which are discussed below. It is important to note that before the implementation of any project, power meter readings are highly recommended to confirm a building's power requirements.

AC sizing:

The first item to take into consideration is the addition of an AC unit to the apartments. Depending on the size of the room and other improvements made to the building (performance of the facade), the indoor AC units can slightly vary. These range from 880W per unit down to 450 W. Since it is difficult to assess the different range of solutions, the installation of a single 880 W units per apartment will be assumed.

Apartment load:

Site visits to multiple NYCHA buildings revealed that a single feeder in a riser connects all the same "type" apartments in the line. This feeder could supply all the floors in high-rise buildings.

Surveying multiple NYCHA buildings has also demonstrated that a number of implemented retrofit projects have already added a dedicated power supply for window AC units to the apartments of other sites, proving that apartment panels can withstand the load increase.

For example, the original electrical drawings of Bethune Gardens show that the apartments were designed with roughly 3 kW capacity taking into account the site wide demand factor. However, electrical power consumption has increased over the years and it appears that the original feeder allowed for enough spare capacity.

Total building load:

Since peak metered demand readings were not available, we assumed that the building as a whole has enough capacity to cater for the increase in load due to the AC units - taking into consideration the worst case scenario where only AC units are required with the existing facade.

Regulations

The generator installation will need to comply with NFPA 110 (Standard for Emergency and Standby Power Systems) which details requirements for the installation, maintenance and testing of generators, depending on the type of generator. Basic requirements are that a generator be inspected weekly and test run for 30 minutes monthly.

New York City Electrical Code:

The framework for the electrical design will be based on the 2011 New York City Electrical Code. Per the Code, a generator must start within 10 seconds for emergency systems and 60 seconds for standby systems. Note that gas generators larger than 750kW may not be able to meet 10 second requirement.

For emergency/standby generators - 200 hours run time in addition to 100 hours of testing & maintenance is recommended. 50 hours of the 100 hours can be used for Demand Response Programs.

Design Flood Elevation:

Equipment will be located above the Design Flood Elevation per Local Law 100 and the design intent of Appendix G of the NYC Building Code. Section 304.1.1(5) of Appendix G requires, in all new and substantial improvements in residential buildings in Flood Zone A, utilities and equipment be located at or above the DFE. Section 7.2.4 of Appendix G, and as amended in Local Law 100, states that all disconnect switches and circuit breakers are to be located above and be accessible from the DFE.

Other applicable regulations:

Local Law 111 requires separate Automatic Transfer Switches (ATS) for emergency, legally required, and optional standby systems for the emergency/standby generator system.

Article 700.9 (B) of the National Electrical Code requires all emergency wiring to be kept separate from all other wiring.

According to Chapter 9 (Fire Protection Systems) of the 2014 New York City Building Code section 901.9.4 for alternations to buildings, a fire alarm system within the new MEP rooms will be required if the alternation is between 30% and 60% of the value of the building. If the alteration exceeds 60% of the value of the building, the entire building will need to comply with the latest fire alarm requirements.

Local Law 111 – Separates Life Safety, Legally Required, and Optional Standby systems. LL111 now requires three transfer switches. Previously two emergency and legally required loads were allowed to be combined into one transfer switch. LL111 also allows natural gas generators to be used in R-2 occupancies. Emergency lighting and fire alarm must be backed up. Buildings 125’ and above in height must have elevators connected to generator.

FDNY – requires fire alarm to have a separate transfer switch.

Exhibit C: Rough order of magnitude cost estimate

Basis of Pricing:

The cost estimate is classified as a Class 5 rough order of magnitude estimate according to Arup's estimate classification matrix (Level 5), which was developed from the Association for the Advancement of Cost Engineering (AACE) best practices. The accuracy range of this estimate has been determined to be -25% and +50%. The accuracy range is a gauge of likely bid prices if the project was issued to tender at this current stage.

Pricing shown reflects probable construction costs obtainable for replacement works on the date of this statement of probable costs. This estimate is a determination of fair market value for the construction of this project. It is not a prediction of low bid. Pricing assumes competitive bidding for every portion of the construction work for all subcontractors, that is to mean 4 to 5 bids. If fewer bids are received, bid results can be expected to be higher.

This document is based on the measurement and pricing of quantities wherever information is provided and/or reasonable assumptions for other works not covered in the drawings and programs as stated in this document. The unit rates reflected herein have been obtained from experience of projects of this nature.

Scope of Project:

NYCHA is interested in measures that could be put in place to allow its senior residents to shelter in place during a summer blackout. The senior residents will take refuge in their own homes during a summer blackout until the electric power is restored. To enable sheltering in place, the apartments should not get extremely hot and at a minimum, provide generator backup power to continue emergency and critical building operations.

The following cases were estimated for cost comparison purposes:

1. Two options: NYCECC 2016 compliant and High Performance scenario
2. A corner and a center location apartment scenarios
3. A critical / base and a 100% electrical backup scenarios are estimated
4. For the electrical backup, three locations for generator and electrical equipment

Scope of Works:

The scope of this cost estimate includes for the followings work:

- Envelope the exterior wall of apartment
- Envelope the Roof of the apartment
- Apply fenestration U-factor to the apartment's windows
- Install infiltration and shading devices in apartments
- Install new cooling / air conditioning units in the apartments
- Supply and install a Electrical Backup system, includes:
- Generator 350kW for critical backup and 500kW for 100% backup
- Sound attenuated enclosure
- Low Voltage Switchboard enclosures
- Main and Feeder circuit breakers
- Electrical feeders
- Build a new electrical room for Electrical Backup system
- Cabling, connections, testing and commissioning

Documentation:

Documentation prepared by Arup to develop this cost estimate.

Project Construction Schedule:

An overall construction duration has not been calculated for this exercise

Contractors Indirects Costs and Overhead and Profit:

Contractor's Indirects include the following allowances based on experience and approved by client:

- General Conditions and Site Management allowance of 15% of total direct construction cost, includes temporary office expenses, safety training, temporary power, tools and consumables, clean up and protection.
- General Requirements allowance of 10%, includes construction staff costs
- An allowance of 2.5% is considered as Bonds and Insurances
- An allowance of 10% is considered as the General Contractor's fees.

Escalation:

Escalation allowance is excluded in this estimate

Other Additions

An allowance of 25% is considered as project contingency due to the lack of design details.

Assumptions

- No major civil works otherwise stated
- Materials Cost based NYCHA's experience, and databases such as RS Means and electrical equipment vendors
- The crew labor unit is obtained from the NECA manual of labor units, contractor's insights and past experiences
- A 15% allowance of the material and crew cost is considered as sub contractor overhead and profit

Items excluded from the Cost Estimate

- The costs or impacts of latent environmental issues that result in litigations or development delays
- Owner's contingency
- Planning and inquiry costs, including legal expenses and fees
- Local planning obligations and agreements
- Site investigation

- Local taxes and duties
- Right-of-way and or land acquisition costs
- Risk-based contingency analysis
- Tests and inspections performed by others, apart from that listed in the estimate
- Program management and construction management costs
- Compensatory costs to other interested parties
- Cost benefits and impacts associated with improvements in construction technology, more severe regulatory requirements, and future construction that may impact the work contemplated under this project
- Removal and disposal of hazardous materials, unless otherwise stated in the cost estimate
- Electrical integration to the building management or communication systems
- Structural costs otherwise stated
- Consultant fees
- Owners Costs
- Preliminary Engineering costs
- Detailed Engineering costs
- Escalation allowance

Items that may affect the cost estimate

Modifications to the scope of work included in this estimate.

Special phasing requirements.

Restrictive technical specifications or excessive contract conditions.

Any other non-competitive bid situations.

Bids delayed beyond the projected schedule.

Loss of labor productivity

Statements of Probable Cost

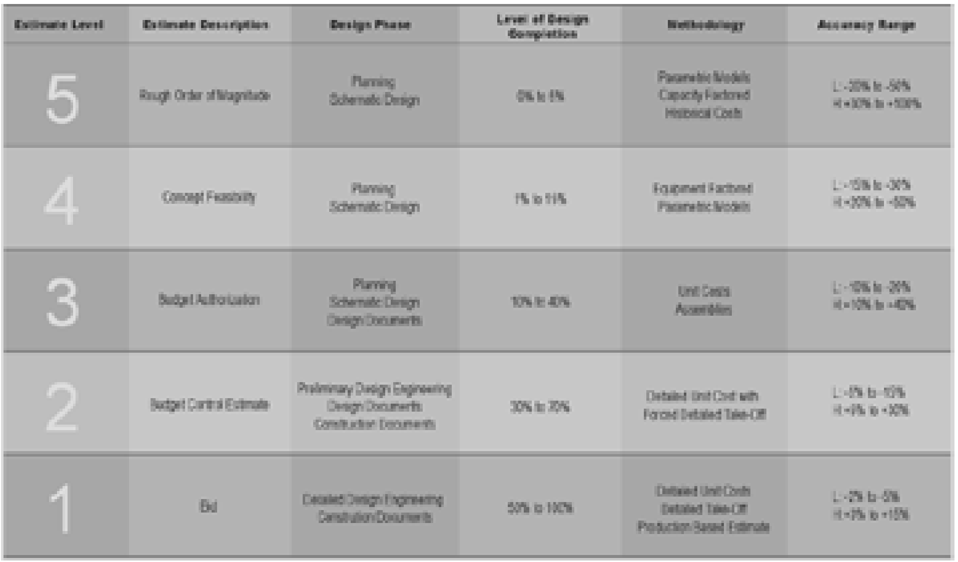
Arup has no control over the cost of labor and materials, general contractor's or any subcontractor's method of determining prices, or competitive bidding and market conditions. This opinion of probable cost of construction is made on the basis of the experience, qualifications, and best judgment of the professional consultant familiar with the construction industry. Arup cannot and does not guarantee that proposals, bids, or actual construction costs will not vary from this or subsequent cost estimates.

Recommendation for Cost Control

Arup recommends that the Owner carefully review this document, including line item descriptions, unit prices, clarifications, exclusions, inclusions and assumptions, contingencies, escalation and markups. If the project is over budget, or if there are unresolved budgeting issues, alternate systems schemes should be evaluated before proceeding into the construction phase.

Request for Modifications

Requests for modifications of any apparent errors or omissions to this document must be made to Arup within thirty (30) days of receipt of this estimate. Otherwise, it will be understood that the contents have been concurred with and accepted.

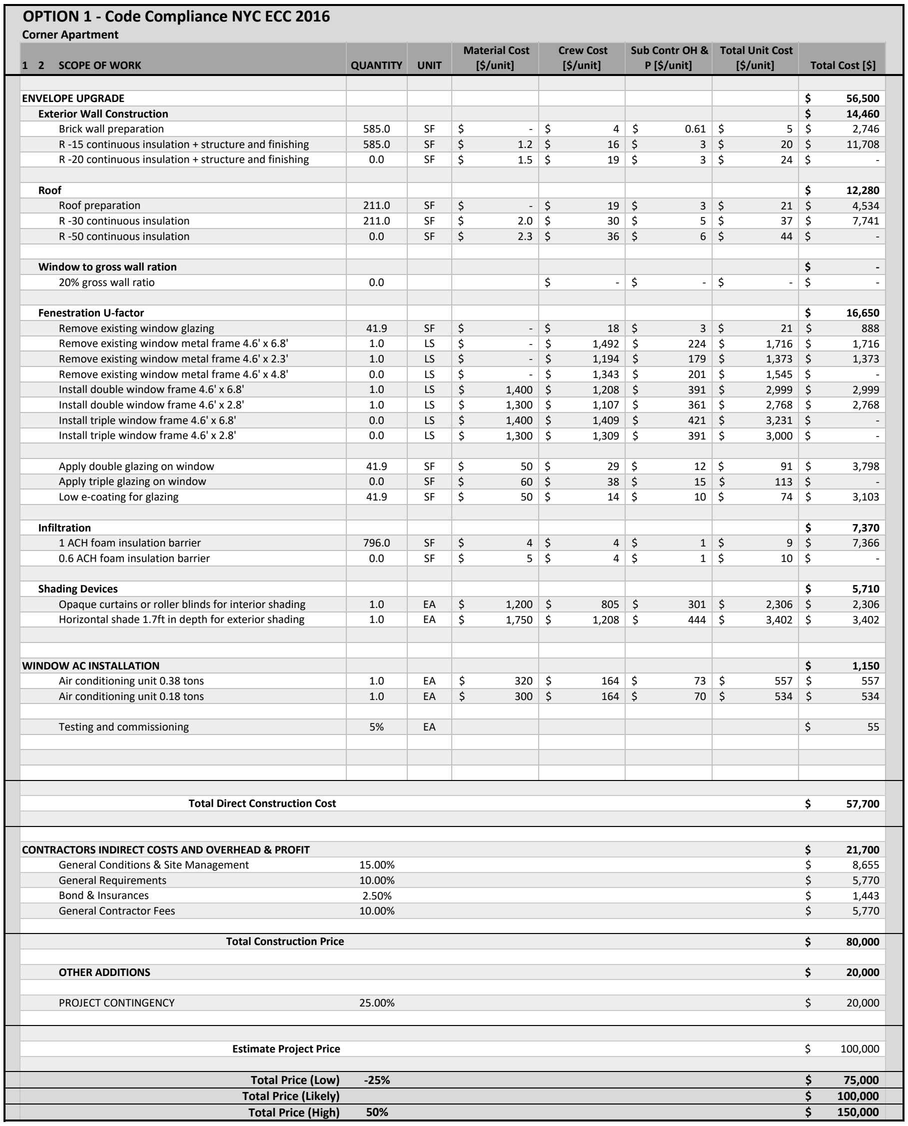


Estimate Level	Estimate Description	Design Phase	Level of Design Completion	Methodology	Accuracy Range
5	Rough Order of Magnitude	Planning Schematic Design	0% to 2%	Parametric Models Capacity Factored Historical Costs	L: -20% to -50% H: +30% to +100%
4	Concept Feasibility	Planning Schematic Design	1% to 15%	Equipment Factored Parametric Models	L: -15% to -30% H: +20% to +50%
3	Budget Authorization	Planning Schematic Design Design Documents	10% to 40%	Unit Costs Assemblies	L: -10% to -20% H: +10% to +30%
2	Budget Control Estimate	Preliminary Design Engineering Design Documents Construction Documents	30% to 70%	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%
1	Bid	Detailed Design Engineering Construction Documents	50% to 100%	Detailed Unit Costs Detailed Take-Off Production Based Estimate	L: -3% to -5% H: +3% to +15%

Estimate Classification Matrix

Detailed Estimates

Corner apartment, 2016 NYCECC compliant case

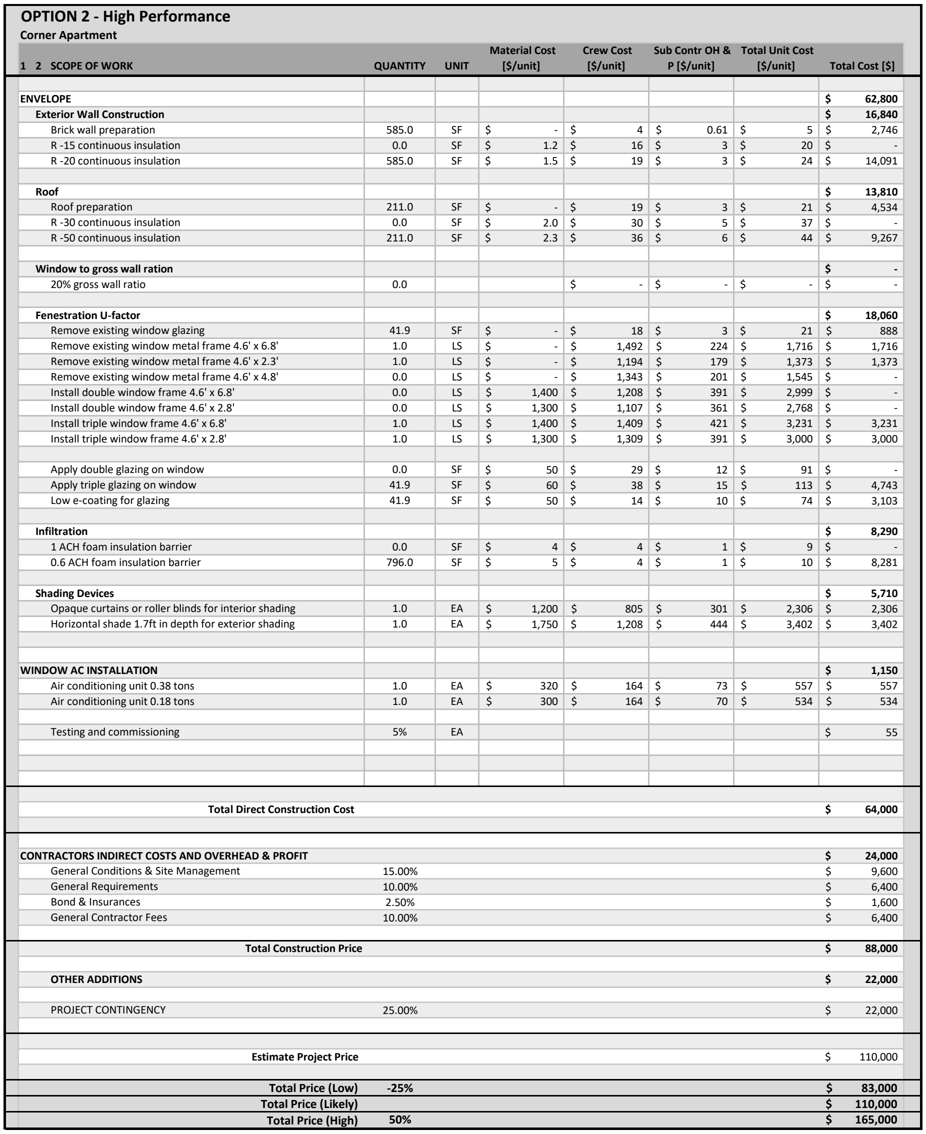


OPTION 1 - Code Compliance NYC ECC 2016

Corner Apartment

1 2 SCOPE OF WORK	QUANTITY	UNIT	Material Cost [$/unit]	Crew Cost [$/unit]	Sub Contr OH & P [$/unit]	Total Unit Cost [$/unit]	Total Cost [$]
ENVELOPE UPGRADE							**$ 56,500**
Exterior Wall Construction							**$ 14,460**
Brick wall preparation	585.0	SF	$ -	$ 4	$ 0.61	$ 5	$ 2,746
R -15 continuous insulation + structure and finishing	585.0	SF	$ 1.2	$ 16	$ 3	$ 20	$ 11,708
R -20 continuous insulation + structure and finishing	0.0	SF	$ 1.5	$ 19	$ 3	$ 24	$ -
Roof							**$ 12,280**
Roof preparation	211.0	SF	$ -	$ 19	$ 3	$ 21	$ 4,534
R -30 continuous insulation	211.0	SF	$ 2.0	$ 30	$ 5	$ 37	$ 7,741
R -50 continuous insulation	0.0	SF	$ 2.3	$ 36	$ 6	$ 44	$ -
Window to gross wall ration							**$ -**
20% gross wall ratio	0.0			$ -	$ -	$ -	$ -
Fenestration U-factor							**$ 16,650**
Remove existing window glazing	41.9	SF	$ -	$ 18	$ 3	$ 21	$ 888
Remove existing window metal frame 4.6' x 6.8'	1.0	LS	$ -	$ 1,492	$ 224	$ 1,716	$ 1,716
Remove existing window metal frame 4.6' x 2.3'	1.0	LS	$ -	$ 1,194	$ 179	$ 1,373	$ 1,373
Remove existing window metal frame 4.6' x 4.8'	0.0	LS	$ -	$ 1,343	$ 201	$ 1,545	$ -
Install double window frame 4.6' x 6.8'	1.0	LS	$ 1,400	$ 1,208	$ 391	$ 2,999	$ 2,999
Install double window frame 4.6' x 2.8'	1.0	LS	$ 1,300	$ 1,107	$ 361	$ 2,768	$ 2,768
Install triple window frame 4.6' x 6.8'	0.0	LS	$ 1,400	$ 1,409	$ 421	$ 3,231	$ -
Install triple window frame 4.6' x 2.8'	0.0	LS	$ 1,300	$ 1,309	$ 391	$ 3,000	$ -
Apply double glazing on window	41.9	SF	$ 50	$ 29	$ 12	$ 91	$ 3,798
Apply triple glazing on window	0.0	SF	$ 60	$ 38	$ 15	$ 113	$ -
Low e-coating for glazing	41.9	SF	$ 50	$ 14	$ 10	$ 74	$ 3,103
Infiltration							**$ 7,370**
1 ACH foam insulation barrier	796.0	SF	$ 4	$ 4	$ 1	$ 9	$ 7,366
0.6 ACH foam insulation barrier	0.0	SF	$ 5	$ 4	$ 1	$ 10	$ -
Shading Devices							**$ 5,710**
Opaque curtains or roller blinds for interior shading	1.0	EA	$ 1,200	$ 805	$ 301	$ 2,306	$ 2,306
Horizontal shade 1.7ft in depth for exterior shading	1.0	EA	$ 1,750	$ 1,208	$ 444	$ 3,402	$ 3,402
WINDOW AC INSTALLATION							**$ 1,150**
Air conditioning unit 0.38 tons	1.0	EA	$ 320	$ 164	$ 73	$ 557	$ 557
Air conditioning unit 0.18 tons	1.0	EA	$ 300	$ 164	$ 70	$ 534	$ 534
Testing and commissioning	5%	EA					$ 55
Total Direct Construction Cost							**$ 57,700**
CONTRACTORS INDIRECT COSTS AND OVERHEAD & PROFIT							**$ 21,700**
General Conditions & Site Management	15.00%						$ 8,655
General Requirements	10.00%						$ 5,770
Bond & Insurances	2.50%						$ 1,443
General Contractor Fees	10.00%						$ 5,770
Total Construction Price							**$ 80,000**
OTHER ADDITIONS							**$ 20,000**
PROJECT CONTINGENCY	25.00%						$ 20,000
Estimate Project Price							$ 100,000
Total Price (Low)	**-25%**						**$ 75,000**
Total Price (Likely)							**$ 100,000**
Total Price (High)	**50%**						**$ 150,000**

Corner apartment, high performance case



OPTION 2 - High Performance

Corner Apartment

1 2 SCOPE OF WORK	QUANTITY	UNIT	Material Cost [$/unit]	Crew Cost [$/unit]	Sub Contr OH & P [$/unit]	Total Unit Cost [$/unit]	Total Cost [$]
ENVELOPE							**$ 62,800**
Exterior Wall Construction							**$ 16,840**
Brick wall preparation	585.0	SF	$ -	$ 4	$ 0.61	$ 5	$ 2,746
R -15 continuous insulation	0.0	SF	$ 1.2	$ 16	$ 3	$ 20	$ -
R -20 continuous insulation	585.0	SF	$ 1.5	$ 19	$ 3	$ 24	$ 14,091
Roof							**$ 13,810**
Roof preparation	211.0	SF	$ -	$ 19	$ 3	$ 21	$ 4,534
R -30 continuous insulation	0.0	SF	$ 2.0	$ 30	$ 5	$ 37	$ -
R -50 continuous insulation	211.0	SF	$ 2.3	$ 36	$ 6	$ 44	$ 9,267
Window to gross wall ration							**$ -**
20% gross wall ratio	0.0			$ -	$ -	$ -	$ -
Fenestration U-factor							**$ 18,060**
Remove existing window glazing	41.9	SF	$ -	$ 18	$ 3	$ 21	$ 888
Remove existing window metal frame 4.6' x 6.8'	1.0	LS	$ -	$ 1,492	$ 224	$ 1,716	$ 1,716
Remove existing window metal frame 4.6' x 2.3'	1.0	LS	$ -	$ 1,194	$ 179	$ 1,373	$ 1,373
Remove existing window metal frame 4.6' x 4.8'	0.0	LS	$ -	$ 1,343	$ 201	$ 1,545	$ -
Install double window frame 4.6' x 6.8'	0.0	LS	$ 1,400	$ 1,208	$ 391	$ 2,999	$ -
Install double window frame 4.6' x 2.8'	0.0	LS	$ 1,300	$ 1,107	$ 361	$ 2,768	$ -
Install triple window frame 4.6' x 6.8'	1.0	LS	$ 1,400	$ 1,409	$ 421	$ 3,231	$ 3,231
Install triple window frame 4.6' x 2.8'	1.0	LS	$ 1,300	$ 1,309	$ 391	$ 3,000	$ 3,000
Apply double glazing on window	0.0	SF	$ 50	$ 29	$ 12	$ 91	$ -
Apply triple glazing on window	41.9	SF	$ 60	$ 38	$ 15	$ 113	$ 4,743
Low e-coating for glazing	41.9	SF	$ 50	$ 14	$ 10	$ 74	$ 3,103
Infiltration							**$ 8,290**
1 ACH foam insulation barrier	0.0	SF	$ 4	$ 4	$ 1	$ 9	$ -
0.6 ACH foam insulation barrier	796.0	SF	$ 5	$ 4	$ 1	$ 10	$ 8,281
Shading Devices							**$ 5,710**
Opaque curtains or roller blinds for interior shading	1.0	EA	$ 1,200	$ 805	$ 301	$ 2,306	$ 2,306
Horizontal shade 1.7ft in depth for exterior shading	1.0	EA	$ 1,750	$ 1,208	$ 444	$ 3,402	$ 3,402
WINDOW AC INSTALLATION							**$ 1,150**
Air conditioning unit 0.38 tons	1.0	EA	$ 320	$ 164	$ 73	$ 557	$ 557
Air conditioning unit 0.18 tons	1.0	EA	$ 300	$ 164	$ 70	$ 534	$ 534
Testing and commissioning	5%	EA					$ 55
Total Direct Construction Cost							**$ 64,000**
CONTRACTORS INDIRECT COSTS AND OVERHEAD & PROFIT							**$ 24,000**
General Conditions & Site Management	15.00%						$ 9,600
General Requirements	10.00%						$ 6,400
Bond & Insurances	2.50%						$ 1,600
General Contractor Fees	10.00%						$ 6,400
Total Construction Price							**$ 88,000**
OTHER ADDITIONS							**$ 22,000**
PROJECT CONTINGENCY	25.00%						$ 22,000
Estimate Project Price							$ 110,000
Total Price (Low)	**-25%**						**$ 83,000**
Total Price (Likely)							**$ 110,000**
Total Price (High)	**50%**						**$ 165,000**

Center apartment, 2016 NYCECC compliant case

OPTION 3 - Code Compliance NYC ECC 2016

Center Building Apartment

1 2 SCOPE OF WORK	QUANTITY	UNIT	Material Cost [$/unit]	Crew Cost [$/unit]	Sub Contr OH & P [$/unit]	Total Unit Cost [$/unit]	Total Cost [$]
ENVELOPE							**$ 43,100**
Exterior Wall Construction							**$ 10,820**
Brick wall preparation	403.2	SF	$ -	$ 6	$ 0.89	$ 7	$ 2,746
R -15 continuous insulation	403.2	SF	$ 1.2	$ 16	$ 3	$ 20	$ 8,071
R -20 continuous insulation	0.0	SF	$ 1.5	$ 19	$ 3	$ 24	$ -
Roof							**$ 8,100**
Roof preparation	139.1	SF	$ -	$ 19	$ 3	$ 21	$ 2,989
R -30 continuous insulation	139.1	SF	$ 2.0	$ 30	$ 5	$ 37	$ 5,102
R -50 continuous insulation	0.0	SF	$ 2.3	$ 36	$ 6	$ 44	$ -
Window to gross wall ration							**$ -**
20% gross wall ratio	0.0			$ -	$ -	$ -	$ -
Fenestration U-factor							**$ 13,400**
Remove existing window glazing	22.2	SF	$ -	$ 35	$ 5	$ 40	$ 888
Remove existing window metal frame 4.6' x 6.8'	1.0	LS	$ -	$ 1,492	$ 224	$ 1,716	$ 1,716
Remove existing window metal frame 4.6' x 2.3'	1.0	LS	$ -	$ 1,194	$ 179	$ 1,373	$ 1,373
Remove existing window metal frame 4.6' x 4.8'	0.0	LS	$ -	$ 1,343	$ 201	$ 1,545	$ -
Install double window frame 4.6' x 6.8'	1.0	LS	$ 1,400	$ 1,208	$ 391	$ 2,999	$ 2,999
Install double window frame 4.6' x 2.8'	1.0	LS	$ 1,300	$ 1,107	$ 361	$ 2,768	$ 2,768
Install triple window frame 4.6' x 6.8'	0.0	LS	$ 1,400	$ 1,409	$ 421	$ 3,231	$ -
Install triple window frame 4.6' x 2.8'	0.0	LS	$ 1,300	$ 1,309	$ 391	$ 3,000	$ -
Apply double glazing on window	22.2	SF	$ 50	$ 29	$ 12	$ 91	$ 2,008
Apply triple glazing on window	0.0	SF	$ 60	$ 38	$ 15	$ 113	$ -
Low e-coating for glazing	22.2	SF	$ 50	$ 14	$ 10	$ 74	$ 1,641
Infiltration							**$ 5,020**
1 ACH foam insulation barrier	542.3	SF	$ 4	$ 4	$ 1	$ 9	$ 5,018
0.6 ACH foam insulation barrier	0.0	SF	$ 5	$ 4	$ 1	$ 10	$ -
Shading Devices							**$ 5,710**
Opaque curtains or roller blinds for interior shading	1.0	EA	$ 1,200	$ 805	$ 301	$ 2,306	$ 2,306
Horizontal shade 1.7ft in depth for exterior shading	1.0	EA	$ 1,750	$ 1,208	$ 444	$ 3,402	$ 3,402
WINDOW AC INSTALLATION							**$ 1,150**
Air conditioning unit 0.38 tons	1.0	EA	$ 320	$ 164	$ 73	$ 557	$ 557
Air conditioning unit 0.18 tons	1.0	EA	$ 300	$ 164	$ 70	$ 534	$ 534
Testing and commissioning	5%	EA					$ 55
Total Direct Construction Cost							**$ 44,300**
CONTRACTORS INDIRECT COSTS AND OVERHEAD & PROFIT							**$ 16,700**
General Conditions & Site Management	15.00%						$ 6,645
General Requirements	10.00%						$ 4,430
Bond & Insurances	2.50%						$ 1,108
General Contractor Fees	10.00%						$ 4,430
Total Construction Price							**$ 61,000**
OTHER ADDITIONS							**$ 15,300**
PROJECT CONTINGENCY	25.00%						$ 15,250
Estimate Project Price							$ 76,300
Total Price (Low)	**-25%**						**$ 57,000**
Total Price (Likely)							**$ 76,000**
Total Price (High)	**50%**						**$ 114,000**

Center apartment, high performance case

OPTION 4 - High Performance

Center Building Apartment

1 2 SCOPE OF WORK	QUANTITY	UNIT	Material Cost [$/unit]	Crew Cost [$/unit]	Sub Contr OH & P [$/unit]	Total Unit Cost [$/unit]	Total Cost [$]
ENVELOPE							**$ 47,300**
Exterior Wall Construction							**$ 12,460**
Brick wall preparation	403.2	SF	$ -	$ 6	$ 0.89	$ 7	$ 2,746
R -15 continuous insulation	0.0	SF	$ 1.2	$ 16	$ 3	$ 20	$ -
R -20 continuous insulation	403.2	SF	$ 1.5	$ 19	$ 3	$ 24	$ 9,713
Roof							**$ 9,100**
Roof preparation	139.1	SF	$ -	$ 19	$ 3	$ 21	$ 2,989
R -30 continuous insulation	0.0	SF	$ 2.0	$ 30	$ 5	$ 37	$ -
R -50 continuous insulation	139.1	SF	$ 2.3	$ 36	$ 6	$ 44	$ 6,109
Window to gross wall ration							**$ -**
20% gross wall ratio	0.0			$ -	$ -	$ -	$ -
Fenestration U-factor							**$ 14,360**
Remove existing window glazing	22.2	SF	$ -	$ 35	$ 5	$ 40	$ 888
Remove existing window metal frame 4.6' x 6.8'	1.0	LS	$ -	$ 1,492	$ 224	$ 1,716	$ 1,716
Remove existing window metal frame 4.6' x 2.3'	1.0	LS	$ -	$ 1,194	$ 179	$ 1,373	$ 1,373
Remove existing window metal frame 4.6' x 4.8'	0.0	LS	$ -	$ 1,343	$ 201	$ 1,545	$ -
Install double window frame 4.6' x 6.8'	0.0	LS	$ 1,400	$ 1,208	$ 391	$ 2,999	$ -
Install double window frame 4.6' x 2.8'	0.0	LS	$ 1,300	$ 1,107	$ 361	$ 2,768	$ -
Install triple window frame 4.6' x 6.8'	1.0	LS	$ 1,400	$ 1,409	$ 421	$ 3,231	$ 3,231
Install triple window frame 4.6' x 2.8'	1.0	LS	$ 1,300	$ 1,309	$ 391	$ 3,000	$ 3,000
Apply double glazing on window	0.0	SF	$ 50	$ 29	$ 12	$ 91	$ -
Apply triple glazing on window	22.2	SF	$ 60	$ 38	$ 15	$ 113	$ 2,508
Low e-coating for glazing	22.2	SF	$ 50	$ 14	$ 10	$ 74	$ 1,641
Infiltration							**$ 5,650**
1 ACH foam insulation barrier	0.0	SF	$ 4	$ 4	$ 1	$ 9	$ -
0.6 ACH foam insulation barrier	542.3	SF	$ 5	$ 4	$ 1	$ 10	$ 5,642
Shading Devices							**$ 5,710**
Opaque curtains or roller blinds for interior shading	1.0	EA	$ 1,200	$ 805	$ 301	$ 2,306	$ 2,306
Horizontal shade 1.7ft in depth for exterior shading	1.0	EA	$ 1,750	$ 1,208	$ 444	$ 3,402	$ 3,402
WINDOW AC INSTALLATION							**$ 1,150**
Air conditioning unit 0.38 tons	1.0	EA	$ 320	$ 164	$ 73	$ 557	$ 557
Air conditioning unit 0.18 tons	1.0	EA	$ 300	$ 164	$ 70	$ 534	$ 534
Testing and commissioning	5%	EA					$ 55
Total Direct Construction Cost							**$ 48,500**
CONTRACTORS INDIRECT COSTS AND OVERHEAD & PROFIT							**$ 18,200**
General Conditions & Site Management	15.00%						$ 7,275
General Requirements	10.00%						$ 4,850
Bond & Insurances	2.50%						$ 1,213
General Contractor Fees	10.00%						$ 4,850
Total Construction Price							**$ 67,000**
OTHER ADDITIONS							**$ 16,800**
PROJECT CONTINGENCY	25.00%						$ 16,750
Estimate Project Price							$ 83,800
Total Price (Low)	**-25%**						**$ 63,000**
Total Price (Likely)							**$ 84,000**
Total Price (High)	**50%**						**$ 126,000**

Critical systems backup

ELECTRICAL - Critical System Backup

1 2 SCOPE OF WORK	QUANTITY	UNIT	Total Unit Cost [$/unit]	Total Cost [$]
Ground Location				**$ 333,000**
Electrical Equipment				
Generator 350kW, 625kVA, natural gas, (critical system backup)	1	EA	$ 86,096	$ 86,096
Sound attenuated enclosure for 350kW generator	1	EA	$ 12,914	$ 12,914
1600A 120/208V main board with 4 sections	1	EA	$ 25,585	$ 25,585
Cooper feeder 3 sets of 4* 500MCM	50	FT	$ 76	$ 3,808
3 sets of 4" RMC Conduit, includes couplings and fitting	50	FT	$ 276	$ 13,811
Circuit Breaker 800A 120/208V	6	EA	$ 6,544	$ 39,263
Circuit Breaker 400A 120/208V	6	EA	$ 3,694	$ 22,162
Circuit Breaker 200A 120/208V	12	EA	$ 2,346	$ 28,150
Cooper feeder 2 sets of 4* 500MCM	50	FT	$ 51	$ 2,539
2 sets of 4" RMC Conduit, includes couplings and fitting	50	FT	$ 184	$ 9,207
LV Distribution Panel, 800A main breaker	3	EA	$ 8,811	$ 26,432
Gas supply 1 1/2" pipe	50	FT	$ 23	$ 1,150
Testing and commissioning	5%	EA		$ 12,853
Electrical Room				
Build Emergency Electrical Room	300	SF	$ 150	$ 44,850
Excavation and site preparation	11.1	CY	$ 43	$ 473
Concrete Slab	300	SF	$ 12	$ 3,450
Structural support for electrical equipment	0	LS	$ 2,875	$ -
20 ton crane	0	HR	$ 125	$ -
Generator on roof, electrical ground				**$ 444,000**
Electrical Equipment				
Generator 350kW, 625kVA, natural gas, (critical system backup)	1	EA	$ 86,096	$ 86,095.72
Sound attenuated enclosure for 350kW generator	1	EA	$ 12,914	$ 12,914.36
1600A 120/208V main board with 4 sections	1	EA	$ 25,585	$ 25,585.20
Cooper feeder 3 sets of 4* 500MCM	200	FT	$ 76	$ 15,231.12
3 sets of 4" RMC Conduit, includes couplings and fitting	200	FT	$ 276	$ 55,242.57
Circuit Breaker 800A 120/208V	6	EA	$ 6,544	$ 39,263.48
Circuit Breaker 400A 120/208V	6	EA	$ 3,694	$ 22,162.36
Circuit Breaker 200A 120/208V	12	EA	$ 2,346	$ 28,149.79
Cooper feeder 2 sets of 4* 500MCM	250	FT	$ 51	$ 12,692.60
2 sets of 4" RMC Conduit, includes couplings and fitting	250	FT	$ 184	$ 46,035.47
LV Distribution Panel, 800A main breaker	3	EA	$ 8,811	$ 26,432
Gas supply 1 1/2" pipe	200	FT	$ 23	$ 4,600
Testing and commissioning	5%	EA		$ 17,844
Electrical Room				
Build Emergency Electrical Room	300	SF	$ 150	$ 44,850
Excavation and site preparation	5.6	CY	$ 43	$ 236
Concrete Slab	150	SF	$ 12	$ 1,725
Structural support for electrical equipment	1	LS	$ 2,875	$ 2,875
20 ton crane	16	HR	$ 125	$ 2,000
Roof Location				**$ 450,000**
Electrical Equipment				
Generator 350kW, 625kVA, natural gas, (critical system backup)	1	EA	$ 86,096	$ 86,096
Sound attenuated enclosure for 350kW generator	1	EA	$ 12,914	$ 12,914
1600A 120/208V main board with 4 sections	1	EA	$ 25,585	$ 25,585
Cooper feeder 3 sets of 4* 500MCM	250	FT	$ 76	$ 19,039
3 sets of 4" RMC Conduit, includes couplings and fitting	250	FT	$ 276	$ 69,053
Circuit Breaker 800A 120/208V	6	EA	$ 6,544	$ 39,263
Circuit Breaker 400A 120/208V	6	EA	$ 3,694	$ 22,162
Circuit Breaker 200A 120/208V	12	EA	$ 2,346	$ 28,150
Cooper feeder 2 sets of 4* 500MCM	200	FT	$ 51	$ 10,154
2 sets of 4" RMC Conduit, includes couplings and fitting	200	FT	$ 184	$ 36,828
LV Distribution Panel, 800A main breaker	3	EA	$ 8,811	$ 26,432
Gas supply 1 1/2" pipe	250	FT	$ 23	$ 5,750
Testing and commissioning	5%	EA		$ 18,138
Electrical Room				
Build Emergency Electrical Room	300	SF	$ 150	$ 44,850
Excavation and site preparation	0.0	CY	$ 43	$ -
Concrete Slab	0	SF	$ 12	$ -
Structural support for electrical equipment	1	LS	$ 2,875	$ 2,875
20 ton crane	16	HR	$ 125	$ 2,000

100% backup

ELECTRICAL - 100% System Backup

1 2 SCOPE OF WORK	QUANTITY	UNIT	Total Unit Cost [$/unit]	Total Cost [$]
Ground Location				**$ 396,000**
Electrical Equipment				
Generator 500kW, 625kVA, natural gas, (100% backup)	1	EA	$ 118,748	$ 118,748
Sound attenuated enclosure for 500kW generator	1	EA	$ 17,812	$ 17,812
2400A 120/208V main board with 4 sections	1	EA	$ 29,995	$ 29,995
Cooper feeder 6 sets of 4* 500MCM	50	FT	$ 152	$ 7,616
6 sets of 4" RMC Conduit, includes couplings and fitting	50	FT	$ 552	$ 27,621
Circuit Breaker 800A 120/208V	6	EA	$ 6,544	$ 39,263
Circuit Breaker 400A 120/208V	6	EA	$ 3,694	$ 22,162
Circuit Breaker 200A 120/208V	12	EA	$ 2,346	$ 28,150
Cooper feeder 2 sets of 4* 500MCM	50	FT	$ 51	$ 2,539
2 sets of 4" RMC Conduit, includes couplings and fitting	50	FT	$ 184	$ 9,207
LV Distribution Panel, 800A main breaker	3	EA	$ 8,811	$ 26,432
Gas supply 1 1/2" pipe	50	FT	$ 23	$ 1,150
Testing and commissioning	5%	EA		$ 15,587
Electrical Room				
Build Emergency Electrical Room	300	SF	$ 150	$ 44,850
Excavation and site preparation	11.1	CY	$ 43	$ 473
Concrete Slab	300	SF	$ 12	$ 3,450
Structural support for electrical equipment	0	LS	$ 2,875	$ -
20 ton crane	0	HR	$ 125	$ -
Generator on roof, electrical ground				**$ 562,000**
Electrical Equipment				
Generator 500kW, 625kVA, natural gas, (100% backup)	1	EA	$ 118,748	$ 118,748
Sound attenuated enclosure for 500kW generator	1	EA	$ 17,812	$ 17,812
2400A 120/208V main board with 4 sections	1	EA	$ 29,995	$ 29,995
Cooper feeder 6 sets of 4* 500MCM	200	FT	$ 152	$ 30,462
6 sets of 4" RMC Conduit, includes couplings and fitting	200	FT	$ 552	$ 110,485
Circuit Breaker 800A 120/208V	6	EA	$ 6,544	$ 39,263
Circuit Breaker 400A 120/208V	6	EA	$ 3,694	$ 22,162
Circuit Breaker 200A 120/208V	12	EA	$ 2,346	$ 28,150
Cooper feeder 2 sets of 4* 500MCM	250	FT	$ 51	$ 12,693
2 sets of 4" RMC Conduit, includes couplings and fitting	250	FT	$ 184	$ 46,035
LV Distribution Panel, 800A main breaker	3	EA	$ 8,811	$ 26,432
Gas supply 1 1/2" pipe	200	FT	$ 23	$ 4,600
Testing and commissioning	5%	EA		$ 23,221
Electrical Room				
Build Emergency Electrical Room	300	SF	$ 150	$ 44,850
Excavation and site preparation	5.6	CY	$ 43	$ 236
Concrete Slab	150	SF	$ 12	$ 1,725
Structural support for electrical equipment	1	LS	$ 2,875	$ 2,875
20 ton crane	16	HR	$ 125	$ 2,000
Roof Location				**$ 586,000**
Electrical Equipment				
Generator 500kW, 625kVA, natural gas, (100% backup)	1	EA	$ 118,748	$ 118,748
Sound attenuated enclosure for 500kW generator	1	EA	$ 17,812	$ 17,812
2400A 120/208V main board with 4 sections	1	EA	$ 29,995	$ 29,995
Cooper feeder 6 sets of 4* 500MCM	250	FT	$ 152	$ 38,078
6 sets of 4" RMC Conduit, includes couplings and fitting	250	FT	$ 552	$ 138,106
Circuit Breaker 800A 120/208V	6	EA	$ 6,544	$ 39,263
Circuit Breaker 400A 120/208V	6	EA	$ 3,694	$ 22,162
Circuit Breaker 200A 120/208V	12	EA	$ 2,346	$ 28,150
Cooper feeder 2 sets of 4* 500MCM	200	FT	$ 51	$ 10,154
2 sets of 4" RMC Conduit, includes couplings and fitting	200	FT	$ 184	$ 36,828
LV Distribution Panel, 800A main breaker	3	EA	$ 8,811	$ 26,432
Gas supply 1 1/2" pipe	250	FT	$ 23	$ 5,750
Testing and commissioning	5%	EA		$ 24,396
Electrical Room				
Build Emergency Electrical Room	300	SF	$ 150	$ 44,850
Excavation and site preparation	0.0	CY	$ 43	$ -
Concrete Slab	0	SF	$ 12	$ -
Structural support for electrical equipment	1	LS	$ 2,875	$ 2,875
20 ton crane	16	HR	$ 125	$ 2,000

Exhibit D: Heat Pump Background Information

An ASHP uses a working fluid (most commonly water or refrigerant) to transfer heat. This report focuses on refrigerant-based systems, which are closed loop and recommended for NYCHA's buildings. The refrigeration cycle is used to move heat in or out of spaces using fans, pumps, and pipes filled with refrigerant. In the summer, the equipment draws heat from inside the building and pumps it out; in the winter, it works in reverse.

A typical ASHP system is comprised of an outdoor section and an indoor section, each with a coil that exchanges heat with the surrounding air via a fan. One outdoor unit can serve one indoor unit, or many. The system uses a compressor to increase the temperature and pressure of the refrigerant that passes through it, and an expansion valve to do the opposite. Refrigerant can be pumped in either direction.

An ASHP system can be ducted or non-ducted. Non-ducted systems heat or cool spaces directly via an indoor fan coil unit, and only refrigerant pipes connect the outdoor and indoor units. These are split systems, with one coil inside and one coil outside. A ducted ASHP heats or cools air that is supplied to indoor spaces via a ducted distribution system, typically from an air handling unit. These are also called packaged systems, with both coils outside. Because NYCHA's buildings are primarily ventilated via windows rather than ducts, non-ducted systems are appropriate.

A third system type, packaged terminal air conditioners (PTAC), can be inserted in sleeves through the wall, similar to the way a standard in-wall air conditioning unit would be installed. These are commonly found in hotel rooms. Split systems are preferred to PTAC systems due to increased efficiency.

Two advanced types of ASHP are those that make use of variable refrigerant flow (VRF) technology, and those that provide heat recovery. VRF allows the refrigerant flow to vary using variable frequency drives and electronic expansion valves, increasing system efficiency. VRF systems with heat recovery capabilities add a third refrigerant line, which can be used to reuse heat extracted from cooled spaces in those with a heating demand. Heat recovery is favorable in a residential setting only if used to supply heat used for domestic water heating, or simultaneous heating and cooling between indoor units. This should be explored if a whole building's heating and cooling system is to be retrofitted.

In addition to being an electrified system, air source heat pumps (especially VRF systems) have a number of benefits. They are more efficient, less intrusive, and locally cleaner than gas alternatives. First and operating costs could be more or less than boilers, depending on the system size and ratio of electricity prices to natural gas prices.

They also have limits. Per New York City building codes, any heat pump system must meet ASHRAE standards 15 and 34, which set maximum refrigerant charges per volume of space served. This is not a problem when only a few apartments are served, but when a whole building is heated using heat pumps, this can force large outdoor units to be broken into smaller groups with independent refrigerant loops. If the building is tall enough, some of these groups must be placed on intermediate floors. There are also limits to the maximum linear length and vertical rise for each outdoor unit. An example of these limits is included in Appendix B. In colder climates, performance declines (because there is less heat to extract from the air). This is not a major concern in New York City's climate where low ambient kits can provide heating down to -4°F.

The recommended system type for a pilot retrofit project is a non-ducted VRF system. They are efficient and flexible, and can be used in any of the layout options presented in the next section.

Exhibit E: Full Building Selection Criteria

The purpose of a pilot project is to collect information. Smaller, standalone buildings (not served by a campus district heating system) are more desirable than

Criteria	Desired Characteristics	Measurement Parameter
Available meter data	15-minute interval meter data must be available to evaluate electrical capacity	15-minute interval data available (Y/N)
Electrical capacity	The existing electrical service should have capacity, preferably on an existing panel	Available capacity in building's electrical service (Y/N) Available capacity on electrical panels (Y/N) Available space for new panels (Y/N)
Electrical condition	New connections should not trigger more involved electrical retrofits	Electrical equipment in safe and working condition (Y/N)
Measurable energy reduction	Increase in electricity use and decrease in gas use should be measurable for pilot study; small enough to measure	Standalone building with own heating system (Y/N) Number of apartments
Metering strategy	Changes in energy should be measured; apartment-level submetering desired	Apartment-level submetering (Y/N) Separate meters for building heat and domestic hot water (DHW) (Y/N)
Minimized conduit & pipework distance	Vertical runs for refrigerant pipework and electrical conduit should be minimized	Vertical height of building, and distance of indoor and outdoor units
Avoided flood risk	New equipment should not be exposed to flooding	Feasible to place outdoor units on roof (Y/N) Point of electrical connection above flood plain (Y/N)
Structural capacity	Roof or façade is structurally capable of bearing new loads from outdoor units	Available capacity in roof structural elements (Y/N)

Minimized noise	Outdoor units should be located away from windows, preferably on the roof	Roof location possible (Y/N)
Internal space to run pipework and conduit	Aesthetically unappealing external runs should be minimized	Internal chase available (Y/N)
External space for outdoor units	Must have location to place outdoor units	Sufficient space available on roof, façade, or ground (Y/N)
Ability to remove the existing method of space heating from apartments	If partially retrofitting, output of existing heating system should be able to be removed	Control strategy for boiler Can remove supply of heat to retrofit apartments in steam/water distribution pipework (Y/N)
Efficiency of existing heating and cooling systems	Buildings with more inefficient systems should be prioritized	Boiler & hot water heater efficiency Boiler & hot water heater control methods
Solar PV potential	Large roof preferred to offset new loads with solar PV production	Total roof area available for solar
Overall building condition	Buildings expected to last longer should be prioritized for retrofits	Building age Observed conditions in building

campus buildings because changes in energy consumption are measurable. Even in standalone buildings, changes are likely to be small, and contingent on climate.

Although there are many buildings that could be good candidates, the driver in this case was the availability of 15-minute electrical interval data. That data is necessary to determine whether a building has excess electrical capacity. Electrical meters that show only monthly consumption convey only average building demand. Historical peak demand is needed. Five standalone buildings have this data:

- Atlantic Terminal Site 4B
- Fort Independence Street – Heath Avenue
- Shelton House
- Two Bridges Ura (Site 7)
- Twin Parks West (Sites 1 & 2)

NYCHA advised that the Twin Parks West (Sites 1 &2) development was not a preferred choice due to other project work onsite. The analysis proceeded with the remaining four buildings.

Exhibit F: Drawings Review

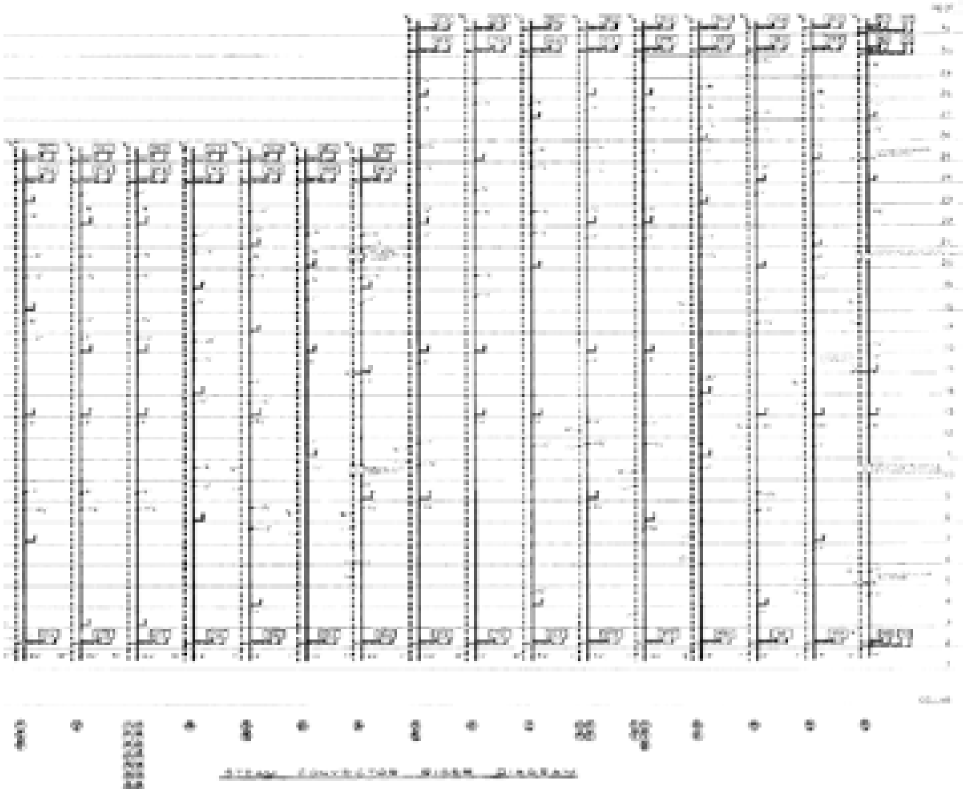
Prior to visiting any of the buildings, a desktop study was conducted to assess retrofit feasibility. Architectural, electrical, mechanical, and structural drawings were reviewed.

The mechanical desktop analysis focused on the two remaining feasible buildings, Fort Independence and Atlantic Terminal. The primary focus of the mechanical analysis was the feasibility of disrupting the supply of heat to the apartments concerned.

Atlantic Terminal

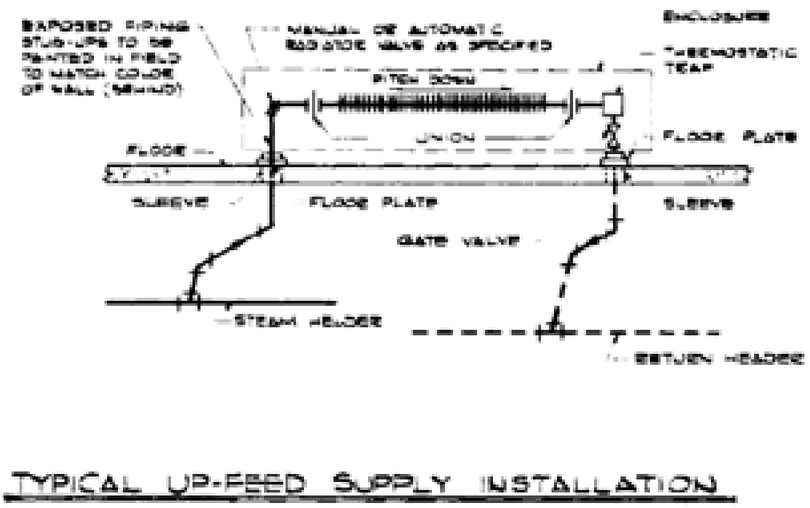
Atlantic Terminal is a 31-story building with two large, gas-fired steam boilers. Steam is first distributed throughout the first floor from pipes originating at the main steam header. From there, each "stack" of apartments is supplied by one steam riser. Supply and return are collocated, shown by solid and dotted lines respectively in the figure below.

To prevent the supply of steam to the apartments that will be served by the heat pump, the steam supply must be disrupted. By selecting apartments in a vertical



Atlantic Terminal Heating Riser Diagram

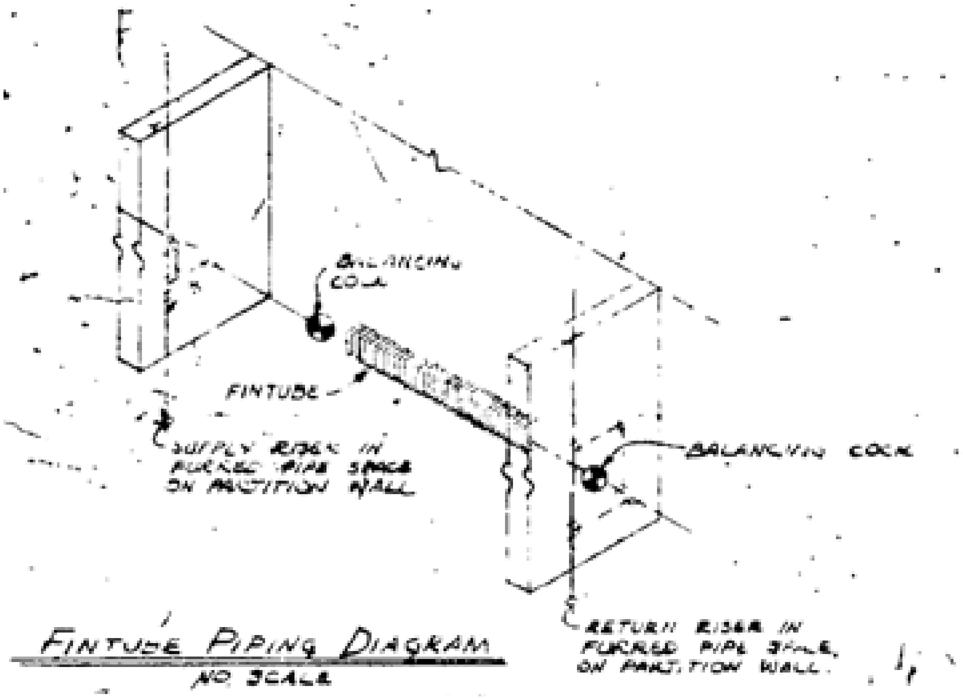
stack at the top of a riser, this disruption can be localized to one riser. The riser should be cut and capped just above the supply for the apartment below the bottommost one served by the heat pump (which will require cutting through plaster in an apartment wall). At that location, a new vent must be installed to prevent the creation of a vacuum in the return riser. Fintube radiators, shown in the figure below, should be removed, and pipes should be capped on either side.



Atlantic Terminal Radiator

Fort Independence

Fort Independence is a 21-story building that sits on a hill (apartments start on the 8th floor on the South side of the building). Heat and hot water demand is met using three gas-fired hydronic hot water boilers. Like Atlantic Terminal, heating pipes from the boiler are distributed throughout the first floor before turning upwards to supply apartments in a vertical stack. From each riser, water is passed through radiators in 1-2 apartments and down a return riser. To prevent the supply of hot water to these apartments, the radiators should be removed and the pipes on either side should be capped. The figure below shows a typical fintube radiator found in the building. Boiler set point will change automatically if controlled from return water temperature (this is expected, but should be confirmed).



Fort Independence Fintube Radiator

Retrofitting either building is mechanically feasible, but Fort Independence is preferred due to the logistically simpler retrofit process. The steam system requires capping the riser and installing a new vent, which is not required of the hydronic heating system at Fort Independence.

A typical outdoor unit for a system of this size will weigh up to 600 pounds, and has a footprint of roughly 10 square feet. This load is fairly small, and either building's roof should be able to support it. Structural capacity was not used as a deciding factor between the two buildings.

Exhibit G: Electric Meter Data Analysis

From an electrical infrastructure standpoint, there are mainly two (2) criteria that will determine which buildings are better candidates for the this project: metered data coupled with record drawings effectively demonstrating the capacity of the building to accommodate a new electrical load and the building's current electrical infrastructure and options it offers for a physical connection.

The first step for the selection is analyzing the metered data to determine the utilization of the building's existing electrical infrastructure. Without any available data, it is difficult to adequately determine if a building is suitable for the retrofit project or not. For this reason, only buildings for which metered readings were available have been retained as suitable candidates.

The metered data shows that readings were taken at an interval of 15 minutes since the installation of the meter. This short interval between readings creates a large amount of data and allows for a better understand of the building's operation while capturing any spikes of power usage that could be otherwise missed with a larger interval. To account for the worst case scenario and ensure that the building has the capacity to accommodate the new heat pump, the highest usage is taken into considerations for calculation purposes.

For buildings with metered data available, the second steps is to review the electrical record drawings. The drawings will offer some insight to the building's electrical distribution and existing infrastructure prior to a site visit.

The main item to focus on initially is the size of the main switchboard – the site's main electrical entrance. Coupled with the metered data, we then determine the site's power availability:

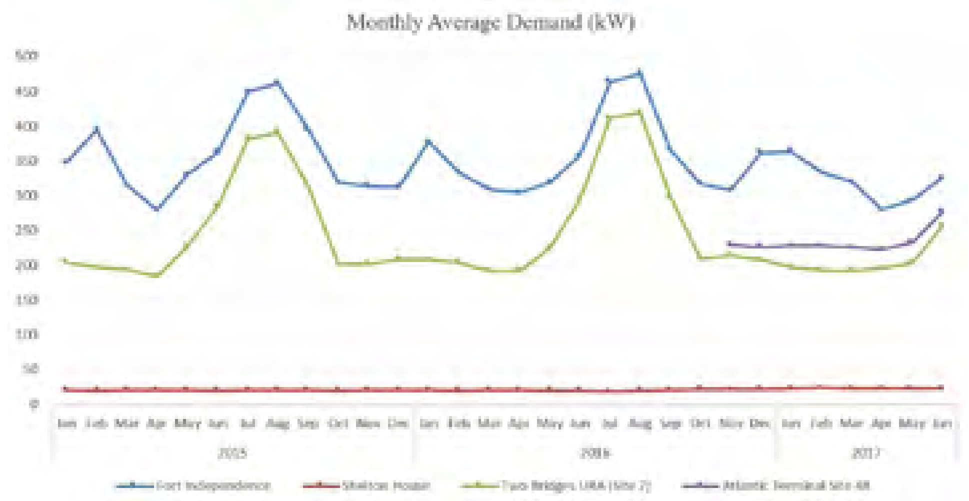
Capacity (Main SWBD) – Usage (Metered data) = Availability

A building's higher power availability will make for a better candidate.

Upon confirmation of the availability, the drawings are also analyzed to identify any potential distribution element where a connection to the new equipment would be possible. Characteristics such as the proximity of the panel to the intended location of the heat pumps, the physical capacity of the panel to accommodate a new connection (existing spare or available spaces), the current usage (size of the panel's supply) and routing the cable connection are all taken into account to list the best designs and possible alternatives.

To get a better initial understating of the load profile and allow for an easier visual representation, a monthly average was computed based on the available 15 minutes interval readings to show the demand in kW for each of the four (4) buildings.

Looking at the profile of the two larger buildings, Fort Independence and Two Bridges URA (Site7), we can see that demand is much larger during the summer



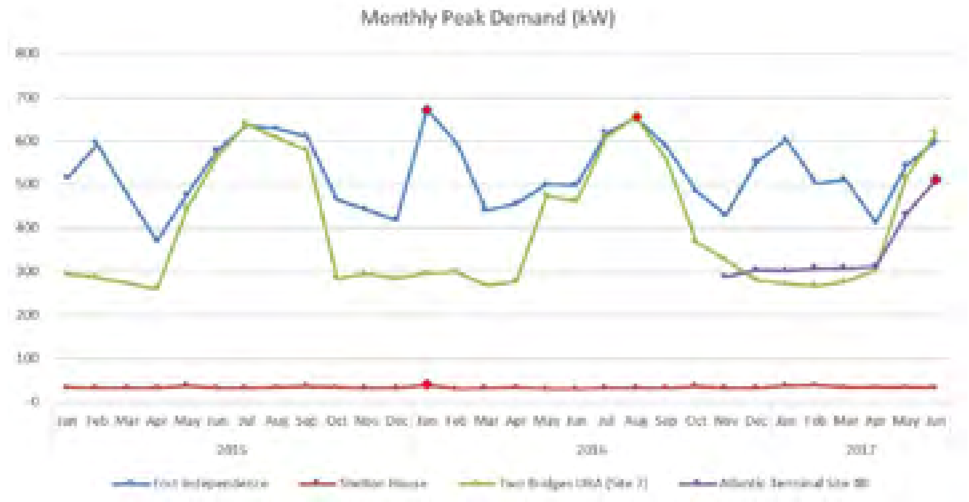
Monthly Average Electricity Demand

months. We can assume that this attributed to a larger used of personal AC in each unit during that time.

The graph above allows us to see that the usage for Shelton House is by far the lowest – meaning that the installation of new heat pumps could have an overall larger impact on the electrical infrastructure as it will represent a bigger amount of the total load. This would make it more measurable. However, the load is too small and too consistent to represent a whole building. It is likely that this meter is measuring only some piece of equipment, or may perhaps be malfunctioning.

Lastly, it is important to note that data available for the Atlantic Terminal Site 4B is goes only back to the end of 2016. Assumptions on the building's usage cannot be made with the same level of confidence level as other sites.

Following the monthly average, the metered readings were parsed to extract the maximum peak demand load in kW for each month. The largest of these values will



Monthly Peak Electricity Demand

	Fort Independence	Atlantic Terminal Site 4B	Shelton House	Two Bridges URA (Site 7)
Peak Recorded Demand (kW)	672	510	39	656

be used to determine the site's Usage when calculating the Availability as detailed previously.

The absolute peak demand values taken from the graph are shown on the above table.

The availability of site record drawings is the second criteria in determining the building's eligibility. Out of the four (4) buildings, only Fort Independence and Atlantic Terminal Site 4B had record drawings to confirm electrical infrastructure availability. The remaining two building were not considered for the project.

As shown below, according to the record drawings, both buildings are estimated to have a high availability. Both should have the electrical capacity required to implement the heat pump retrofit without necessitating any changes or upgrade to the Con Edison service. A low power factor (0.8) was used to work with a conservative availability.

As previously mentioned, due to limited historic data available for Atlantic Terminal Site 4B, the usage in summer months cannot be fully confirmed. Seeing as these months generally allow us to view a building's highest electrical power usage, Fort Independence will be prioritized. Both buildings will be considered nevertheless.

Building	Peak Recorded Demand (kW)			Bus Rating (A)	Fuse Rating (A)	Usage (%)	Spare Availability (kW)
	2015	2016	2017				
Fort Independence	635	672	602	5000	5000	47%	767
Atlantic Terminal Site 4B	N/A	304	510	4000	4000	44%	641

Exhibit H: Site Visits

Fort Independence and Atlantic Terminal were visited to confirm information found in the drawings, to collect new information, and to document observations pertinent to retrofitting a heat pump system.

Atlantic Terminal

Atlantic Terminal Site 4B was visited on July 19, 2017 to examine suitability for a heat pump pilot. The boiler room, gas meter room, electrical spaces, rooftop, and apartment spaces were visited.

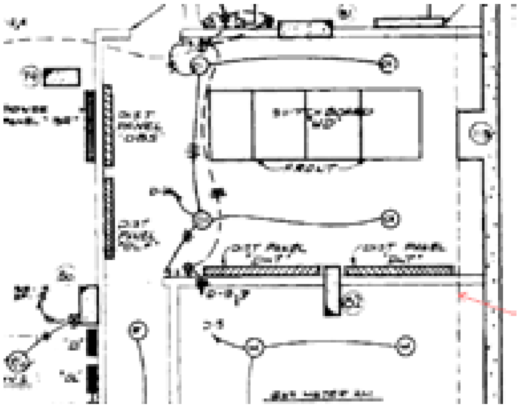
The following mechanical observations could be made:

- The building is served by two large condensing steam boilers. One was down for scheduled maintenance during the visit; the summer heat load can be handled with one boiler. Domestic hot water is heated with steam produced from the boiler. Boilers were installed in 2001 and appear to be in good working order. One of the motors in the hot water pumps was not functional during the visit.
- The gas supply to the boilers was separately metered, which is beneficial for the measurement of energy use reduction.
- The boiler room here is below ground (and more susceptible to flood risk) but not in a flood zone.
- Apartments were visited on the top floor of the building, and seemed conducive to a heat pump retrofit. Valves were located inside of the fintube radiators; these could be closed, or the whole radiator could be removed. The top of the steam risers were visible in an opening in the wall. There was ample wall space to hang indoor units.
- There was ample space on the roof for outdoor units.

The following observations could be made on the electrical infrastructure:

- Main electrical infrastructure elements correctly shown on the record drawings. Size of Con Edison service accurately shown at 4000A.
- All distribution panels are located in the building’s basement. This would result in a long cable run to supply heat pumps on the roof (26 or 32 floors total).

- Candidates for potential connection point of heat pumps:
  - Power Panel “BR”, 3P+N, 400A (fused: 300A), outside of Main electrical room and near column 79. Relatively new panel in good condition with spaces; spares available, but breakers are “on”.
  - Dist. Panel “DCF”, 3P+N, 600A (fused: 400A), inside Main electrical room. Old panel with exposed cooper bars directly under doors. Spare available, but connection would likely require complete change of the panel due to condition.
  - Dist. Panel “DBS”, 3P+N, 1200A (fused: 900A), inside Main electrical room. Old panel with exposed cooper bars directly under doors. Spare available, but connection would likely require complete change of the panel due to condition.
- Replacement of panels inside the electrical room would likely require the installation of the new panel outside the room due to spatial constraints.



Atlantic Terminal Distribution Panels

- An additional distribution panel dedicated to the heat pumps would be required on the roof level.

- The indoor units proper to each apartment would be supplied directly from that apartment's dedicated single phase panel.

Fort Independence

Fort Independence was visited on July 20, 2017 to confirm the assessment conducted with building drawings. The boiler room, pump room, electrical spaces, rooftop, and apartment spaces were visited.

The following mechanical observations could be made:

- The apartments are served by three hydronic boilers, one of which was operating during the visit. The boilers appeared to be in good working order. The boilers also provide the hot water stored in the hot water tank, which provides domestic hot water to the apartments.
- Gas meters were not observed during the visit; it is assumed, but should be confirmed, that these meters are present to measure differences in energy consumption after the heat pumps are installed.
- The apartments visited were on the 21st floor, so the top of the risers were accessible. The internal chase did not appear to be large enough to fit new piping or conduit. The radiators were inspected for valves, but none were identified. This confirms the need to remove the radiators and cap the pipework on either side to disrupt the existing heating supply. There is wall space to hang indoor units. Air conditioning units were observed to be in-window.
- The roof had plenty of space for outdoor units, but it is assumed a path must be left clear between the two points of egress at the top of each stairway.

The following electrical observations could be made:

- Main electrical infrastructure elements correctly shown on the record drawings. Size of Con Edison service accurately shown at 5000A.
- Main distribution items located on the building's 2nd floor, with some dist. panels on the 3rd, 6th, 7th and 21st floors. On top of the main building's

Con Edison Service Size

roof as a location preferred location for the new heat pumps, the site offer an alternative surface on the roof of the community center – adjacent to the main electrical room on the 2nd floor. Both locations offer close proximity to existing distribution panel, thus limiting the works for a new connection and reducing the length of the cable runs necessary.

- Candidates for potential connection point of heat pumps:
  - Panels “LP-D/LP-DD”, 3P+N, 200A (fused: 175A) or Panel “PP-BR”, 3P+N, 100A, all located just outside of the Main electrical room on the 2nd floor. These would be likely sources in the event that the heat pumps are placed on the roof of the community center. Relatively new panels in good condition with spaces and spares available. Readings would be necessary to confirm actual usage of panes due to low rating of main supplies.
  - Dist. Panel “PP-1”, 3P+N, 600A (fused: 500A), in equipment room on the 21st floor. Panel in good condition. Possibility to reuse (1) exiting 100A spare breaker and another (1) 30A breaker “off”, but shown as supplying a make-up air unit.
  - Dist. Panel “PP-2”, 3P+N, 400A (fused: 300A), in another equipment room on the 21st floor. Panel in good condition. Possibility to reuse (1) exiting 100A spare breaker and another (2) 30A breakers “off”, but shown as both supplying a make-up air unit.
  - Dist. Panel “MDS-2”, 3P+N, 200A (fused: 1600A), on the 6th floor. n. A ncy

Panel PP-1

Panel PP-2

with the record drawings which show additional circuits. Possibility to replace panel with new one of same capacity, but with higher number of circuits as a secondary plan.

- No replacement of the existing panels seems necessary.

Panel MDS-2

- An additional distribution panel dedicated to the heat pumps could be required on the roof level (21st floor). It is possible to simply use all spare breakers available to limit any new electrical distribution items to a minimum. This will be determined by the solution implemented.
- The indoor units proper to each apartment would be supplied directly from that apartment's dedicated single phase panel.

After the review of building drawings and site visits, it was determined that the installation of a heat pump at either building is feasible. Fort Independence is preferred due to the location of the available electrical panels and the simplified logistics of working with a hydronic heating system. Atlantic Terminal could be used if desired.

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