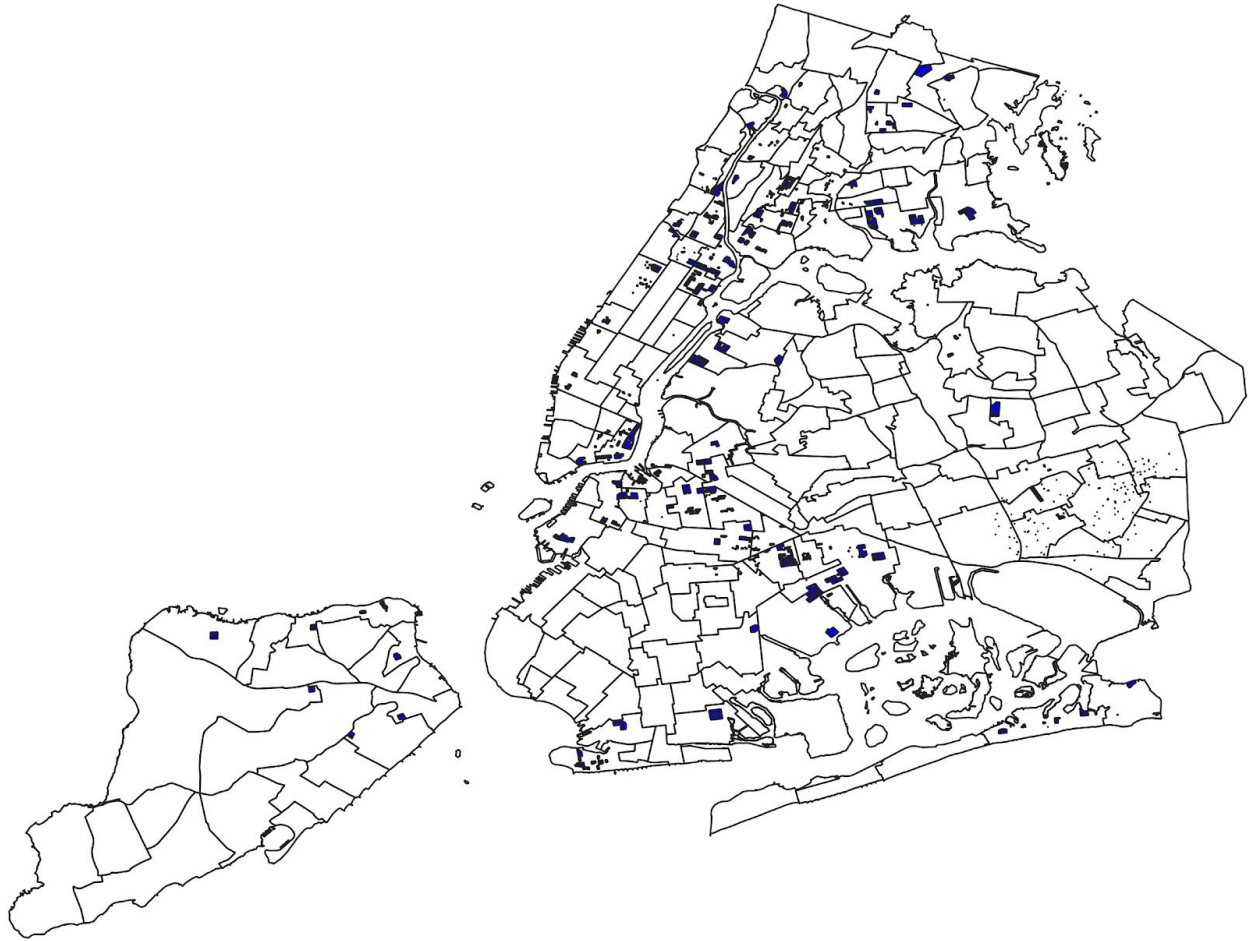


# Weatherproofing of NYCHA Buildings for Energy Savings



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11.165: Urban Energy Systems and Policy

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# Introduction

Nearly 70% of the greenhouse gas (GHG) emissions in New York City come from buildings (City of New York, 2018). As the largest landlord in the City, the New York City Housing Authority (NYCHA), the public housing administrator for the City, is the greatest contributor to these emissions. NYCHA houses 400,000 people, or 4.4% of all New Yorkers (NYCHA, 2019a), approximately the same population as Minneapolis, Tulsa, or New Orleans, meaning that its policies and actions impact many people throughout the five boroughs of New York. Combining this large population, sizable ownership of property — NYCHA represents 7.9% of the City’s rental apartments (NYCHA, 2019a) — and outdated infrastructure, NYCHA housing represents an under-addressed area in terms of energy efficiency improvements. Much of NYCHA’s outdated infrastructure is due to costs as NYCHA funding has declined in the past few decades and is currently in need of \$32 billion in repairs (NYCHA, 2019a). This means that NYCHA lacks the resources to invest in high-cost clean energy solutions, while its low-income residents similarly lack resources to invest in these technologies themselves. On the other hand, this means that NYCHA residents have the most to gain as even small monetary savings from energy efficiency improvements can have significant impacts on their day-to-day lives. Likewise, NYCHA itself would benefit due to savings from reduced energy costs, allowing it to pay off its debt. Many of these repair costs are due to the fact that on average, NYCHA buildings are over sixty years old, and have been poorly maintained in that time (Ferré-Sadurní, 2018). Over 30% of these repairs are for building components such as windows, floors, roofs, and doors, which can be improved to increase insulation, reducing heating and cooling demands.

More than two years ago, NYCHA implemented the first phase of its \$300 million retrofitting of 120,000 apartments (NYCHA, 2017a). This phase involved a \$56 million energy savings program of lighting, water conservation, and heating upgrades for 16 public housing developments in Manhattan, Brooklyn, and the Bronx. This program was part of Mayor Bill deBlasio’s OneNYC 2050, a green buildings plan to reduce greenhouse gas emissions in the City by 80% by 2050, and was facilitated by the U.S. Department of Housing and Urban Development (HUD). It will reduce annual utility costs by more than \$3.5 million. Almost two years ago, NYCHA announced \$103 million in new energy contracts to upgrade lighting and heating systems, building ventilation systems, and water conservation at 41 developments. These new energy performance contracts (EPCs) will save NYCHA \$8.6 million annually while reducing energy by approximately 15% (NYCHA, 2018a). However, these contracts have not addressed all of the infrastructure and energy efficiency issues of NYCHA’s outdated housing, specifically increasing insulation and reducing energy demands.

To address these issues, this paper proposes a two-pronged approach for NYCHA to improve the energy efficiency of the most expensive aspects of its buildings that it has not already upgraded: **roofs** and **windows**. Although it is acknowledged that existing regulations should be amended to reduce energy use in subsidized housing (Reina & Kontokosta, 2017), it is important to evaluate the extent to which positive change can be seen within the current legal and economic constraints. Additionally, New York City has the greatest amount of public housing and some of the most progressive energy policies of all U.S. cities, so the proposed changes outlined in this paper evaluate how successful these policies can be in easing the transition to more energy efficient public housing, if they are effective at all. This would inform other cities on whether to implement similar policies.

## Roofing

NYCHA reports that they need to perform \$2.3 billion in roof repairs (Ferré-Sadurní, 2018). In addition, roofs provide a fantastic opportunity to implement several types of energy-saving measures. This paper looks into the feasibility of integrating alternative roofing, such as white and green roofs, into NYCHA buildings, how much they would reduce the heating and cooling demands of these buildings, and how cost-effective and energy-efficient these reduced demands would be. Although green roofs are more expensive, they were expected to reduce heating and cooling demands more than white roofs. On the other hand, due to NYC CoolRoofs, a City-run initiative, white roofs would be free to install and have low maintenance requirements.

## Windows

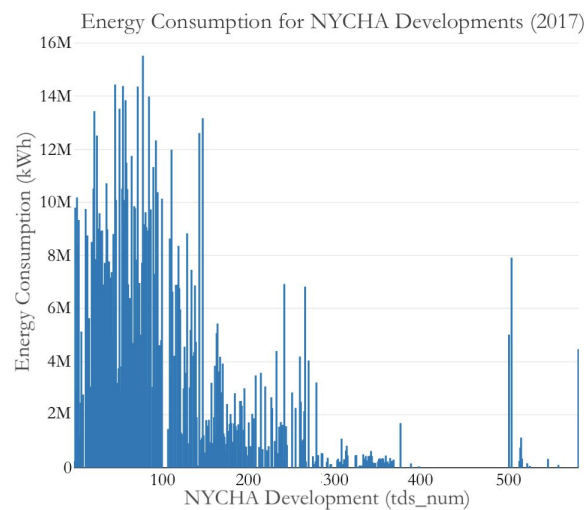
NYCHA reports that they need to perform \$3.2 billion in window repairs (Ferré-Sadurní, 2018). This paper looks into how much more it would cost to install insulated windows, if the cost is feasible at the scale of the repairs, and if the energy savings are worth the investment. The costs and benefits of various window insulation measures are compared to determine the most cost-effective and energy-efficient solution to implement in NYCHA buildings in need of window repairs. Ease of use and aesthetics were also considered to ensure that the window insulation method chosen was not just feasible, but desirable, to implement.

Overall, this paper evaluates the feasibility and effectiveness of various energy-saving methods for roofs and windows in NYCHA public housing buildings. By comparing these methods to current methods, as well as relevant procedures and regulations in the City, the most effective solutions, both in the short- and long-term,

for energy efficiency in NYCHA buildings will be determined. Through the analysis of quantitative data, existing programs, and relevant legislation, this paper aims to provide a framework to ensure that NYCHA is able to perform repairs that are beneficial to itself, its residents, and New York City at large.

## Data Analysis of Energy Consumption

Before determining the appropriate energy-saving measures to implement and for which housing developments, it is important to understand the different housing developments and their energy usage. By looking at the Electric Consumption And Cost (2010 - March 2019), the 2017<sup>1</sup> energy consumption was found for all NYCHA buildings. As shown in Figure 1, there was a wide range of energy consumption between NYCHA buildings, which was mostly attributed to their different sizes and populations.

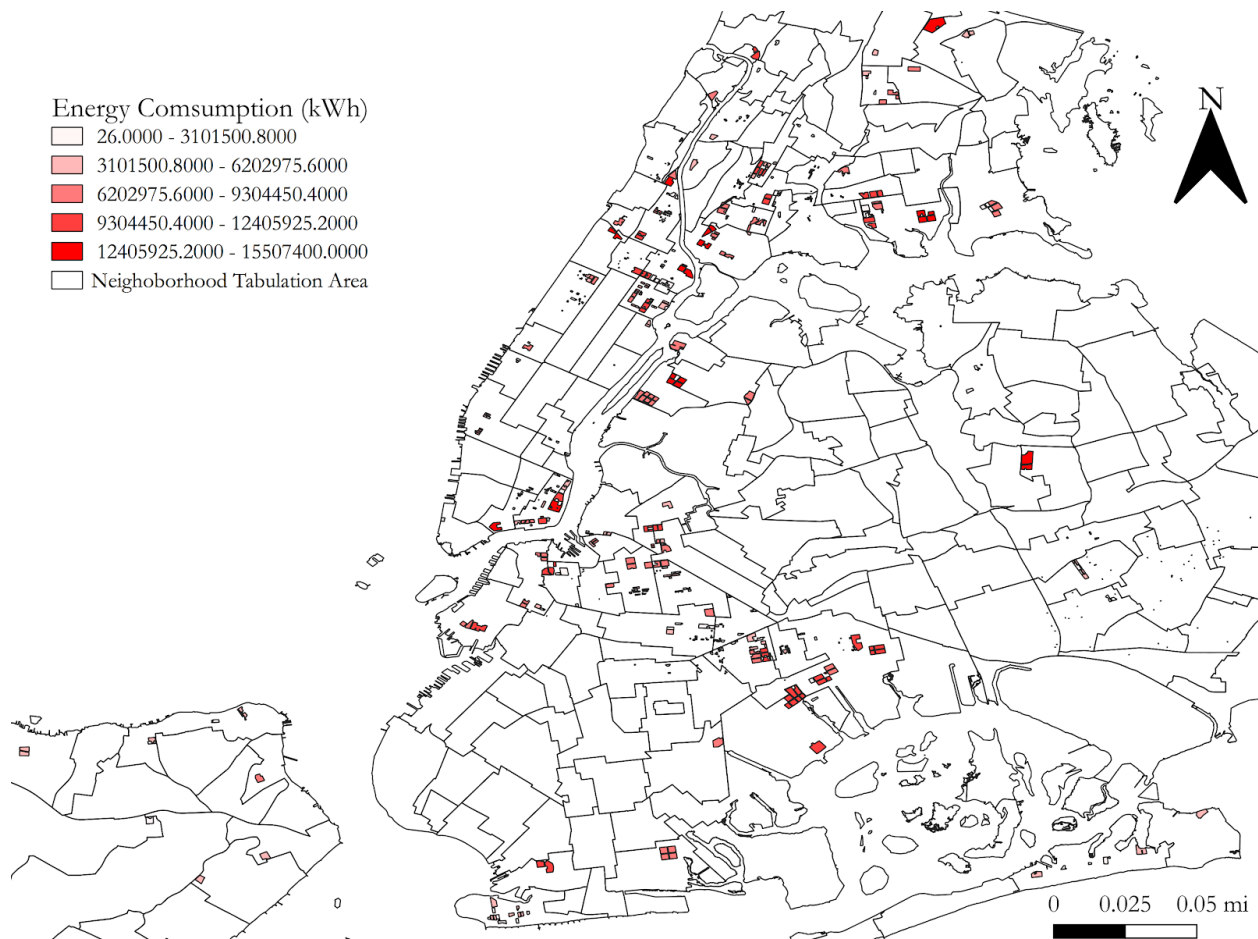


**Figure 1.** Energy consumption distribution in 2017 for all NYCHA developments.

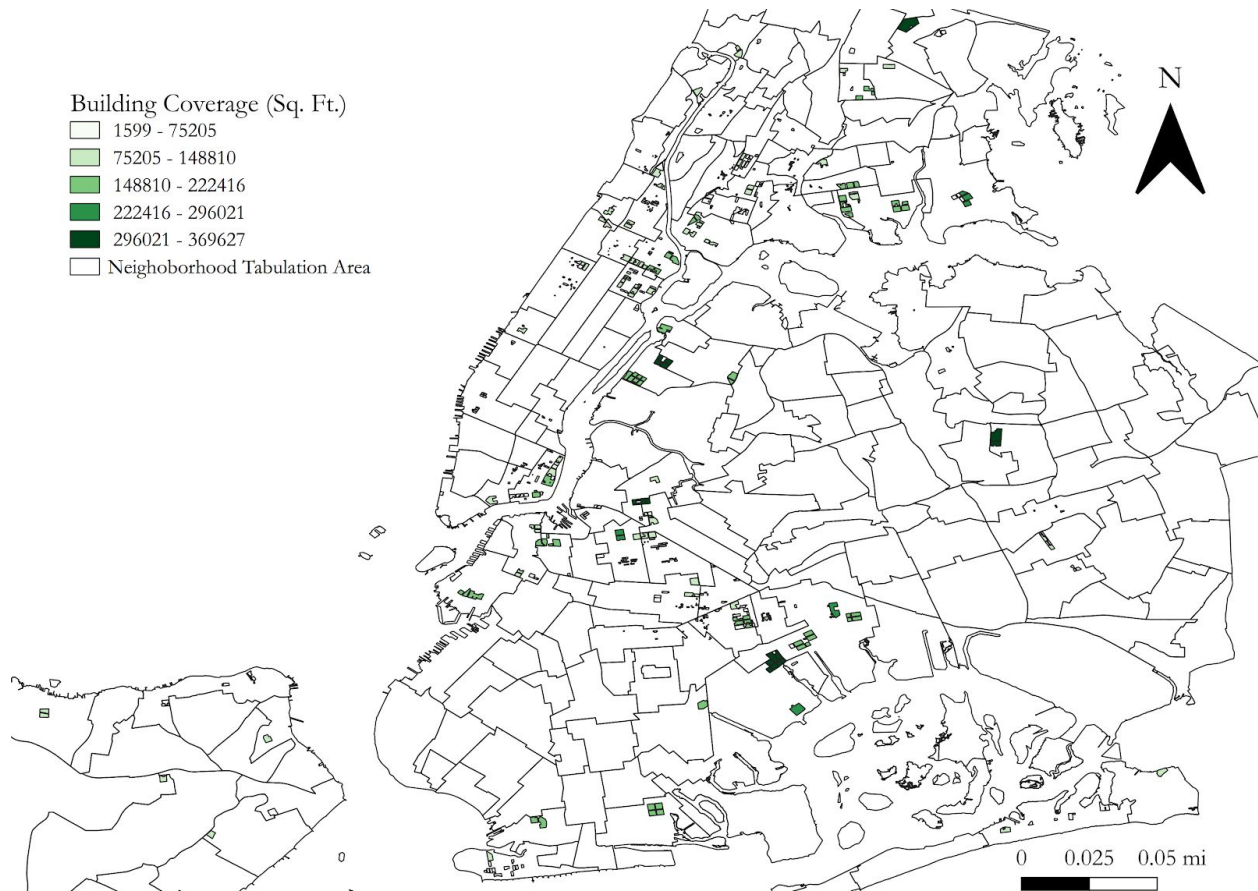
As shown in Figures 2 and 3, the greatest energy usage (redder areas) was found in the largest housing developments (greener areas), confirming the initial trend justification. By combining this data with the Map of NYCHA Developments (NYCHA, 2019c) and a map of the New York City Neighborhood Tabulation Areas (DCP, 2019), this difference in energy consumption could be viewed in the context of the city and the footprint of the housing developments.

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<sup>1</sup> 2017 was chosen as it is the most recent year with fully report energy consumption for all NYCHA developments.

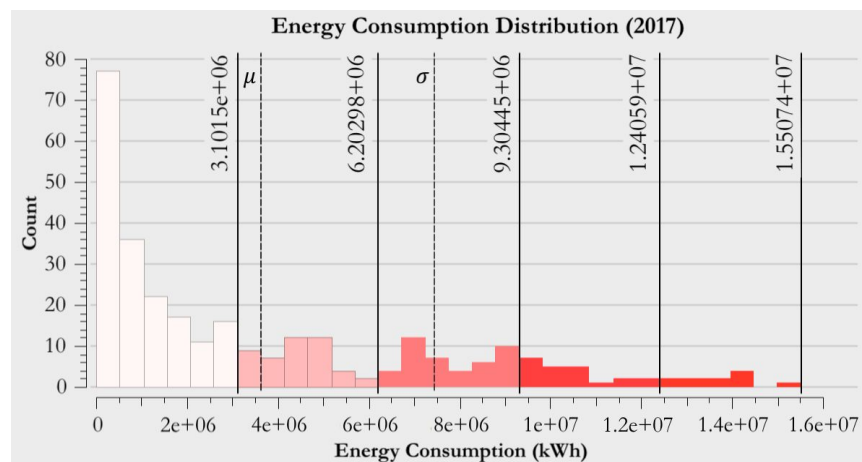


**Figure 2.** Energy consumption distribution in 2017 for all NYCHA developments.



**Figure 3.** Building coverage area in 2017 for all NYCHA developments.

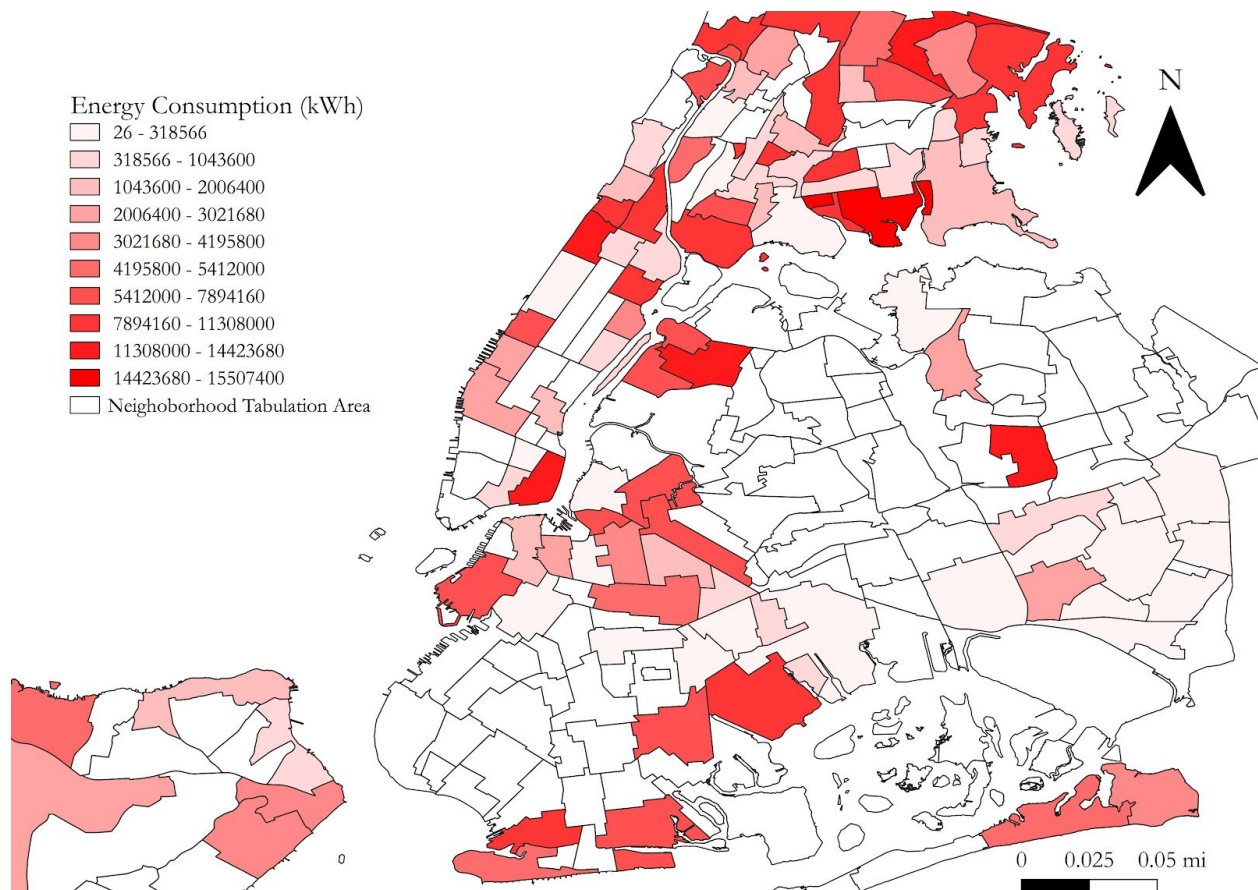
As shown in Figure 4, a small number of buildings consume far more energy per year than the vast majority of others. These buildings should be targeted for energy efficiency measures as they have the most to gain. Additionally, since these buildings also tend to be the largest, they have the most space to implement energy efficiency improvements, including more roof area for solar panels or greenery.



**Figure 4.** Histogram of energy consumption in 2017.



Because clustering could allow for greater implementation efficiency and for a nearby control case to compare to a small-scale pilot study, the locations of NYCHA buildings, especially those that consume the most energy, are important. Additionally, the location of buildings could affect the feasibility of certain energy-saving methods for those buildings, especially for roofing. It would be interesting to note if microclimate effects, such as those from nearby greenery or tall buildings, affect energy usage in buildings in different settings throughout the City. The amount of NYCHA energy consumption was found for each neighborhood. As shown in Figure 5, the greatest NYCHA energy consumption is clustered on the Lower East Side of Manhattan, Harlem, the South Bronx, Wakefield in the North Bronx, Long Island City in Queens, and northeastern Brooklyn.



**Figure 5.** Energy consumption of NYCHA buildings categorized by neighborhood tabulation area.

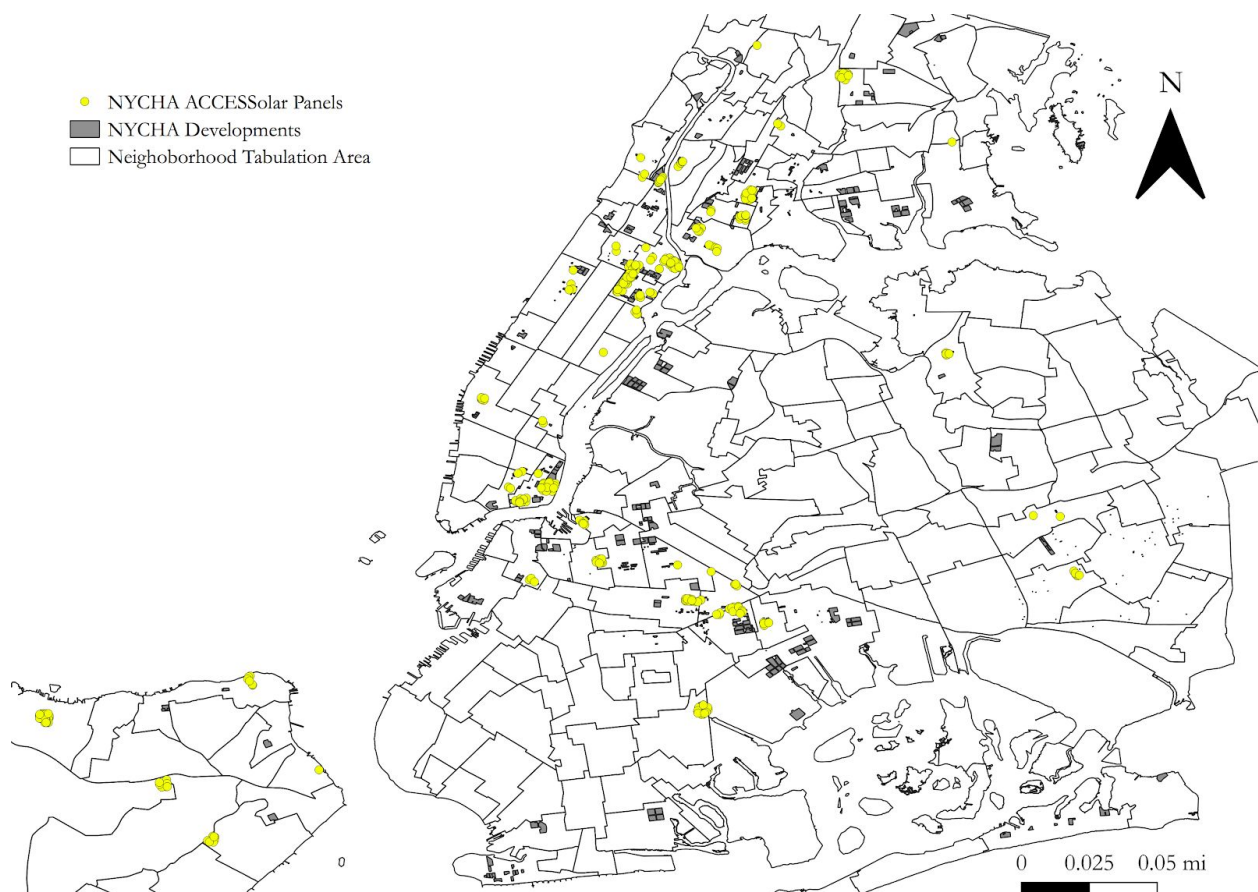
Due to the numerous programs and legislation offered by the New York City government (New York City Mayor's Office of Sustainability, 2019), the primary method for energy efficiency analyzed in this paper was alternative roofing. Because of this, in addition to annual energy consumption, usable roof area was a key factor in deciding which buildings should be targeted. It was then necessary to decide which kind of alternative

roofing was best for use on NYCHA developments. This was determined using a cost benefit analysis and an investigation of existing legislation.

## Cost Benefit Analysis

### Roofing

There are three main energy-saving roofing alternatives to the standard black asphalt roof: green roofs, white (or cool) roofs, and solar panels. In order to choose which roofing type to implement, a cost benefit analysis was performed, factoring in fixed costs such as installation, variable costs such as maintenance, and benefits such as energy cost savings. Additionally, current roofing types and ease of implementation were considered.



**Figure 6.** Map of NYCHA ACCESSolar sites.



It is important for NYCHA buildings to generate their own power because NYCHA purchases its power from the New York Power Authority (NYPA). NYPA rate structures and regulations make power purchase agreements (PPA) impractical on NYCHA property and forbid NYCHA from off-taking from community solar systems (NYCHA, 2018b). Currently, the ACCESSolar program has installed solar panels on 65 NYCHA developments, as shown in Figure 6. Since ACCESSolar is currently installing solar panels on NYCHA buildings, solar panels were removed as a roofing option. This left green roofs and cool roofs as the remaining roofing types to be evaluated.

The short- and long-term costs and benefits of green and cool roofs were compared, as shown in Table 1. The roof area selected for initial analysis was 10,000 ft<sup>2</sup> as this was approximately the average roof size of the top 20% of NYCHA developments by energy consumption in 2017. Smaller and larger areas were tested after the initial analysis to confirm that the trends hold for different roof areas.

**Table 1.** Costs estimates for a green and cool roof on a 10,000 ft<sup>2</sup> roof after 2.2 years

Time (years)	2.2	Area (sq ft)	10000					Legend	
	Green Roof	Source	Notes	CoolRoof	Source	Notes		Inputs	Outputs
Installation Cost relative to conventional, black roof (\$/sq ft)	-11	<a href="https://www.">https://www.</a>	Range (size)	0	<a href="https://www.">https://www.</a>	Free installation for affordable housing		Exact	>0
NPV Maintenance Cost rel. conventional, black roof (\$/sq ft/y)	-17.5	<a href="https://www.">https://www.</a>	Range (size)	-0.7	<a href="https://www.">https://www.</a>	Liquid applied coating. Avg roof lifetime 25 y		Estimate	0
NPV Stormwater (\$/sq ft/y)	13.5	<a href="https://www.">https://www.</a>	Range (size)	0				Ignored	<0
NPV Energy (\$/sq ft/y)	7	<a href="https://www.">https://www.</a>	Range (size)	0.032	<a href="https://web.">https://web.</a>	Estimates from ORNL calculator		Variable	
Tax abatement (\$/sq ft)	4.5	<a href="https://www.">https://www.</a>	\$100,000 cap. One-time	0					
NPV CO2 (\$/sq ft/y)	2.1	<a href="https://www.">https://www.</a>	All sizes	0.25	<a href="http://www.">http://www.</a>	10 metric tons CO2			
NPV Real Estate Effect (\$/sq ft/y)	110	<a href="https://www.">https://www.</a>	Range (size)						
NPV Community Benefits (\$/sq ft/y)	30.4	<a href="https://www.">https://www.</a>	All sizes						
<b>TOTAL (\$)</b>	<b>1000</b>			<b>88</b>					

In a comparison of payback periods, white roofs seem more cost-effective because they have a near-zero payback period, while green roofs have a payback period of 2.17 years. However, after 2.17 years, green roofs save far more in energy costs than white roofs. For example, after five years, green roofs would save the building owner \$85,000 in energy costs, while white roofs would save only \$200. Additionally, this does not factor into green roofs' greater supplementary benefits, including increased real estate value and community benefits. This trend holds for smaller roof areas, such as for smaller buildings or if a larger roof were split between a green roof and solar panels. Thus, by comparing the roofing materials, green roofs were determined to be the most cost effective roofing material outside of the immediate time frame, while white roofs were immediately profitable but did not significantly reduce costs in the longer term.

## Windows

NYCHA currently has serious issues with heating and window insulation. As shown in Figure 7, this has caused many NYCHA residents to take matters into their own hands and insulate their windows with whatever they can easily access and afford: cardboard, trash bags, tape, and blankets (Ferré-Sadurní, 2018). In addition to drafts reducing energy efficiency, a lack of sufficient heating is a violation of New York City's heat

law, which requires buildings to maintain an indoor temperature of at least 68°F during the day when it is below 55°F outside, and at least 62°F at night no matter the outside temperature (HPD, 2019). Increased insulation, especially from windows, would reduce NYCHA's heating burden, and would increase the quality of life for NYCHA apartment residents during the winter.



**Figure 7.** Examples of homemade window insulation measures in NYCHA apartments (Kholood Eid for The New York Times, from Ferré-Sadurní, 2018)

In recent decades, NYCHA has been focused on switching from single-pane double-hung windows with thermally-unbroken metal frames to double-glazed sliding windows with thermally-broken aluminum frames (NYCHA, 2017b). Since NYCHA has already focused on energy efficient window pane coatings, other aspects of windows were considered, such as number of panes, spacing, and covering, as shown in Table 2. The costs and benefits of various window insulation improvements were considered to determine the most cost-effective, energy-saving window improvement, within the constraints of NYCHA buildings. The insulating powers of different window adjustments were compared using their R-values, which are the capacity of insulating materials to resist the flow of heat. This means that adjustments that provide higher R-values are better insulators.

**Table 2.** Cost estimates and R-values for standard 27-inch windows.

	Material	R-value	Source	Notes	Cost (\$/window)	Source	Notes
Single pane glass	Single pane glass	0.9	<a href="http://digital">http://digital</a>	ASHRAE Handbook of Fundamentals, 1977	60	<a href="https://www">https://www</a>	
Double pane glass	1/4" air space	1.5	<a href="http://digital">http://digital</a>		375	<a href="https://www">https://www</a>	
	1/2" air space	2	<a href="http://digital">http://digital</a>		0		
Air space	3/4"-4" deep	0.9	<a href="http://digital">http://digital</a>		7	<a href="https://www">https://www</a>	
Drapery	Conventional (not insulated or sealed)	0.2	<a href="http://digital">http://digital</a>	Manufacturer's Test Data	15	<a href="https://www">https://www</a>	
	Two-layer system (drapery and lining on separate tracks)	1.94	<a href="http://digital">http://digital</a>		37.8	<a href="https://www">https://www</a>	
	Window Quilt	3.7	<a href="https://www">https://www</a>				
	Comice and drapery	1.3	<a href="https://exter">https://exter</a>		2.25	<a href="https://exter">https://exter</a>	\$0.10 for comice, \$0.40+ for comice+ drapery (depends on fabric)
Roller-shade	Conventional	0.18	<a href="http://digital">http://digital</a>	U.S. Department of Energy (DOE). (1981). "A Comparison of Products for Reducing Heat Loss Through Windows."	60	<a href="https://www">https://www</a>	\$20-60+\$10-20 labor for 27"
Venetian blinds	Venetian blinds	0.2	<a href="http://digital">http://digital</a>		20	<a href="https://www">https://www</a>	\$11-215 per window
Interior shutter	3/4" polystyrene core b/w				250	<a href="https://www">https://www</a>	
	1/8" plywood panels	4.9	<a href="http://digital">http://digital</a>				
Cellular shades	Single cell	1.6	<a href="https://cellul">https://cellul</a>	Blindster	50	<a href="https://www">https://www</a>	\$35-50+\$10-20 labor for 27"
	Premium blackout double	5	<a href="https://www">https://www</a>		78.11	<a href="https://www">https://www</a>	
	Premium blackout single	5	<a href="https://www">https://www</a>		65.27	<a href="https://www">https://www</a>	
	Premium light filtering double	4.6	<a href="https://www">https://www</a>		57.41	<a href="https://www">https://www</a>	
	Group B fabrics	4.35	<a href="https://www">https://www</a>		88.15	<a href="https://www">https://www</a>	
	Deluxe light filtering double	4.5	<a href="https://www">https://www</a>		51.5	<a href="https://www">https://www</a>	
Insulation board	Clip-on	11.5	<a href="https://exter">https://exter</a>	University of Maine	1.8	<a href="https://exter">https://exter</a>	Hard to remove
Insulated	1 layer of fiberfill	2.5	<a href="https://exter">https://exter</a>		4.5	<a href="https://exter">https://exter</a>	
	2 layers of fiberfill	4	<a href="https://exter">https://exter</a>		5.625	<a href="https://exter">https://exter</a>	
Roman shades	3 layers of fiberfill	5.5	<a href="https://exter">https://exter</a>		3	<a href="https://exter">https://exter</a>	
	Prelayed fabric	7	<a href="https://exter">https://exter</a>		11.25	<a href="https://exter">https://exter</a>	

By visually inspecting this data, it is clear that the most cost-effective insulation measure for windows is the use of a clip-on insulation board. However, these boards are difficult to remove regularly, so it is best to use them for north-facing windows where the heat loss is greater than the solar gain for the entirety of the winter (Coffin, 2012). Operating under the assumption that most NYCHA residents would prefer to have access to their windows during the winter, and the fact that NYCHA buildings are apartments, so many residents would not have north-facing windows, it is best to consider an option that is easier to remove on a regular basis. Other than insulation boards, and window coatings, which have already been implemented by NYCHA, there are two main, unobtrusive ways to improve the insulation of windows.

From 2005 to 2011, the number of broken or missing windows in NYCHA buildings increased 945% (Flegenheimer, 2014). In 2011<sup>2</sup>, NYCHA developments were three times as likely to have broken or missing windows, compared to other buildings in New York City (Flegenheimer, 2014). If the windows are currently broken, as many windows in NYCHA developments are, the number and type of panes is important, as the panes will have to be fully replaced.

There are three options for the number of panes: single pane, double pane, and triple pane. Triple pane glass was immediately eliminated because its installation costs are too high and may require larger window frames than currently exist in NYCHA buildings. Double pane glass, when installed with the maximum ½" air

<sup>2</sup> 2011 was considered as it was the last year for which data was available.

space, has double the R-value but six times the installation cost of single pane glass. Because of this, double pane glass was not cost-effective, so single pane glass was selected with a 1-2" deep air space. This maximizes the R-value of single pane glass while leaving room for future installation of further insulation.

In addition to pane type, window coverings, including blinds, shades, and drapery, provide an alternative to insulation boards that can be easily removed when a resident wants to access the window. First, choices with high costs and low R-values were removed from analysis by visual inspection. Then, using Equation 1, the U-value was found for a combination of each shade type with single pane glass (R-value =  $0.9 \frac{^\circ\text{F} \cdot \text{ft}^2 \cdot \text{h}}{\text{BTU}}$ ) and a 1-2" air space (R-value =  $0.9 \frac{^\circ\text{F} \cdot \text{ft}^2 \cdot \text{h}}{\text{BTU}}$ ).

$$\text{U-value} \left[ \frac{\text{BTU}}{^\circ\text{F} \cdot \text{ft}^2 \cdot \text{h}} \right] = \frac{1}{\text{R-value}_1 + \text{R-value}_2 + \text{R-value}_3 + \dots \left[ \frac{^\circ\text{F} \cdot \text{ft}^2 \cdot \text{h}}{\text{BTU}} \right]} \quad (1)$$

**Equation 1.** U-value of a window insulation combination (Boschetti, 1984).

Next, using Equation 2 and the calculated U-values, heat loss was calculated for each combination of single pane glass, air space, and shade type.

$$\text{H [kWh]} = 24 \left[ \frac{\text{h}}{\text{d}} \right] \cdot \text{HDD} \left[ \frac{^\circ\text{F}}{\text{y}} \right] \cdot \text{U-val} \left[ \frac{\text{BTU}}{^\circ\text{F} \cdot \text{ft}^2 \cdot \text{h}} \right] \cdot \frac{\text{A [ft}^2\text{]}}{\text{window}} \cdot \# \text{ windows} \cdot \frac{1 \text{ kWh}}{3412 \text{ BTU}} \quad (2)$$

**Equation 2.** Heat loss from windows (Boschetti, 1984).

Finally, the payback period for each window pane and covering combination was calculated using Equation 3.  $7.52 \frac{\text{\$}}{\text{kWh}}$  was used as the fuel cost, representing the average 2018 cost of U.S. No. 2 fuel oil with losses and conversion factors for standard boilers.

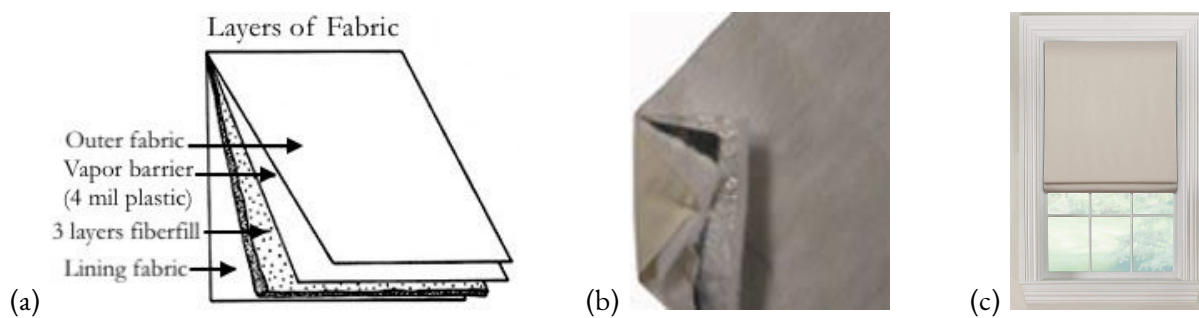
$$\text{PB [y]} = \frac{\text{Cost}_{\text{window}} [\text{\$}]}{\text{Cost}_{\text{fuel}} \left[ \frac{\text{\$}}{\text{kWh}} \right] \cdot (\text{H}_{\text{original}} \left[ \frac{\text{kWh}}{\text{y}} \right] - \text{H}_{\text{insulated}} \left[ \frac{\text{kWh}}{\text{y}} \right])} \quad (3)$$

**Equation 3.** Payback period for upgraded windows.

In order to compare the reduction in heat loss due to the increased insulation, and to find the payback period, the heat loss from current NYCHA windows was calculated. According to the New York City Standard Specification for aluminum double hung windows, current NYCHA windows have an average U-value

throughout the year of  $0.23 \frac{BTU}{°F \cdot ft^2 \cdot h}$  (HPD, 2010). Via Equation 2, this corresponds to a heat loss of 29.09 kWh per window.

By ranking the combinations by payback period, the most cost-effective solution was found to be single pane glass with insulated Roman shades with prelayered fabric, which had a payback period of 3.56 years, as shown in Table 3. This combination had a total U-value of  $0.1136 \frac{BTU}{°F \cdot ft^2 \cdot h}$  and, through Equation 1, a heat loss of 14.37 kWh per window, which is a nearly 50% decrease from the current NYCHA windows. As shown in Figure 8, these shades would be composed of six layers: one layer of lining fabric, three layers of fiberfill, one vapor barrier layer made from 4 mil plastic, and one outer fabric layer.



**Figure 8.** (a) Layers of fabric and insulation for prelayered Roman shades, (b) quilted, prelayered fabric with all layers except the decorative fabric that faces the room (Coffin, 2012), and (c) Roman shade on window (Furniture Fresh, 2019).

**Table 3.** Calculated values for all window insulation layers.

	Material	U-value	H (kWh)	Payback (y)	Factor	Value	Source	Notes
Single pane glass	Single pane glass				NYC HDD (2017)	3996	<a href="https://www.">https://www.</a>	
Double pane glass	1/4" air space				Fuel cost (\$/kWh)	0.19334097	<a href="https://www.">https://www.</a>	
	1/2" air space				Window Area (sq ft)	4.5		Standard 27" window
Air space	3/4"-4" deep				Number of windows	1		
Drapery	Conventional (not insulated or sealed)	0.5	63.24	-0.95418098	Original H	29.0904189	<a href="https://www.">https://www.</a>	U-value of 0.23
	Two-layer system (drapery and lining on separate tracks)	0.2674	33.8182	-14.7690367	Tax credit (\$)	0.1	<a href="https://www.">https://www.</a>	10% of cost, up to \$200, exclude installation
	Window Quilt	0.1818	22.9964	28.8738766	<b>Legend</b>			
	Cornice and drapery	0.3226	40.8	-0.89445562	Variable			
Roller-shade	Conventional	0.5051	63.8788	-8.02851612	U-value	H	Payback	
Venetian blinds	Venetian blinds	0.5	63.24	-2.72623137	<Original U-value	>Original H	>5 y	
Interior shutter	3/4" polystyrene core b/w 1/8" plywood panels	0.1493	18.8776	113.94992	>Original U-value	<Original H	5-10 y	
Cellular shades	Single cell	0.2941	37.2	-28.7004633			0-5 y	
	Premium blackout double	0.1471	18.6	34.6603486				
	Premium blackout single	0.1471	18.6	28.9627571				
	Premium light filtering double	0.1563	19.7625	28.6498269				
	Premium light filtering single-Group B fabrics	0.1626	20.5659	48.1359312				
	Deluxe light filtering double	0.1587	20.0762	26.5948728				
Insulation board	Clip-on	0.0752	9.50978	0.42792167				
Insulated Roman shades	1 layer of fiberfill	0.2326	29.414	-64.7417992				
	2 layers of fiberfill	0.1724	21.8069	3.59501357				
	3 layers of fiberfill	0.137	17.326	5.34174724				
	Prelayered fabric	0.1136	14.3727	3.55821116				

## Legislation, Politics, and Logistics

As noted by Reina & Kontokosta, 2017, modifying regulations is a key component of reducing energy consumption in public housing developments. Because of this, it is important to recognize the current legislation affecting energy usage and energy efficiency measures in NYCHA buildings. New York City has several energy efficiency measures, some of which NYCHA participates in.

In early 2017, NYCHA joined the NYC Carbon Challenge for Multifamily Buildings, a pledge to reduce building-based greenhouse gas emissions by 30% or more over the subsequent ten years (NYCHA, 2017c). This corresponds to a reduction of 330,200 metric tons of CO<sub>2</sub> emissions (tCO<sub>2</sub>e). NYCHA plans to use its participation in the NYC Carbon Challenge as the first step in reaching the OneNYC goal.

On April 18, 2019, the New York City Council passed the Climate Mobilization Act (CMA), a component of the City's 1.5°C Climate Action Plan (Bergland, 2019). The CMA includes several local laws for New York City to reach carbon neutrality by 2050 as part of its commitment in the Paris Agreement. New York City's commitment of reducing greenhouse gas emissions by 80% by 2050, or 80 x 50, is detailed in the OneNYC report (New York City Mayor's Office of Sustainability, 2015) and its plan to reach this goal is outlined in New York City's Roadmap to 80 x 50 (New York City Mayor's Office of Sustainability, 2016).

Local Law 97 is the main component of the CMA, requiring all buildings larger than 25,000 square feet to meet strict carbon reduction targets. As affordable housing, the 60% of NYCHA buildings larger than 25,000 are exempt from Local Law 97. However, it is interesting to see how feasible it would be for NYCHA buildings to be in compliance with this legislation as NYCHA is the largest landlord in New York City and the CMA is an important part of New York City's plan to abide by the Paris Agreement (Bergland, 2019). If NYCHA buildings were to abide by Local Law 97, it would have to reach strict emissions limits every five years, as shown in Table 4.

**Table 4.** Local Law 97 emissions limits for permanent residences (Bergland, 2019).

Occupancy Group	2024-2029 Limit (tCO <sub>2</sub> e/ft <sup>2</sup> )	2030-2034 Limit (tCO <sub>2</sub> /ft <sup>2</sup> )	2030-2034 % Reduction Relative to Current Sector Performance	2035-2050 Limit (tCO <sub>2</sub> /ft <sup>2</sup> )	2050 Limit (tCO <sub>2</sub> /ft <sup>2</sup> )
R-2 permanent residences	0.00675	0.00407	20%	TBD	0.0014

Emissions limits for 2035-2050 will be determined by the Office of Building Energy and Emissions Performance, but the legislation sets out a citywide average emissions intensity target of 0.0014 tCO<sub>2</sub>e/ft<sup>2</sup>/yr for all covered buildings by 2050, a roughly 60% reduction beyond the 2024-2029 limits (Bergland, 2019). The



2050 emissions limit is an average of emissions limit across all building types, so the given number may change as specific sector limits are set in the coming years. Building emissions are determined according to designated greenhouse gas coefficients for various fuel types. While the CMA assigns coefficients for 2024-2029, those for subsequent compliance periods will be determined later. Local Law 97's emissions reduction targets are premised on New York City's electric grid becoming much cleaner in the future, which could include additional solar installations on NYCHA building roofs. In order to reach these goals, New York City must significantly reduce its carbon emissions. Since NYCHA is the largest landlord in the City, and insulated shades would decrease window heat loss by nearly 60%, the implementation of insulated shades would be a large step in helping the City reach its ambitious carbon reduction goals. The insulating power of green roofs would further help the City reach these goals. Although no specific climate regulations exist for windows, the City has clear legislation incorporating roofing into its green plan.

## Roofing

Local laws 92 and 94 require buildings undergoing major roof renovations to be covered with solar panels, green roofs, or some combination of the two (New York City Mayor's Office of Sustainability, 2019). The laws also require all buildings to reduce urban heat hazards, which could encompass white roofs, green roofs, and other types of green infrastructure. Because of the extensive repairs that need to be done to many NYCHA buildings, in order to be compliant with the first component of these laws, white roofs should not be implemented.

As part of the NextGeneration NYCHA Sustainability Agenda, NYCHA committed to siting 25 MW of renewable energy capacity on its properties by 2025 (NYCHA, 2019b). To reach this goal, NYCHA created the ACCESSolar (ACcelerating Community Empowered Shared Solar) program. ACCESSolar generally installs 40 kW or less of solar capacity per rooftop, which is not enough to power an entire building, but would supplement a building's energy supply, reducing its dependence on a "dirty" energy grid (NYCHA, 2019b). Because of this program, solar panels were removed from consideration for this paper as NYCHA already has a plan to implement solar for NYCHA buildings, at least at a small scale.

## Discussion

When considering increased insulation, it is important to recognize the effects this will have on indoor air quality. With increasing insulation, there will be less air flow between the indoors and outdoors, requiring increased ventilation. This ventilation would add to the cost of increased insulation, increasing the payback

period. However, these additional costs were not factored into the analysis in this paper because NYCHA already has plans to update ventilation in their apartment buildings. In April 2016, NYCHA released its NextGeneration Sustainability Agenda, which detailed its plans to modernize its ventilation systems by providing fans that use less energy and require fewer repairs for the 65% of all NYCHA apartments that have mechanical ventilation (Ghabaee, 2019). These upgrades will provide adequate, code-required ventilation rates to all mechanically ventilated spaces, facilitating the implementation of further insulation.

There is also the question of NYCHA's ability to maintain new insulation features such as green roofs and shades. In recent years, NYCHA has struggled with its inability to address major maintenance issues such as elevator outages, broken boilers, and mold due to a lack of funds and manpower (Santiago, 2019). Without dramatic change, by 2027, 90% of NYCHA apartments will no longer be cost-effective to repair (Ferré-Sadurní, 2018). Although the changes proposed in this paper will require time, money, and skilled workers to implement, they will save far more resources than they cost, starting within six years of implementation. If started in the next few years, these improvements could be completed before 2027. The need for improved insulation is an increasingly pressing issue for NYCHA because 87% of NYCHA apartments went without heat or hot water during the 2018-2019 heat season (Ricciulli, 2019). Increased insulation would keep the cold out of apartments during the winter while heating repairs are made.

## Conclusions

Overall, NYCHA's implementation of energy-saving roofing and windows would improve the energy efficiency and climate resiliency of its buildings. Green roofs were found to be the most beneficial roofing material while single pane glass with Roman shades with prelayered fabric was the most cost-effective window pairing. Combined, these improvements would take under six years to pay off, and would provide long-lasting benefits, ranging from energy and maintenance savings for NYCHA to an increased quality of life for residents of NYCHA buildings. Improved insulation would provide NYCHA with the much-needed funds to repair the aging infrastructure on its properties, creating a sustainable solution, both environmentally and economically, that targets the root cause of the problems that affect NYCHA residents.

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