RetrofitNY Cost-Compression Study Phase Two:

Opportunities for Cost-Effective Improvements in Net Zero-Level Performance Multifamily Residences

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RetrofitNY
Cost-Compression Study Phase Two:

Opportunities for Cost-Effective Improvements in Net Zero-Level Performance Multifamily Residences

Final Report

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Notice

Abstract

New York State Energy Research and Development Authority's (NYSERDA) Request for Proposal (RFP) 3750 RetrofitNY High-Performance Retrofit Solutions Design aimed to spark the creation of standardized, scalable solutions and processes to improve the performance of multifamily residential buildings in New York State. This report focuses on functional specifications to achieve a net zero or near-net zero level of performance in the one- to three-story, low-rise typology for multifamily residential housing in New York State.

Detailed information is presented on the window, wall, roof, foundation, air tightness, heating, cooling, dehumidification, domestic hot water, and ventilation system efficiencies and loads that correspond to the target performance levels. These figures are provided for use in sizing and designing solutions that will be aligned with the target market's needs. Target price points for envelope and mechanical solutions are also provided.

Keywords

Net zero, construction cost, incremental cost, retrofit cost, RetrofitNY, PON 3750, electrification, air-source heat pumps, energy-recovery ventilation, envelope improvement, cost compression, specification, EUI, energy use intensity

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Executive Summary

This report focuses on functional specifications to achieve a net zero or near-net zero level of performance in the one- to three-story, low-rise typology for multifamily residential housing in New York State. For the one- to two-story buildings in the low-rise typology, a site energy use intensity (EUI) of 27–30 kilo-British thermal units per square foot (kBtu/ft^2) per year is a good target for achieving net zero performance. For three-story buildings, however, a lower EUI of 21 kBtu/ft^2 is needed to achieve a net zero solution using roof mounted solar PV panels, due to the greater occupied square footage per usable roof area. The low-energy usage needed in buildings four stories and taller to achieve net zero energy (NZE) performance via roof-mounted solar PV is next to impossible to achieve in the studied climate.

The following functional specifications are presented for achieving net zero performance for the low-rise typologies. The EUI target for one- and two-story buildings assumes electric resistance, domestic hot water heating, while the target for the three-story and taller buildings assumes a heat pump water heater.

Metric	Performance Target
Heating/cooling demand	12 kBtu/ft^2·yr
Dehumidification	0.012 lbs/lb
Energy recovery ventilations rates	20 cfm/bath and 25 cfm/kitchen exhaust with corresponding supply (min 15 cfm/person)
Domestic hot water supply	Load modeled per EERE DHW Event Generator
Overall building EUI (one- to two-story)	27 kBtu/ft^2·yr
Overall building EUI (three-story+)	21 kBtu/ft^2·yr

In addition to the requirements listed above, the following criteria are also recommended:

1. It is recommended that the combined space heating and cooling site EUI not exceed 6 kBtu/ft^2·year.
2. Minimum heating season space temperature: 68°F (daytime: 6 a.m.–1:00 p.m.), 62°F (nighttime: 10 p.m.–6 a.m.) which aligns with New York City code requirements.
3. Maximum cooling season space temperature: 78°F as encouraged by NYC for low-intensity cooling to prevent adverse health effects.
4. Apartment ventilation will be continuous and comply with the following:
   - The average daily air change due to ventilation should be between 0.3 and 0.5 air changes per hour (ACH) when possible to ensure adequate ventilation while preventing overly dry air.
   - Exhaust and supply streams should be balanced within 10% of each other as measured at the ventilation unit.
5. Lighting and plug load EUI assumptions should be no less than 12 kBtu/ft^2 per year.

Additional detailed information is presented on the window, wall, roof, foundation, air tightness, heating, cooling, dehumidification, domestic hot water, and ventilation system efficiencies and loads that correspond to the target NZE EUIs presented above. These figures are provided for use in sizing and designing solutions that will be aligned with the target market's needs.

Target price points for envelope and mechanical solutions are also provided. These price points are calculated based on a payback on avoided utility cost from a high-performance solution plus the base cost of business as usual replacement strategies.

Much of the information and many of the recommendations in this report are based on the final reports generated by the six solution provider teams selected through NYSERDA's Request for Proposal (RFP) 3750 RetrofitNY High-Performance Retrofit Solutions Design which was aimed at sparking the creation of standardized, scalable solutions and processes to improve the performance of multifamily residential buildings in New York. Refer to the Phase One report for a more detailed review of those studies.

1 Introduction: Recommended Site Energy Use Intensity Target for Low- and Mid-Rise Typology

This report focuses on functional specifications to achieve a net zero or near-net zero level of performance in both the one- to two-story, low-rise and the four- to six-story, mid-rise typologies for multifamily residential housing in New York State. Much of the information and many of the recommendations in this report are based on the final reports generated by the six-solution provider teams selected through New York State Energy Research and Development Authority's (NYSERDA) Request for Proposal (RFP) 3750 RetrofitNY High-Performance Retrofit Solutions Design which was aimed at sparking the creation of standardized, scalable solutions and processes to improve the performance of multifamily residential buildings in the State. Refer to the Phase One report for a more detailed review of those studies.

While the RetrofitNY teams didn't evaluate any three-story buildings in the low-rise typology, further research conducted by NYSERDA revealed that a significant portion of the State's existing building stock consists of three-story buildings with up to nine units (see Table 1), and therefore, they are specifically called out in this report.

Table 1. Breakdown of Low-Rise Typology by Number of Stories and Units per Building

Low-Rise Buildings	Number of Bldgs. Sampled	Units per Building					
		1–9	10–19	20–29	30–39	40–49	50+
One-Story	817	45%	16%	8%	5%	4%	22%
Two-Story	9,650	66%	8%	5%	3%	2%	15%
Three-Story	13,532	79%	10%	3%	2%	1%	5%

For the one- to two-story buildings in the low-rise typology, a site energy use intensity (EUI) of 27 kilo-British thermal units (kBtu) per square foot ($/ft^2$) per year is a good target for achieving net zero performance. This recommendation is based on Steven Winter Associates' (SWA) review of the results in the RetrofitNY reports along with calculations to determine the amount of solar needed to achieve a net zero solution. SWA's calculations for the three low-rise projects resulted in values between 29 and 30 $kBtu/ft^2$ per year for a site EUI that could be offset by solar photovoltaic (PV) on the roof. The following are the assumptions behind this threshold:

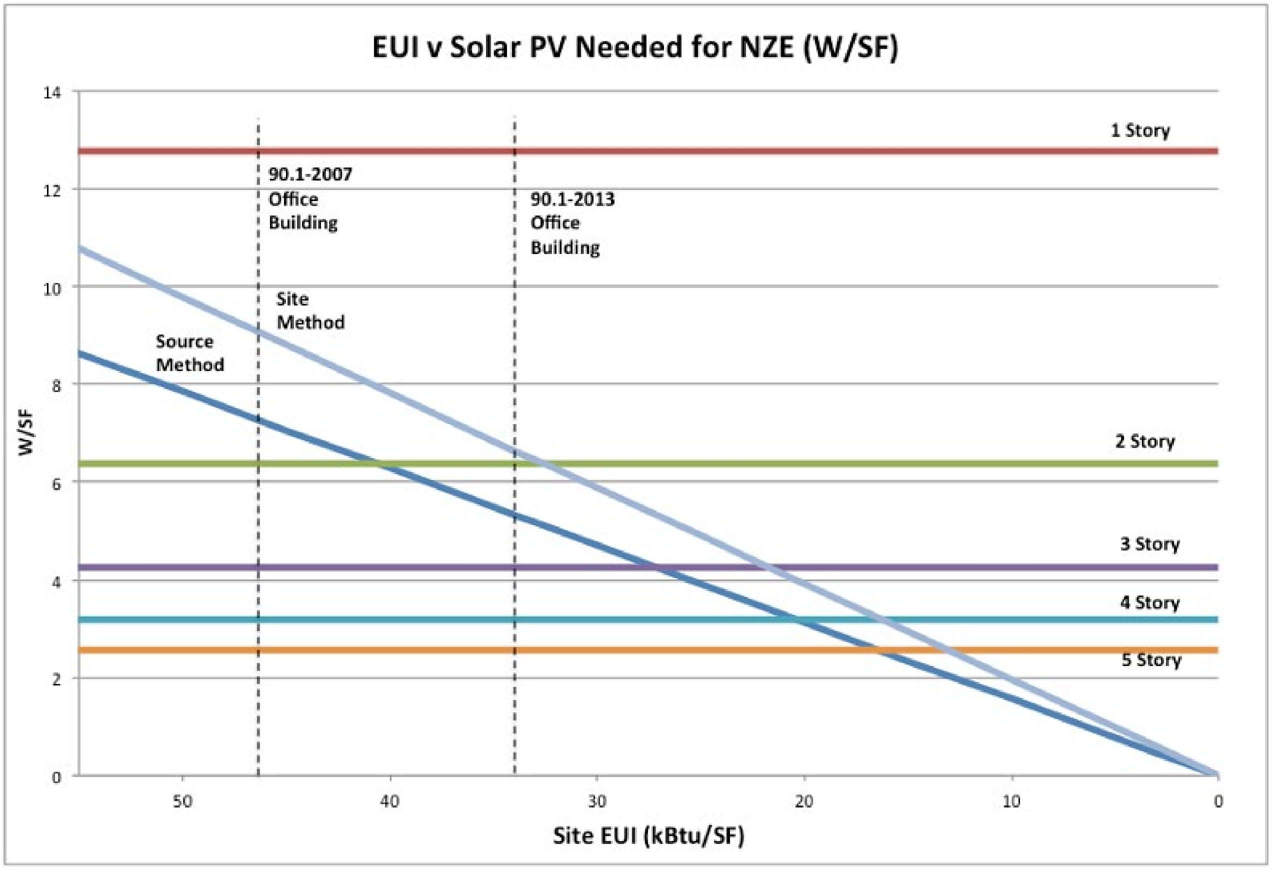
- Eighty percent of the roof is available (this may be high, but low-rise buildings tend to have less equipment on their roofs)
- Eighteen watts (W)/ft^2 for PV output
- Total calculated kilowatt-hour (kW) per year (/yr) output of array determined with PV watts for each of the three locations

This value is also in line with the New Buildings Institute analysis[1] of net zero EUI targets based on number of stories in the building. In their graph below, the green two-story line intersects with the grey line indicating that, for a two-story building with a site EUI of about 30 kBtu/ft^2 per year, the building would require about 6.5 W/ft^2 (of total conditioned area) of PV production per square foot of available roof area.

1 Net Zero Energy is Achievable Here's How, by Joshua Radoff; https://www.buildinggreen.com/blog/net-zero-energy-achievable-here-s-how

Figure 1. Energy Use Intensities versus Solar PV Needed for Net Zero Energy Performance (New Buildings Institute)

Source: Joshua Radoff



When this factor is applied to the RetrofitNY projects, the required PV production for net zero performance comes in slightly under the total capacity that can fit on 80% of each of the project roofs. Based on this cross-check, NYSERDA's value of 27 kBtu/ft^2 for the final designs was a good target and could probably be relaxed a little more if needed. If kept at 27 kBtu/ft^2 per year for the low-rise (one- to two-story) projects, there will be a buffer built in.

For three-story buildings, however, a lower EUI is needed to achieve a net zero solution using roof mounted PVs. Using Figure 1 again, the light blue-gray site EUI line can be followed down to the intersection with the purple three-story line at approximately 21 kBtu/ft^2. This lower EUI allowance is a result of the greater occupied square footage per usable roof area. Because of this, SWA has provided two EUI targets for the low-rise typology—one for the one- to two-story buildings (27 kBtu/ft^2) and another for three-story buildings at 21 kBtu/ft^2.

SWA's recommended EUI target for the mid-rise typology is the same as the three-story example. As can be seen in Figure 1, the taller the building, the lower the EUI must be to achieve net zero performance using roof installed PV only. The EUIs shown for buildings four stories and taller are next to impossible to achieve, making net zero energy performance for taller buildings problematic beyond the issue of available roof area.

First, as multifamily buildings get taller, their common area end uses often get larger due to requirements for double loaded corridor lighting, elevators, cold water booster pumps and central recirculating mechanical systems. Due to code and health concerns, there are limited opportunities to reduce these loads. Additionally, the equipment needed for the central systems is generally installed on the roof of taller buildings further reducing the amount of roof mounted PV that can be installed. Building integrated PV can be considered to help offset the EUI but its effectiveness/applicability may be drastically affected by shading from nearby buildings, orientation, and its slope. Where possible, ground mounted PV or installation on a neighboring building could be considered as well.

2 Task 4: Functional Specification for Low- and Mid-Rise Typologies

The following functional specifications for achieving net zero performance for the low- and mid-rise typologies are based on SWA's extensive expertise and experience consulting on high-performance buildings along with its prior work performed for NYSERDA in this area. The EUI target for one- and two-story buildings assumes electric resistance domestic hot water heating, while the target for the three-story and taller buildings assumes a heat pump water heater. The values in Table 2 summarize the corresponding performance targets.

Table 2. Recommended Performance Targets

Metric	Performance Target
Heating/cooling demand	12 $kBtu/ft^2 \cdot yr$
Dehumidification	0.012 lbs/lb
Energy recovery ventilations rates	20 cfmf/bath and 25 cfmf/kitchen exhaust with corresponding supply (min 15cfm/person)
Domestic hot water supply	Per EERE DHW Event Generator[a]
Overall building EUI (one- to two-story)	27 $kBtu/ft^2 \cdot yr$
Overall building EUI (three-story+)	21 $kBtu/ft^2 \cdot yr$

[a] See: https://www.energy.gov/eere/buildings/downloads/dhw-event-schedule-generator for further detail.

In addition to the requirements listed in Table 2, the following criteria are also recommended.

- It is recommended that the combined space heating and cooling site EUI not exceed 6 $kBtu/ft^2 \cdot year$.
- Minimum heating season space temperature: 68°F (daytime: 6 a.m.–10 p.m.), 62° F (nighttime: 10 p.m.–6 a.m.) which aligns with New York City code requirements.
- Maximum cooling season space temperature: 78°F as encouraged by NYC for low-intensity cooling to prevent adverse health effects.
- Apartment ventilation will be continuous and comply with the following:
    - The greater of 20 cubic feet per minute (cfm) per bathroom + 25 cfm per kitchen exhaust or 15 cfm per person based on number of bedrooms +1.
    - The average daily air change due to ventilation should be between 0.3 and 0.5 air changes per hour (ACH) when possible to ensure adequate ventilation while preventing overly dry air.
    - Exhaust and supply streams should be balanced within 10% of each other as measured at the ventilation unit.

Lighting and plug load EUI assumptions should be no less than 12 $kBtu/ft^2$ per year.

- Three-story and taller typologies must include heat pump water heaters.

2.1 Panelized Envelope Solutions

2.1.1 Results from RetrofitNY Study

Table 3 and Table 4 summarize the façade efficiencies assumed in the midterm and final phase of the design analysis performed by the RetrofitNY teams. This information combined with SWA's extensive experience analyzing high-performance buildings informed the recommended efficiencies for the fenestration and the panelized wall and roof assemblies in Table 5.

Table 3. RetrofitNY Results Summary—Low-Rise Typology

	ICAST Mid/Final	King + King Mid/Final	SWBR Mid/Final[c]
Climate Zone	*5*	*5 (on border of 6)*	*6*
Roof [F ft² hr/Btu]	R-70/R-70	R-62.5/ R-62.5[a]	R-70/ R-80
Walls [F ft² hr/Btu]	R-25/R-25	R-37/ R-17[b]	R-43/ R-41
Windows [Btu/hr ft² F]	U-0.18/U-0.18	U-0.16/ U-0.16	U-0.18/ U-0.18
Foundation [F ft² hr/Btu]	R-20/R-10	R-5/ R-5	R-10/ R-10
Air Tightness [ACH@50]	1.0 ACH/2.5 ACH	2.0 ACH/2.0 ACH	1.1 ACH

a Values less efficient in final are in red.

b Values that existed in baseline and will not be altered are in green.

c Few midterm results could be found for SWBR. Assumed most values were the same in both phases of the study.

Table 4. RetrofitNY Results Summary—Mid-Rise Typology

	Bright Power Mid/Final	CBRA Mid/Final	LEVY Mid/Final
Climate Zone	*4*	*4*	*4*
Roof [F ft² hr/Btu]	R-66/R-46	R-60/ R-60	R-52/ R-37
Walls [F ft² hr/Btu]	R-24/R-0	R-30/ R-30	R-20/ R-20
Windows [Btu/hr ft² F]	U-0.28/U-0.28	U-0.16/ U-0.16	U-0.22/ U-0.28
Foundation [F ft² hr/Btu]	R-24/R-0	R-20/ R-20	R-8/ R-0
Air Tightness [ACH@50]	0.3 ACH/2.3 ACH	0.5 ACH/0.5 ACH	2.0 ACH

2.1.2 Recommended Building Envelope Efficiencies

Table 5 summarizes the recommended package of efficiencies for the envelope components for each of the three climate zones in New York State. These values correspond with the values derived in the RetrofitNY study and were confirmed through some simple Passive House Planning Package (PHPP) modeling for a building of a similar type and size in each of the three climate zones. shows the results of the modeling and the range of values associated with the range of heating degree days for each climate zone. Assuming the recommended assumptions and criteria listed above, both the site EUI thresholds of 27 and 21 kBtu/ft^2 per year and the combined heating/cooling energy demand of 12 kBtu/ft^2 per year can be met with these efficiency values for most locations in the State.

Table 5. Proposed Façade Efficiencies by Climate Zone

	Zone 4	Zone 5	Zone 6
Panelized envelope R value	R-30	R-35	R-45
Fenestration U values	U-0.16	U-0.16	U-0.16
Roof system R value	R-50	R-60	R-75

Table 6. Energy Use Intensities and Heating/Cooling Demand Results by Climate Zone

	Zone 4	Zone 5	Zone 6
Heating Degree Days [65°F]	5400	5400< HDD 65F ≤ 7200	7200< HDD 65F ≤ 9000
Heating + Cooling Demand [kBtu/ft^2·yr]	12	11–13	11–14
Heating + Cooling EUI [kBtu/ft^2·yr]	4	4–6	5–7
Site EUI (one to two-story) [kBtu/ft^2·yr]	26	26–29	27.5–31.5
Site EUI (three+-story) [kBtu/ft^2·yr]	19	19–21	20–23

2.1.2.1 Modeling Assumptions

The following assumptions were held constant across all climate zones:

- Occupants: number of beds +1
- Solar Heat Gain Coefficient: 0.4
- Doors: R-2.5
- Ventilation: 84% effective
- Infiltration: 1.5 ACH@50
- Domestic Hot Water: 15 gallons/person/day, electric resistance tank for one- to two-story and heat pump water heater for three-story and higher

2.1.3 Infiltration Rates

The air leakage rate of the building following completion of the envelope improvements should be no higher than 1.5 air changes per hour at 50 pascals of pressure. Controlling infiltration rates through the envelope is paramount to ensuring performance and durability of the structure. Heating and cooling load calculations rely heavily on the assumptions made for this characteristic. Therefore, a detailed plan for implementing air tightness of the panelized approach is required along with a strategy for field testing the performance of the panelized walls, windows, and roof during and after construction. Details showing the air barrier strategy must be created for all connections, penetrations, and openings in the façade. Specific materials should be called out and compatibility between the sealants and building materials confirmed. All sealants should be in serviceable locations, long lasting, and easy to apply.

Factory testing of a mock-up must be conducted on each unique proposed panel solution and should include the following:

- Air infiltration: Fixed Wall: 0.06 cfm/ft^2 of wall area at 6.24 psf per ASTM E283/ Operable vents and doors: 0.10 cfm/ft^2 of crack at 6.24 psf per ASTM E283/ Continuous air and vapor control layers will be provided.
- Water Infiltration: No water infiltration will occur under a differential static pressure of 12 lb/ft^2 after 15 minutes of exposure in accordance with ASTM E331.

2.1.4 Overall Façade U-values

Recommendations for façade efficiencies are given in Table 5. These are guidelines and can be altered as long as the overall U-value for the building envelope including the windows does not exceed what it would otherwise have been if those recommended values are used. Calculations proving similar overall U-values are required. The items in the following sections must be included in the overall U-value calculations.

2.1.4.1 Panel Connections to Structures

Panel connections back to the structure can drastically reduce the overall performance of the façade if techniques for reducing thermal breaks are not incorporated. Thermally broken ties, clips, and rails should be used to make these connections. Three-dimensional thermal modeling should be utilized when determining the overall R-value of the panelized solutions.

2.1.4.2 Panel to Panel Joints

Panel connections traditionally prove to be large thermal bridges. These connections will be modeled using two- or three-dimensional thermal modeling to assess the magnitude of heat loss at these joints and to ensure condensation control has been maintained.

2.1.4.3 Window and Door Installation

Punched openings in the façade can represent a significant source of heat loss if not detailed properly. Window and door installation will be evaluated on a per linear foot basis using two-dimensional thermal modeling. Temperatures along the entire install must prove to be above the dewpoint at the winter design temperature for the location where the solution is to be installed. Interior conditions of 68°F and 50% relative humidity will be used to determine the dewpoint.

2.1.5 Bulk Water Management

A clearly delineated water management layer must be provided for the panelized system. Details showing the bulk water management strategy must be created for all connections, penetrations, and openings in the façade. Specific materials should be called out and compatibility between the sealants and building materials confirmed. All serviceable sealants will be in accessible locations, long lasting, and easy to apply.

2.1.6 Moisture Vapor Control

Moisture vapor will be controlled through a combination of proper levels of ventilation and the incorporation of a vapor control strategy within the panelized solution. A moisture analysis for each panelized system will be conducted according to ASHRAE Standard 160 Criteria for Moisture-Control Design Analysis in Buildings and must show that there is no potential for mold or decay on the interior surfaces of the building or within the panels.

A dewpoint analysis must also be conducted using two-dimensional thermal modeling to verify where the dewpoint falls within the wall assembly and that there is no potential for damage at that location.

2.1.7 Windows and Doors

The efficiency targets for the windows are listed in Table 5. Again, these are recommendations and can be altered if the overall U-value of the façade solution can be maintained. The target R-value for the doors in buildings with common exits is 2.5°F·ft^2·hr/Btu. For single-family homes, duplexes, and row houses where each dwelling unit has its own exit, the target value for doors should R-7. The most efficient opaque doors, where fire rated assemblies are not required, are typically foam filled, fiberglass doors, which are readily available in cost-effective solutions. Storm doors are recommended to increase the efficiency of these components.

2.1.8 Examples of Potential Panelized Systems

2.1.8.1 SenerPanel—BASF

The SENERPANEL CI system combines the Senergy Insulated Wall Systems with the benefits of indoor factory panel fabrication. Up to 12 inches of expanded polystyrene (EPS) can be used to provide R-45 continuous exterior insulation while meeting International Building Code (IBC) fire requirements, including National Fire Protection Association (NFPA) 285 and American Society for Testing and Materials (ASTM) E119. This high-insulation value can be further improved by replacing conventional EPS with BASF Neopor GPS insulation, which offers up to R-60 at a 12-inch insulation thickness.

2.1.8.2 BuildSmart

BuildSMART provides prefabricated building envelope systems in the United States and Canada. Their process is computer driven allowing them to offer mass-customization. Build SMART exterior wall panel assemblies are produced per order. The company collaborates with architects to ensure that the design intent, R-value, and fire resistance requirements of each project are satisfied. Panels can be produced to meet particular energy requirements, cost requirements, and design goals. The firm claims to meet Passive House thermal bridging and insulation requirements.

2.1.8.3 Bensonwood

Bensonwood builds high-performance prefabricated wall and roof systems at their manufacturing facility in southwestern New Hampshire. All components are engineered with virtual models before construction starts eliminating potential issues, guaranteeing a high-quality and consistent assembly every time. Panels can meet Passive House and net zero standards for high-performance building.

2.1.8.4 Ecocor

Ecocor produces panelized Passive Homes using prefabricated panels. The panelized wall sections are transported to the building site, where they are erected in a fraction of the time conventional construction requires. This provides more precision, better quality, and the construction time is much shorter compared to building similar houses entirely on site.

2.2 Mechanical Pod

Integrated product specifications for the mechanical pod should include the following:

- Design and performance considerations for consolidated HVAC solutions to deliver heating, cooling, ventilation, dehumidification, and domestic hot water for:
  - one- to three-story, low-rise multifamily residential housing in New York State
  - four- to seven-story, mid-rise multifamily residential housing in New York City

Considerations for consolidated HVAC solutions will include spatial constraints, performance impacts, and installation considerations. All solutions will include open-source controls capable of connection to non-proprietary, cloud-based monitoring platforms. Controls interfaces for residents will be located in the occupied space.

2.2.1 RetrofitNY Results Summary

The RetrofitNY modeling summary results did not provide the peak heating or cooling loads (outputs the mechanical solution must meet) for either the interim or final designs. Table 7 is a summary of the heating, cooling, domestic hot water (DHW), and ventilation information that SWA was able to obtain from the teams.

Table 7. Summary of Mechanical Loads from RetrofitNY Project Team Models

	ICAST	King + King	SWBR
Heating EUI (kBtu/ft^2/year)	2.98	5.1	2.2
Heating peak load (Btuh/ft^2)	not provided	not provided	not provided
Climate zone	*5*	*5 (on border of 6)*	*6*
Cooling EUI (kBtu/ ft^2/year)	1.82	0.7	1.1
Cooling peak load (Btuh/ft^2)	not provided	not provided	not provided
Domestic hot water EUI (kBtu/ft^2/year)	5.94	5.3	5.4
Ventilation EUI (kBtu/ ft^2/year)	Not reported*	Not reported*	5.4

* Ventilation loads were included in rolled up electrical load totals.

Table 8. Summary of Mechanical Loads from RetrofitNY Project Team Models

	BrightPower	CBRA	LEVY
Heating EUI (kBtu/ft^2/year)	5.7	1.03	0.7
Heating peak load (Btuh/ft^2)	not provided	3.5	6.2
Climate zone	*4*	*4*	*4*
Cooling EUI (kBtu/ ft^2/year)	1	0.92	2.2
Cooling peak load (Btuh/ft^2)	not provided	1.8	4.2
Domestic hot water EUI (kBtu/ft^2/year)	4.7	6.6	7.2
Ventilation EUI (kBtu/ ft^2/year)	Not reported	2.12	0.6

Therefore, SWA calculated both heating and cooling loads using the PHPP software for a three-story, 10-unit building with the same envelope and mechanical efficiencies recommended per climate zone in this functional specification. The results are displayed in Table 9.

Table 9. Heating and Cooling Loads by Climate Zone

Loads		Cooling		Heating	
Zone	HDD	Btu/hr per 1000 ft^2	tons/1000 ft^2	Btu/hr per 1000 ft^2	tons/1000 ft^2
4	5200	2470	0.21	5930	0.5
5	5400	2250	0.19	5640	0.5
	7200	2190	0.18	6800	0.6
6	7200	1820	0.15	5980	0.5
	9000	690	0.06	6780	0.6

2.2.1.1 Supplemental Domestic Hot Water Load Data

DHW loads are highly variable based on occupant density and resident schedule. The tools linked to below provided by United States Department of Energy and the National Renewable Energy Lab can be used to generate typical residential load profiles for residential units of varying size. Certain aspects of DHW use can be reduced by the installation of low-flow fixtures, but other end uses, such as filling pots and bathtubs, require a set volume of water regardless of in-unit intervention, which creates a minimum for the DHW water needed. DHW solutions will be able to meet typical usage profiles.

Table 10. Typical Domestic Hot Water Usage Profiles

Apartment Size	Avg Daily Draw (Hot + Cold) (gal per day)	Avg Daily Draw (Hot Only) (gal per day)	Avg Daily Draw (Cold Only) (gal per day)
One Bedroom	46	30	16
Two Bedroom	58	37	21
Three Bedroom	70	45	25
Four Bedroom	81	52	29
Five Bedroom	93	60	33

[a] https://www.energy.gov/eere/buildings/downloads/dhw-event-schedule-generator

[b] https://www.nrel.gov/docs/fy10osti/47685.pdf

2.2.1.2 Recommended Mechanical System Efficiencies

The proposed system must be able to meet the peak loads with some safety factor and do so efficiently enough to meet or improve upon the heating, cooling, and domestic hot water EUI targets provided. Tradeoffs on efficiency can be made between heating, cooling, and DHW efficiencies individually, but the solution must be efficient enough to stay under the sum of the EUI targets shown above.

Table 11. Example Efficiencies Modeled by RetrofitNY Project Teams

	ICAST	King + King	SWBR	BrightPower	CBRA	LEVY
DHW	2.75 COP	3.3 COP	0.93 EF	2.95 COP	90+ AFUE	4.5 COP
Heating	11 HSPF	2.2 COP@5F	10 HSPF	3.6 COP	3.6 COP	3.5 COP
Cooling	19.6 SEER		21 SEER	11 EER	12.7 EER	3.5 COP
Ventilation*	85	65	72	85	83	85

Note: not all values were available for all projects.

* Sensible effectiveness

2.3 System Interactions/Considerations

2.3.1 Dehumidification

Dehumidification is not broken out as a separate end use but is assumed to be included in the cooling load. The proposed solution will include dehumidification, accounting for the fact that traditional off-the-shelf terminal units are typically not available in sizes small enough to match the site EUI targets above. Oversized cooling equipment engineered to meet sensible cooling loads typically cycle off and on before adequate dehumidification can occur.

The proposed solution will address dehumidification by providing (1) properly sized cooling units, (2) a dehumidification system in or additional to the ventilation system, or (3) a combination of both. Climate data, including cooling wet bulb and dry bulb design conditions, will be used to determine dehumidification load. The indoor humidity will remain under 0.012 lbs/lb for at least (1) 90% of annual operating hours if active cooling is provided or (2) 80% of annual operating hours without active cooling.

2.3.2 Ventilation

Minimum mechanical ventilation rates required by local building code will be required for all systems (see IMC Section 403.3.2 for rates for R-2 occupancies three stories or less in height).[2] The minimum continuous outdoor airflow rate will be determined in accordance with Equation 4-9.

Figure 2. IMC Section 403.3.2 and Equation 4.9

Source: See ICC Digital Codes Library[3]

$$Q_{OA} = 0.01A_{floor} + 7.5(N_{br} + 1) \quad \text{(Equation 4-9)}$$

where:

Q_{OA} = outdoor airflow rate, cfm

A_{floor} = floor area, ft^2

N_{br} = number of bedrooms; not to be less than one

TABLE 403.3.2.3
MINIMUM REQUIRED LOCAL EXHAUST RATES FOR GROUP R-2, R-3, AND R-4 OCCUPANCIES

AREA TO BE EXHAUSTED	EXHAUST RATE CAPACITY
Kitchens	100 cfm intermittent or 25 cfm continuous
Bathrooms and toilet rooms	50 cfm intermittent or 20 cfm continuous

Natural ventilation will not be relied on for meeting ventilation rates in occupied units or common areas.

2 https://codes.iccsafe.org/content/IMC2018P3/chapter-4-ventilation#IMC2018P3_Ch04_Sec403.3.2

3 https://codes.iccsafe.org/content/IMC2018P3/chapter-4-ventilation#IMC2018P3_Ch04_Sec403.3.2

All exhaust air will be routed through an energy or heat recovery ventilation unit (ERV/HRV) unless prohibited by code or when located a great distance from the nearest supply air intake to make it ineffective. Ventilation strategies should include methods for preventing freezing in the cores while providing the minimum required ventilation rates. Supply temperatures to the space will be no colder than 62°F in the heating season. Energy recovery ventilator (ERV) fan power input should be no higher than 0.76 Watts per cfm at continuous flow. Exhaust and supply flow rates will be balanced to within 10% of each other to ensure maximum recovery efficiency. Sound levels should be no higher than 25 decibels (dBA) in bedrooms and 30 dBa in extract rooms such as kitchens and baths. Note that sound levels in occupied spaces are driven largely by the grille and ductwork serving the space. Manufacturers can recommend maximum termination noise limits and/or suggested grille models for their systems.

Exhaust gas and electric dryers require make-up air if they exhaust over 200 cfm to the exterior. To reduce thermal bridging and air leakage around penetrations and remove the need for make-up air, it is recommended that exhaust dryers be eliminated and replaced with condensing or heat pump units.

2.3.3 Domestic Hot Water

The proposed domestic water heating solution will be capable of producing high-temperature hot water for instantaneous delivery of at least 130°F and/or storage of at least 145°F. These temperatures are seasonal minimums that may be exceeded but not reduced.

2.3.4 Heating and Cooling

Any proposed solution must maintain low enough noise output to comply with local noise ordinances. New York State towns and cities have individual official rules, but typically, noise from HVAC equipment must result in less than 45 dBa of noise at a resident’s open window. This is a cumulative noise limit; with noise from individual products low enough so that an array of units deployed in a given building will not surpass the total noise limit.

Any product specification should utilize inverter-driven compressors and electronically commutated motors (ECM) wherever applicable. The target market of retrofit buildings will have exceptionally low-space conditioning loads, which will require solutions that can modulate down to very low outputs.

2.4 Further Considerations

Manufacturers can propose new solutions to meet the typical loads of a high-performance building based on a series of typical loads and considerations provided above. The manufacturers may choose to meet those loads in a variety of ways. The end-use energy budget (above) is so low that SWA believes no efficiency requirements need to be given. This will allow manufacturers to make tradeoffs between

heating, cooling, and water heating as required. Efficiency values modeled by the RetrofitNY teams are also provided above for reference, but it is noted that the teams achieved the energy budget target with a range of efficiencies varying by end use.

Solutions may tend towards terminal-unit-driven (such as split heat pumps where the terminal unit output is constrained within a range). They may also tend towards system-driven (such as a unitized hydronic solution where the single outdoor size governs, and the terminal units are simple and flexible via flow balancing). SWA recommends providing per-square foot targets and goals and allowing the manufacturers to roll those up to room-level or apartment-level as is rational for the type of system they are proposing. The totalized EUI targets from Table 7 will be used as budgets for total heating, cooling, DHW, and ventilation system solutions.

Residential units in properties with central domestic hot water supply may require some reconfiguration to be compatible with unitized integrated solutions. The domestic hot water solution will likely require a storage tank for each zone served, which would probably take the form of a storage tank replacing an existing storage water heater in the apartment.

2.5 Products and Features [Nearly] Available Today

Many products on the market or about to enter the market have excellent features to be encouraged in future product development. In instances where features are proprietary and/or subject to patents, SWA has not evaluated the ready availability of these features.

2.5.1 Domestic Water Heating

Sanden is using CO_2 as a refrigerant for low global warming potential (GWP) and excellent cold weather performance. They also use a variable speed system to ensure consistent thermal output at a very wide range of outdoor air temperatures, so the plant does not need to be oversized to meet design day output. The only unit available in the U.S. today is a residential-sized unit, which supplies 15,400 British thermal units per hour (Btuh).

Colmac has bigger sized units and thoughtfully designed components for service and modular connection. Their units use R410a refrigerant or an R134a and R410a cascade. This plus vapor-injected scroll compressor use allows their units to deliver hot water in cold climates. These refrigerants produce lower temperature water than CO_2-based systems do in cold weather, typically dropping down below 140°F on design days.

Both manufacturers produce split system heat pumps with water connections. These units are sited outdoors so they do not create any uncomfortable cold spots in the occupied units.

2.5.2 Space Heating/Cooling

Gree has developed a variable refrigerant flow (VRF), "outdoor unit" that fits inside of a packaged terminal air conditioner and heat pump (PTAC) sleeve (42 inches x 16 inches). This outdoor sleeve unit is then connected to typical indoor heat pump units via typical flexible mini split line sets. The product is exciting for a few reasons. The sleeve form factor of the outdoor unit allows it to work with outdoor airflow on only one side of the unit. A typical split system outdoor unit requires airflow on front and back. Moving towards a panelized modular product will be much easier if the product only requires one side be exposed to the outdoors.

Gree also has a product line that combines a heat pump outdoor unit with a solar inverter, allowing for direct connection from solar PV to the heat pump via DC power. This eliminates inverter losses on all solar power used for heating or cooling. Additional solar production leaves the heat pump unit as AC power, just as with a standalone inverter. The unit would be eligible for solar incentives because it functions as an inverter, further improving its cost-efficacy. The equipment can also be combined with battery storage.

Several VRF manufacturers offer heat recovery components for generating domestic hot water from the heat pump loop. This equipment is available for three/four-pipe commercial VRF systems only, not for residential grade or non-simultaneous switchover heating and cooling systems.

Residential-grade heat pump systems (mini splits and multi splits) tend to have significantly lower costs than commercial or light commercial systems do. The first cost for the material is lower and the use of line sets to indoor units makes it much easier to install than braising or pressing rigid piping. Many more installers are trained in the installation of these smaller systems, as well. These systems require shorter

line lengths than commercial systems, which can be a barrier to using them in mid-rise or high-rise buildings. However, with distance less of a constraint on low-rise retrofit projects, the lower cost residential units may be a better fit.

2.5.3 Ventilation

2.5.3.1 Wishlist Features

Ideally ERV outlets should be integrated with heating/cooling terminal units to allow for simple installation where preconditioned ERV air is supplied at the terminal unit for additional heating or cooling. This would allow for use of ERVs in producing tempered air, which is less expensive than ERVs producing fully conditioned air. The terminal unit in the space would receive some load from ventilation, which would increase the load on the unit. The increased load would not be an issue as market offerings of the unit tend to be too large for low, high-performance loads, making it correctly sized in this situation. Residents would get tempered air added to their space anytime the terminal unit was off, and they would get conditioned fresh air anytime the unit was on.

Integral inlet/outlets for unitized ERVs that provide adequate separation of the two air streams and that allow for easy cleaning of the intake screen to prevent clogging would simplify installation and maintenance.

3 Task 5: Identify Target Price Points

A competitive target price point will encourage building owners to pursue a high-performance solution as part of their business model. The solution will gain increasing market share once the payback falls within the typical investment period, that is, with owners beyond the innovators and early adopters choosing to invest their capital. With investment decisions driven primarily by returns, this report presents those equivalent adjusted price points solutions should achieve.

3.1 Payback Strategies

The following tables outline calculation steps for identifying target price points. Table 12 and Table 13 show a typical distribution of building loads that approximate the high-performance building EUI target. These loads have been translated into estimated operating costs based on typical utility rates, with upstate electricity costs significantly lower than those for New York City.

Table 12 compares these cost breakdowns for a net zero-ready building against those for a gas-heated building. The breakdown illuminates the difference in operating costs an owner could expect if converting from a typical gas-heated, low-rise building to the RetrofitNY solution, with and without solar PV to cover the remaining electrical load. The net zero operating cost is shown for both New York City and upstate conditions. No solar PV is assumed where an operating cost is shown, and the operating cost is shown as $0.00 where solar PV is assumed installed to meet the full building load for net zero operations.

An allowed payback window of 20 years is assumed. This window is multiplied by the operating cost savings to calculate the incremental solution cost allowable in each scenario. The solution cost is estimated assuming a 1,000 ft^2 apartment size.

Table 12. Estimated Operating Costs for Net Zero Solutions in Upstate and New York City Markets against a Typical Moderately Well-Performing, Gas-Heavy Building

	Typical Newer Existing Building on Gas kBtu/ft² Site	Typ NYC Building Example: Op Cost $/ft² per Year	Typ Upstate Building Example: Op Cost $/ft² per Year	Adjusted Loads: Net Zero Building kBtu/ft² Site	Net Zero Example: Op Cost NYC $/ft² per Year	Net Zero Example: Op Cost Upstate NY $/ft² per Year	Net Zero Example: Op Cost NYC $/ft² per Year	Net Zero Example: Op Cost Upstate NY $/ft² per Year
Heat Load	36	$0.28	$0.28	3	$0.15	$0.11	$0.00	$0.00
Cooling Load	15	$0.82	$0.60	8	$0.46	$0.34	$0.00	$0.00
DHW Load	20	$0.16	$0.16	3	$0.18	$0.13	$0.00	$0.00
Misc. House Loads	3	$0.19	$0.14	3	$0.16	$0.12	$0.00	$0.00
Plug Loads	5	$0.29	$0.21	5	$0.26	$0.19	$0.00	$0.00
Total	79	$1.73	$1.39	22	$1.20	$0.89	$0.00	$0.00
Allowed payback window (years)	20							
Equivalent Incremental Install Cost $/dwelling unit—Gas Baseline					$10,495	$10,032	$34,576	$27,776

The same information is shown again in Table 13, but this time against a starting condition of a building served by VRF instead of gas as the pre-retrofit condition. The higher operation cost for the pre-retrofit building compared to the gas pre-retrofit condition results in greater supportable installation costs for the solution in this scenario.

Table 13. Estimated Operating Costs for Net Zero Solutions in Upstate and New York City Markets against a Typical Moderately Well-Performing VRF Building

	Same Building on Central Heat Pump (VRF) and Central HP DHW	Typ NYC Building Example: Op Cost $/ft² per Year	Typ Upstate Building Example: Op Cost $/ft² per Year	Adjusted Loads: Net Zero Building kBtu/ft² Site	Net Zero Example: Op Cost NYC $/ft² per Year	Net Zero Example: Op Cost Upstate NY $/ft² per Year	Net Zero Example: Op Cost NYC $/ft² per Year	Net Zero Example: Op Cost Upstate NY $/ft² per Year
Heat Load	9	$0.49	$0.36	3	$0.15	$0.11	$0.00	$0.00
Cooling Load	12	$0.65	$0.48	8	$0.46	$0.34	$0.00	$0.00
DHW Load	5	$0.30	$0.22	3	$0.18	$0.13	$0.00	$0.00
Misc. House Loads	3	$0.19	$0.14	3	$0.16	$0.12	$0.00	$0.00
Plug Loads	5	$0.29	$0.21	5	$0.26	$0.19	$0.00	$0.00
Total	34	$1.92	$1.42	22	$1.20	$0.89	$0.00	$0.00
Allowed payback window (years)	20							
Equivalent Incremental Install Cost $/dwelling unit—VRF Baseline					$14,338	$10,565	$38,419	$28,309

The solution costs presented above do not include business as usual costs. These are purely incremental. A true total cost of solution should be calculated as follows:

$$\boldsymbol{BAU + incremental = total\ supportable\ cost}$$

Where:

$$\boldsymbol{incremental = annual\ savings \times payback}$$

A typical business-as-usual retrofit cost seen in the Phase One analysis is about $60,000 per unit. Therefore, the supportable cost of the net zero solution would be approximately $85,000–$95,000 per unit installed.

3.2 Cost-Compression Pathways

The total supportable cost of a solution will change with changing utility rates and with changing standards of conducting business as usual. If legislation such as New York City's Climate Mobilization Act assigns a real dollar value to carbon emissions, avoided emissions would then drive up the avoided operating costs, which in turn increases the supportable incremental installation cost of the proposed net zero solution.

Table 14 summarizes the cost estimates from the project team against the supportable net zero project costs calculated above. The King + King team is on target while all other teams have significant overages. It is worth noting that the King + King project does not include substantial exterior wall improvements due to high level of insulation applied during prior renovation, so it does not reflect a comprehensive scope per the program's goals. Comprehensive scopes all require significant cost compression to approach becoming attractive investments.

Table 14. Summary of Cost-Compression Needs Relative to RetrofitNY Project Estimates

Project Team	Site Location	BAU + Incremental Cost $/Unit	Calculated Target Cost $/Unit	Cost Overage %
BRIGHT POWER	NYC	$148,852	$95,721	56%
CBRA	NYC	$205,063	$95,721	114%
LEVY	NYC	$114,718	$95,721	20%
KING + KING	Upstate	$88,085	$88,921	-1%
SWBR	Upstate	$138,151	$88,921	55%

See the Phase One report for detailed manufacturer responses regarding the impact of scaling on price points. Many manufacturers had differing responses to the impact of scale on price, so there is no single one-size-fits-all pathway for compression. Some manufacturers would expect cost decreases of significant magnitude with increased market share. Others would not. The authors also cannot speak to the savings in labor expected from a modular solution or the increase in cost from one manufacturer aggregating specialty products into a modular mechanical pod. Table 14 does show the approximate scale of cost compression that needs to be achieved through those various balancing tradeoffs.

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