# Deep Retrofits for Multifamily: Experiences in Scaling to Zero Energy

## Preprint


Lieko Earle,[1] Paul Torcellini,[1] and Loic Chappoz[2]

*1 National Renewable Energy Laboratory*
*2 NYSERDA*



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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

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# Deep Retrofits for Multifamily: Experiences in Scaling to Zero Energy

*Lieko Earle, NREL*
*Paul Torcellini, NREL*
*Loic Chappoz, NYSERDA*

## ABSTRACT

Zero net energy (ZNE) buildings are needed to reverse the growing trend of increasing energy consumption. But to make dramatic changes, existing buildings must be renovated at scale. In addition, the building stock must be electrified so that its energy needs could be met by renewable generation. Such aggressive goals often mean very high custom design and capital construction costs. Suitable options for comprehensive envelope retrofits can be too expensive to be practical, and electrification requires upgrades to building-level electrical infrastructure. This paper is a case study of eight projects—primarily multifamily residential—that strived for zero-energy, all-electric retrofits. The design teams were challenged to create solutions that could be replicated at scale, showing decreasing costs with broader adoption. Key technologies considered in designing cost-effective, scalable solutions include industrialized prefabricated retrofit components, modular HVAC solutions, and innovative domestic hot water systems. We trace the progress toward the goals set and examine the choices made by the teams as they encountered technical, logistical, and cost barriers. We also discuss financial challenges for multifamily retrofits, provide guidance for incentives, and examine procurement processes for design services and technologies.

## Background

Nationwide, nearly 36 million households live in multifamily buildings, accounting for roughly 26% of all households in the United States (U.S. Census Bureau, 2018). In urban areas, a large fraction of buildings (and therefore, of energy consumption) is multifamily, so these buildings represent a significant opportunity for energy-efficiency upgrades. Within the multifamily domain, affordable housing makes a particularly compelling case for retrofits based on social equity ambitions: Data show that low-income families spend substantially greater fractions of their income on utility bills and are more likely to suffer the health consequences of living in poor indoor air-quality (IAQ) environments. For example, New York households with incomes below 50% of the Federal Poverty Level spend a staggering 35% of their annual income on home energy bills (Fisher, Sheehan & Colton, 2020). As such, retrofitting housing for underserved populations has the potential to both address the affordable housing preservation crisis and help break the cycle of poverty.

Until recently, research in retrofit strategies for existing buildings has historically focused on single-family homes. This is starting to change as housing density is on the rise in urban areas, and several large-scale projects are underway to develop and evaluate net-zero energy ready (NZER) retrofit packages for multifamily buildings, specifically targeting the affordable housing sector. This paper examines the processes and preliminary outcomes of two initiatives embarked on by New York State Energy Research and Development Authority (NYSERDA) between 2018 and 2019, under its RetrofitNY[1] ("Retrofit New York") program. Subject-matter

[1] https://www.nyserda.ny.gov/RetrofitNY

experts from several national laboratories consulted on these projects and helped review design proposals and provide feedback to the design teams. The cross-disciplinary design teams included architects, engineers, energy efficiency consultants, and sometimes, builders and cost estimators.

A central theme to the projects described here is how to retrofit the exterior of buildings using prefabricated panels manufactured offsite. The Dutch organization Energiesprong[2] has been implementing whole-building retrofits based on this concept. Energiesprong uses an innovative public-private partnership that creates the right combination of housing regulations, supply-chain coordination, and financing structures to roll out ZNE retrofits featuring prefabricated exterior insulation, insulated rooftops with solar panels, and new smart heating, ventilation and air-conditioning (HVAC) and domestic hot water (DHW) systems, all within one week from start-to-finish and without displacing the residents. More than 5000 such retrofits have been completed in the Netherlands in the past five years. Energiesprong is also active in the United Kingdom, France, Germany, and Italy, and its success has inspired a number of projects in North America to experiment with similar approaches. In addition to NYSERDA's RetrofitNY, for example, the Rocky Mountain Institute (RMI) launched REALIZE,[3] a prefabricated mass-scale retrofit and financing program, with support from the U.S. Department of Energy (DOE) and California Energy Commission (CEC).

## RetrofitNY

RetrofitNY is a NYSERDA-led initiative that seeks to adapt Energiesprong's deep energy retrofit strategy for New York's affordable multifamily housing. Through a competitive first pilot round, RetrofitNY awarded six design-build teams across New York State (three in New York City, three upstate) in June 2018 to design proof-of-concept high-performance retrofit solutions for low- and mid-rise typologies in the state. The program provided each team with a stipend to help offset the incremental cost of developing a retrofit strategy that goes far beyond a routine and conventional building renovation. A key component of RetrofitNY is the financing plan: Designs must meet the compliance requirements set out in the Request for Proposal (RFP), and NYSERDA would provide up to $40,000 per apartment unit in "gap" funding to enable adoption of innovative measures that are too costly at present without broad market adoption.

The teams were charged to design retrofit solutions that approach NZE levels of performance using products and technologies available in the current market. Each team was led by a partnership between a design-build team and a building owner, and projects required tight collaboration between the designers, financing entities, construction companies, and building owners. Key success metrics were defined to be:

- Improved living conditions for the occupants, including thermal comfort, better IAQ, and aesthetically pleasing façade choices;
- Implementation process that minimizes inconveniences and interruptions (such as displacement) for the occupants;
- Sufficient reduction in utility and maintenance costs as a result of the measures such that the retrofit investments could be justified through financing;

[2] https://energiesprong.org
[3] https://rmi.org/our-work/buildings/realize/

- Scalability of proposed solutions so that they could serve as templates for broad-scale retrofit programs; and
- Demonstrated feasibility of high-performance retrofits for the most prevalent types of multifamily residential buildings in New York State, that also provides a baseline for the current state of the U.S. market.

High-level descriptions of the six projects are given below, and key design features for each retrofit are outlined in Table 1.[4] All six projects were taken through the schematic design phase. The first three in the list are in New York City, and the remainder are in other areas upstate. Each of these buildings had already planned to undergo significant capital improvement work outside the scope of the high-performance energy retrofit, as part of the business-as-usual refinancing cycle. This refinancing process provides great opportunities for NZE retrofits because the major investments available to repair or replace existing systems reduce the incremental cost of the energy retrofit. But the process also adds complexity because multiple stakeholders must be involved, such as NY State and NY City affordable housing agencies and private financiers.

RiseBoro Passive House Retrofit – A partnership between Chris Benedict, RA, and RiseBoro Community Partners, this project is a four-story, 46-unit building in Brooklyn. The envelope is upgraded with a liquid-applied air barrier, exterior expanded polystyrene (EPS) exterior insulation and finish system (EIFS) insulation, and efficient windows to meet PHIUS 2015 standards, creating a completely new look for the building. A new rooftop HVAC system is composed of individual air-source heat pumps for each dwelling unit with roof-mounted outdoor units, and several energy recovery ventilators (ERVs) roof-mounted at the exhaust stacks. Space conditioning is delivered to the dwelling units by installing the heat pumps' refrigerant lines and ERVs' ducts along the building's original exterior, just inside the new EIFS cladding. The natural gas connection is retained, and a condensing boiler coupled with three storage tanks provides inexpensive DHW. Construction started in September 2019 and is expected to be completed in the third quarter of 2020.

Figure 1 – RiseBoro existing building (L) and rendering of post-retrofit (R)
*Photo courtesy: "RetrofitNY: RiseBoro Passive House Retrofit with Tenant in Place Schematic Design" (NYSERDA 2019)*
*Rendering courtesy: Chris Benedict, R.A.*

[4] Full reports for each of the six projects are available at https://www.nyserda.ny.gov/All-Programs/Programs/RetrofitNY/Resources-and-Reports

The Levy Partnership Net Zero Energy Retrofit – The Levy Partnership worked with Joint Ownership Entity (JOE) NYC to develop a zero-energy ready all-electric retrofit strategy for a 20-year old, six-story, 21-unit low-income building in Harlem. Four inches of EIFS over the existing brick veneer is applied on only the side and rear walls of the building because additional insulation on the front side would violate code restrictions by extending the façade over the lot line. A clever feature of this retrofit is a plan to repurpose a decommissioned trash chute for routing supply air ducts to each apartment. A variable refrigerant flow (VRF) heat pump and $CO_2$-based heat pump water heater (HPWH) will replace the existing heating-oil fired boiler and DHW system. As of July 2020, the project is in the process of finalizing its refinancing plan, and the owner intends to implement the deep retrofit scope described here.

Figure 2 – The Levy Partnership existing building (L) and rendering of post-retrofit (R)
*Photo courtesy: "RetrofitNY: The Levy Partnership Net Zero Energy Schematic Design" (NYSERDA 2019)*
*Rendering courtesy: CTA Architects P.C.*

Bright Power and Volmar Construction – Bright Power worked with partners to design a deep-energy retrofit for a pair of five-story, 21-unit buildings in the Bronx. Envelope improvements include additional insulation in the roof cavity and above the roof deck, double-glazed window replacements, and targeted air sealing with blower-door testing. HVAC is provided through a central VRF heat pump and ERV for continuous ventilation. The design provides each unit with its own HPWH for DHW. Although the RetrofitNY scope could have been financed with NYSERDA's support, the calculated return on investment (ROI) does not meet the owners' criteria; hence, they ultimately decided not to implement the entire RetrofitNY scope. However, key elements of the design—namely, the HPWH system for DHW and the solar canopy—are being installed, making this renovation highly innovative and demonstrating the owners' commitment to progressing toward NZE buildings.

Figure 3 – Bright Power existing building (L) and rendering of post-retrofit (R)
*Photo courtesy: "RetrofitNY: Bright Power Net Zero Energy Retrofit Schematic Design" (NYSERDA 2019)*
*Rendering courtesy: Magnusson Architecture & Planning P.C.*

Christopher Court NZE Retrofit – King + King Architects designed a retrofit for a two-story, eight-unit building in Phoenix (near Syracuse) that is part of a five-building campus first constructed in 1991. Rock Property Management Company (Rock PMC) previously took steps to improve the energy performance of this campus, so basic upgrades such as additional insulation for the envelope and replacing lighting with LEDs could be skipped in favor of targeted improvements such as enclosing the common corridor and replacing the electric resistance water heaters in each unit with a central HPWH. As of July 2020, this project is in the process of finalizing their refinancing plan, and the owner intends to proceed with the scope designed by the King + King Architects team.

Figure 4 – Christopher Court existing building (L) and rendering of post-retrofit (R). The rendering is a simplified version of the building; there are no plans to remove windows.
*Photo courtesy: Rock PMC; Rendering courtesy: King + King Architects*

Portville Square NZE Retrofit – SWBR Architects and Conifer Realty designed a retrofit package for a two-story, 24-unit, affordable senior housing building in Portville, in western NY. The envelope is upgraded with exterior panelized pre-insulated cladding with integrated triple-glazed windows designed by Cocoon Construct to be factory-produced and transported to the site ready for application. The electric baseboard heaters in each unit are replaced with a high-efficiency air-source heat pump, adding cooling capability. For financial reasons, the owner decided not to implement the entire RetrofitNY scope; however, the team is considering using a similar design on future renovation projects.

Figure 5 – Portville Square existing building (L) and rendering of post-retrofit (R)
*Photo courtesy: Conifer Realty, LLC; Rendering courtesy: SWBR Architects*

ICAST NZE Retrofit - The International Center for Appropriate and Sustainable Technology (ICAST) designed a retrofit project in collaboration with the Troy Housing Authority (THA) and its developer, Beacon Communities, Inc. The building is a two-story, six-unit building that is part of a six-building apartment complex named Martin Luther King in Troy. In order to ensure that the upgraded building does not look out of place among the rest of the complex, the insulation plan covers the existing brick on the first floor with foamboard insulation and then applies siding on the first floor that matches what is being used to re-side the other buildings in the complex. Air sealing with continuous air barrier is accomplished using the aerosol technique from Aerobarrier. Each unit will have its own heat pump, ERV, and HPWH. Although the owner decided not to implement the RetrofitNY scope because of a financial deadline, the project is proceeding with significant energy efficiency upgrades. Beacon Communities, Inc. remains committed to the approach and is considering using prefabricated panelized envelope systems for future renovation projects.

Figure 6 – Beacon Communities rendering of post-retrofit
*Rendering courtesy: Rida Architecture, PLLC*

Table 1 – Summary of Key Retrofit Design Features in Six RetrofitNY Projects

| | Envelope | HVAC & IAQ | DHW | Distributed Energy Resources (DER) | Other Notes |
|---|---|---|---|---|---|
| **RiseBoro Passive House** | EPS EIFS targeting PHIUS 2015. Liquid-applied air barrier to existing exterior brick façade before EIFS. | Individual heat pump in each unit. Heating/cooling energy use intensity (EUI) of 1.95 kBtu/ft$^2$·year. ERVs roof-mounted at exhaust stacks. | 3 x 120-gal storage tanks. 199,000 BTU condensing gas boiler. | 40-kW rooftop photovoltaics (PV) | Site EUI of 18.1 kBtu/ft$^2$·year. Machining EPS panels offsite should speed installation; remains to be seen how this will impact cost. |
| **The Levy Partnership** | Rear and exposed side walls will have 4” of EPS EIFS (R-20), and new double-pane low-e windows. Roof will be replaced and have 4” of polyisocyanurate installed underneath (R-31). Liquid-applied air barrier to existing exterior brick façade before EIFS. | Replace existing window/through-wall AC units and boiler/forced hot-water baseboard heating with new VRF system with in-unit evaporators. Heating/cooling EUI of 2.9 kBtu/ft$^2$·year. Active balanced ventilation via central rooftop ERVs with minimum efficiency reporting value (MERV) 13 filters. MERV 8 filters on air-handling unit (AHU) inside each unit. New range hood in each unit. | $CO_2$ HPWH. 4 x 119-gal storage tanks. Demand recirculation controls to improve system efficiency. | 43-kW rooftop solar canopy system. Preliminary analysis suggests 60,000 kWh/year production, offsetting significant portion of owner-paid electrical bill. | Plan includes smart power strips, USB outlets and new refrigerators in kitchens. Final site EUI is 30.2 kBtu/ft$^2$·year (21.3 with PV). The business case for retrofit is not quite there yet without subsidies/free financing. |
| **Bright Power** | Existing uninsulated walls. R-30 blown cellulose in roof cavity. R-16 rigid insulation above roof deck. Targeted air-sealing informed by blower-door testing. Target 2.33 ACH50. New low-e windows. | Central VRF with 3.6 coefficient of performance (COP). Each apartment will have one indoor unit ducted to living rooms and bedrooms. Central ERV with exterior risers. 945 CFM serves all 21 apartments. | Central HPWH with low-flow fixtures. 2 x 210-gal storage tanks on roof. | Solar pergola, 42 kW per building | No renovation for kitchen/bath. Electric resistance range with ENERGY STAR range hood. Smart power strips. Add common laundry room in one building (currently no onsite laundry). Site EUI of 29.6 kBtu/ft$^2$·year. |
| **Christopher Court** | Existing envelope in good condition, so no upgrades. Some air sealing proposed based on blower-door tests. New windows, patio and building entry doors will be high-performance, triple-glazed UPVC spec. Enclose each existing exterior entrance and stair. | Air-source heat pump (ASHP) per apartment with indoor unit & thermostat in each room. Heating/cooling EUI of 5.7 kBtu/ft$^2$·year. Central ERV. | Central $CO_2$ HPWH. Aqua stat to control the DHW recirculation loop to maintain proper loop temperature without operating pumps unnecessarily. | Due to space and shading limitations, the PV system as designed will only achieve NZE based on first-year production (Production expected to decline over time.) 471 panels can fit over five buildings for total installed capacity of 169.56 kW. | Free installation of LED lamps in all tenant-owned fixtures. Site EUI of 22.7 kBtu/ft$^2$·year. |

| | | | | | |
|---|---|---|---|---|---|
| **Portville Square** | Existing: 2x6 exterior walls with R-19 fiberglass batt insulation and 6 mil polyethylene vapor retarder. Additional R-24 continuous insulation at the exterior walls. Exterior panelized pre-insulated cladding design by Cocoon Construct with integrated triple-glazed Passive House rated windows factory-installed. Aerobarrier air seal using blower door. | Dedicated outside air system (DOAS) packaged ASHP for each unit with a total enthalpy energy recovery wheel to pretreat incoming ventilation air. | Existing individual electric resistance water heaters replaced as needed based on age / condition. | Ground-mounted PV array onsite. 134.6-kW system will produce 158,400 kWh/year to accommodate electric water heaters. Plans to use energy produced by the solar array to offset the building "house" energy usage; all tenants will pay apartment electrical energy usage. | All existing lighting in apartments, common spaces, and building exterior will be replaced with LED luminaires. Site EUI of 26.7 kBtu/ft$^2$·year. |
| **ICAST** | No insulation in wall cavity. Minimum R-24.8 continuous insulation at exterior walls. | ASHP. Heating/cooling EUI of 5.0 kBtu/ft$^2$·year. ERV for each apartment and laundry room. | HPWH in each unit. Solar thermal collector feeding hot water to input of laundry room HPWH. | Onsite PV plant provided by Troy Housing Authority (not part of RetrofitNY scope). | Electric ranges retrofit with smart burners, thermostatically controlled not to exceed 650°F. Site EUI is 21.4 kBtu/ft$^2$·year. |

## Design, Review, and Feedback Process

There were several touchpoints throughout the course of the six-month design phase to facilitate mutual exchange of technical knowledge and ideas among the teams.

Together with NYSERDA, and with support from DOE's Building Technologies Office (BTO), the National Renewable Energy Laboratory (NREL) facilitated a "Strategies Workshop with RetrofitNY Awardees" in July 2018 as a kick-off event to inspire the brainstorming that would be needed to meet the project needs. Discussions centered around decision-making for optimally integrated design, goal setting, and the concept of innovation as a result of process, i.e., the idea that process drives creativity of solutions. We reviewed key goals set forth in the RFP, outlined pathways, and discussed issues and solutions to consider for several topics: façade and windows, HVAC and DHW, appliances and lighting, and photovoltaics (PV) and electric metering. The teams had already been selected as awardees and therefore were no longer in competition with one another, so participants were free and encouraged to share candidly both their best ideas and their primary concerns, adding much value to the discussions. One concrete outcome from the workshop was that NYSERDA set up a collaboration platform on SharePoint so that teams could have dialogues on specific themes/threads and share relevant files. A feature of the site was a library for manufacturers and suppliers to post information about their projects. A discussion board enabled teams to indicate their specific project needs and engage directly with industry professionals about their products.

A Midterm Design Review was conducted three months into the project. BTO and NREL coordinated a team of reviewers from NREL, Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and Lawrence Berkeley National Laboratory (LBNL) to provide detailed comments on the team's designs. The goal was to identify major challenges and red flags early in the process so that problems could be mitigated later on when more of the design elements become fixed. For the reviewers, it was interesting to see that although the projects targeted a range of building types, common themes emerged and that teams were generally struggling with very similar problems. These are discussed below. NYSERDA held another workshop to discuss these issues. A Final Design Review was conducted roughly three months after the Midterm Review, and a final workshop featured the teams presenting their final design results. During this workshop, teams shared designs, costs, and challenges with the different stakeholders involved in the financing and approval of the renovation projects, such as the NY State and NY City affordable housing agencies and the NYC Department of Buildings and Fire Department.

Based on the learnings from these six pilot designs, the RetrofitNY staff is engaging with industry stakeholders to reduce project costs and streamline processes to facilitate cost-effective net-zero retrofits.

**SUNY Residence Hall ZNE Pilot**

Designing high-performance retrofits for apartment buildings is one example of a program that, if pursued with scalability as a goal, could enable a significant shift in the energy-use characteristics of apartment buildings and permanently enhance the quality of life for apartment dwellers across the state. There exists a similar opportunity for the future of dormitory buildings in New York.

The Dormitory Authority of the State of New York (DASNY) and the State University of New York (SUNY) Oneonta Campus partnered with NYSERDA under the RetrofitNY program to retrofit SUNY's existing residence halls. A competitive solicitation was issued, seeking a high-performance ZNC-ready (zero-net carbon ready) design-build retrofit solution for Ford Hall, a 55,000 $ft^2$ dormitory on the campus of SUNY College at Oneonta. (Note that the high-level design goals were similar to those of the RetrofitNY RFP. The difference in terminology used between RetrofitNY's "NZE" goals and DASNY's "ZNC" goals is semantics.) The scope is essentially a gut rehabilitation (including asbestos abatement) of the existing building to accommodate 300 beds (instead of the current 270) plus 6,000 $ft^2$ of additional programmatic space, and any required mechanical system upgrades to meet the target energy use intensity (EUI) of 32 $kBtu/ft^2 \cdot year$. As with the multifamily RetrofitNY projects described above, replicability of the solution was a key figure of merit, and therefore it was anticipated that winning designs would incorporate at least some offsite manufactured strategies.

An interesting difference between this effort and the multifamily projects is that campus buildings are components of a much larger system rather than a stand-alone facility connected to a public utility, as is the case with an apartment building in a city. Campus utility systems allow many opportunities for energy generation through district geothermal or solar plants as well as utilizing campus infrastructure for energy distribution. The need to scale to handle a campus environment is critical to success for a university environment. For example, larger-scale heat-pump technology including systems large enough to serve campus-wide systems could be considered, rather than heat pumps sized to handle individual living units.

Several best practices for a performance-based design-build were used in the procurement process including stipends and providing an energy target. Establishing these goals upfront provides a strong mechanism to achieve exceptional energy performance at the best possible market price. Prospective bidders were given a not-to-exceed cost cap of $21M.

Four teams were shortlisted as finalists, and two of them dropped out before submitting a final design. NREL participated in the technical review and feedback process for the two finalists. Both final proposals were very close in proposed costs based on the criteria, but neither was able to stay under the $21M cost cap. Consequently, the program team was unable to award the contract. Although this particular project did not proceed as planned, there were valuable learnings along the way.

Upon studying the RFP and submitted design documents, it became apparent that the design teams chose to meet the performance criteria and ignore the cost ceiling in order to meet the client's needs. The not-to-exceed is a best practice for a performance-based procurement using design-build and can be highly successful; however, there need to be some flexible parameters for competition. If the price is fixed and there is a list of "must-have" criteria, then there is the risk of over-constraining the problem by requiring too much scope for the available funding. The least expensive mechanism with a variable scope is a design build, but the owner must prioritize each element listed in the desired scope. Also, if the RFP is too prescriptive in how to achieve desired EUI targets (such as specifying U-factors and R-values for fenestration and envelope), then it may pose a hurdle to finding the optimal solution. Ideally, these would all be performance factors associated with the goals to provide the most creative solutions.

**Common Themes, Successes, and Challenges**

Throughout the review processes, there were common themes, winning ideas, as well as persistent "sticky" problems that engineering teams were challenged to resolve. We summarize the most notable issues below.

*Conditioned-space moisture management cannot be an afterthought* – With envelope retrofits being a central component of these projects, the need for careful moisture management is paramount. Although the RetrofitNY RFP outlined criteria to require that relative humidity be kept below 50% year-round, most teams did not perform explicit moisture analysis as part of the energy modeling. Although moisture analysis to meet passive house requirements can help to ensure that water will not condense in the walls, it is also important to look at the moisture balance in the living space. In the summer, air-conditioning may sufficiently manage nearly all of the latent load, which is a combination of outdoor air (minimized with reduced infiltration) and internal gains such as cooking and bathing. In the winter, the tightened envelope is likely to limit drying, resulting in condensation and mold on interior surfaces and interstitial spaces. Without a detailed moisture analysis, it is difficult to know how much drying will occur with ERVs, and whether active dehumidification is indicated. A humidity study on an hourly basis is needed, especially in high-humidity areas such as bathrooms.

*Envelope retrofits present numerous challenges* – Prefabricated façade panel solutions, the intended center point of the RetrofitNY program, still faces cost challenges, although this is starting to change. More manufacturers are commercializing this type of product, and quoted prices are coming down rapidly, e.g., from $140/ft$^2$ of envelope for the DASNY project coming down to $40/ft$^2$ for the latest (February 2020) estimate on the ICAST project. At the latter price, the DASNY project would likely have been able to proceed. There remain technical issues to be solved, further complicated by relevant code/policy constraints. Existing issues include:

- Envelope strategies at edge points require careful attention to details of thermal bridging around windows, protrusions, and parapets.
- There are code-compliance challenges for mid-rise buildings in NY City. There is a setback code issue where the new envelope is "thicker" and protrudes out from the

existing edge of building (lot line). Also, minimum clearance requirements on fire escapes and the geometry around their attachments add complexity to external insulation and prefab panels.
- Ability to quickly scan a building and generate a prefabricated panel is still an emerging technology where tools and processes are not yet commercially mature.

*Systems engineering and the "fine print" of newer technologies* – The aggressive energy target of site EUI of 20 kBtu/ft$^2$·yr or less specified in the RFP inspired many teams to embrace innovative technologies over more conventional retrofit measures. When employing novel systems, due diligence is required to ensure effective integration; the system cannot simply be treated as a "black box" drop-in replacement. The details of the technology and any unintended implications of deployment must be carefully studied. For example:

- HPWHs located in the dwelling unit discharge cold air, so space-heating systems must account for any additional heating load introduced. If this cold air impacts the tenants' comfort, they may cover the vent that discharges the air into the apartment. The cool air will stay in the mechanical closet, bringing the temperature down to the range that will bring the HPWH into electric resistance mode. If this issue is not addressed upfront during design, it can adversely impact the resulting energy performance. Ultimately, HPWHs need the evaporator unit to be located outside the structure of the building in cold climates. Cascading heat pumps from water heating to space conditioning forces the heating systems to be substantially oversized, adding cost.
- Centralized HPWHs need additional space to house storage tanks compared to the gas boilers that are being replaced. Typically, HPWHs are not drop-in units and cannot directly replace boilers due to loss of efficiency with de-stratified tanks.
- An unintended consequence of local ordinances that require building owners to provide heat is that heat pump retrofits become less attractive: Heat pumps both heat and cool, so replacing a furnace or boiler with a central heat pump system effectively burdens the building owners with air-conditioning bills in addition to heating bills.
- There are a variety of subsidy mechanisms for building owners that exist at the Federal, State, and City levels as well as public housing authorities that are designed to offset certain utility costs. These subsidies can have the effect of disincentivizing fuel switching from gas to electric.
- Heat-recovery systems need to consider long-term coincident loads to achieve the rated recovery effectiveness. It also can be difficult to plumb in these systems to maximize the benefit of recovery from showers and sinks.
- ERVs can create moisture issues in the wintertime as moisture is transferred back into the unit compared to HRVs. This problem results from tighter envelopes.

*Aggressive solutions for major appliances, miscellaneous electric loads (MELs), and tenant-supplied equipment are required to meet target EUIs* – ENERGY STAR's "Most Efficient" list[5] should be consulted for all appliance upgrades. Refrigerators should be small (or just large enough to meet the needs), top/bottom designs (as opposed to side-by-side, which are less energy-efficient.) When it comes to MELs and tenant-supplied end uses, each single measure can account for only a small fraction of the desired total load reduction, so every possible mitigation

[5] https://www.energystar.gov/products/most_efficient

strategy should be pursued. In addition to replacing all hard-wired lighting fixtures with LEDs, replacement LED bulbs should be provided for occupant-owned plug-in lamps. Light bulbs should be carefully selected for the appropriate color temperature to meet practical and comfort and aesthetic needs of the occupants and the space. The need for portable space heating should be eliminated rather than simply reduced. Effective MEL reduction will require creative solutions. For example, is it possible to consolidate Internet service to reduce the number of active modems within each building? Fresh strategies for how to incentivize occupants to be more cognizant of their MEL-related energy use could prove worthwhile, especially in these multi-family buildings, where a single campaign can affect the behavior of numerous households.

*Solar metering* – Many tenant-occupied buildings have separate meters for each dwelling, with each tenant paying for their own electric utilities. Central connections (with disconnects as required) would reduce the cost of installing PV systems. Common meters for apartment buildings typically have few loads, so attaching the PV system is not optimal. Owners could centrally meter the building and charge tenants individually based on usage, but such an arrangement is difficult to execute in New York, where owners cannot act as a for-profit utility. Community solar programs offer a mechanism to distribute the electricity to tenants, but this system is in its infancy and not yet widely available.

*Scaling up: Out-of-the-box thinking and long-view interpretation of cost effectiveness may be in order for market transformation* – For promising technologies, such as panelized exterior insulation, whose price points are still too high for market adoption, strategies must be engineered and scaled to bring down the cost. The go/no-go should not be based on today's cost but on potential future cost, and programs need to be created to facilitate the required market transformation. For example, why is a certain type of equipment expensive today? If the reason is that the technology is manufactured in limited quantities, can a utility or government agency intervene and subsidize a bulk purchase at large scale? If 1,000,000 were made, the cost may come down substantially. If a measure is labor intensive, what are effective strategies for labor reduction? Perhaps by incorporating offsite manufacturing and assembly of certain systems, installation time could be cut in half. One-off solutions are challenging to scale up, particularly custom, labor-intensive processes. On the other hand, mass deployment of identical measures could be accomplished relatively inexpensively and quickly. It is crucial to identify the replication potential of each piece of the puzzle and identify where solutions are suitable to automation. If there is any way for the owner to understand and react to net present value (NPV) metrics, they should be employed.

*Understanding New Technology* – Many new technologies are not just drop-in replacements for old technology. In-unit HPWHs require a place to dump cooling loads and need air circulation. They change the heating load profiles of a space. The characteristics of some HPWHs also require stratification of storage tanks for maximum efficiency; installing these units in a recirculating loop system can create performance issues. The main issue is that a good technology, when not installed in accordance with manufacturer's recommendations, can damage the emerging market for that technology because it will not work "as advertised."

## Conclusions

Although the details of technical solutions continue to challenge every engineer and program manager, by far the most impactful lessons to come out of these programs have been around crafting the right process to catalyze meaningful innovation and incremental movement toward ultimate goals. The very best ideas grounded in physics cannot solve the world's most pressing problems without the programmatic support and infrastructure in place to facilitate the trial and adoption of novel techniques and systems. A competitive solicitation for a design-build performer is only a small part of the end-to-end process of identifying the most practical pathways for scalable solutions. In particular, more focused efforts to drive down the cost of promising emerging technologies are needed as well as the proper use of new technologies. These could include a combination of research into cost-reduction opportunities, creative strategies for managing cost through bulk purchasing and other ideas, as well as providing robust support on the manufacturing and distribution side to enable massive scale-ups.

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