report

Strategies for a High Comfort, Low Energy Retrofit in NYC

Pursuing Passive

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report sections

Improving the performance of buildings must be a central component of any response to the challenges of climate change. This is both an imperative and an opportunity. Responding to climate change by aggressively improving the performance of the built environment will produce buildings that are superior in virtually every capacity, and focus attention on an industry whose processes have lagged behind those of other sectors.

It is imperative to draw down the energy use of buildings worldwide to ensure an equitable and sustainable future. Buildings contribute 40% of global carbon emissions and an astonishing 70% in New York City alone[1]. New York City estimates that carbon emissions of the building sector need to be reduced by 60% in order to meet our current climate action goals[2]. This will require not only increasing the stringency of our energy codes for new construction, but introducing a radical expansion of existing building retrofits, a sector notoriously resistant to innovation. Extensive, holistic renovation of occupied buildings is expensive and disruptive for the occupants, and since such work is rarely undertaken there is no natural market to exploit. The diversity of our building stock (in size, age, construction, etc.) further complicates matters by making it difficult to scale solutions—there is no one size fits all approach. There are many resources that describe generalized solutions for building types, but building owners will require strategies more specific to their particular building before studying the feasibility of a deep retrofit. With this in mind, we have selected an existing high-rise multifamily building in New York City that represents a common building type and will serve as the case study for this report.

The subject building is 15-stories tall, 123,000 gross square feet, and includes 163 apartments. Having carefully selected a building with both features and challenges common to a broad range of buildings, we have applied the standard that we feel offers the most promising mix of reliability and effectiveness: Passive House.

Passive House distinguishes itself from other standards and guidelines by focusing on occupant comfort and truly reliable heating and cooling energy savings, producing high quality, cost effective buildings ready for a future of electrification, high utility costs and more frequent extreme weather events. Passive House also includes a comprehensive standard explicitly for retrofits of existing buildings, called EnerPHit.

The primary retrofit components of achieving the EnerPHit standard for our subject building are relatively simple:

- Replace the windows with high performance units
- Reclad the façade with insulation and an airtight layer
- Upgrade the ventilation to a balanced system with heat recovery
- Replace the heating and cooling with a high efficiency system
- Upgrade domestic hot water and other systems

The study emphasizes selecting those improvements that most effectively meet the requirements of EnerPHit and describes ways to phase these in over time while the building is occupied. We identify the most important technical and market challenges of pursuing a deep retrofit, as well as the significant benefits and the costs. With each passing day, the urgency with which we must draw down our carbon emissions increases. We are entering a period in which incremental measures that provide limited emissions reductions might be insufficient in the long run. This report explores feasible improvements that will allow us to meet our climate action goals and, in the absence of relevant examples of deep retrofits, provides high-level guidance for the owners of similar buildings.

Is it feasible? This study finds that retrofitting a high-rise, freestanding residential building to the Passive House standard presents very few technical challenges and would result in substantial benefits that would also require significant capital and extensive tenant engagement to complete successfully. We find it possible to conduct such a holistic retrofit in several phases while the building remains fully occupied, but it is far less expensive and far more effective in terms of carbon emissions reductions to perform the retrofit in a single phase. This report focuses on the technical strategies required to meet the requirements of the EnerPHit standard and enjoy the significant benefits available. We have included cost estimates for the various measures, and although deep financial analysis is outside our purview, there is clearly a pressing need for access to capital to perform these critical upgrades.

To convince building owners to embark on costly and disruptive projects, we must identify the clear benefits of transforming their buildings—which include comfort, health and asset value in addition to energy savings. Passive House has a demonstrated record of delivering improved interior comfort and air quality as well as reliable, consistent energy savings from heating and cooling systems. The deep retrofit described in this report delivers a far superior asset for both owner and occupant while also playing a central role in avoiding climate catastrophe.

The primary barriers to embarking on such an extensive upgrade are capital and disruption to tenants. The total estimated cost of all the strategies outlined in the report is $10.14 million, which equates to roughly $82 per square foot or $62,000 per unit. We estimate the total cost of business-as-usual upgrades to the building would be roughly $3.64 million. Subtracting these costs produces a net additional cost of $6.5 million to achieve EnerPHit certification (which equates to $53/sf, or $40,000/unit). Phasing the work adds a significant premium of $1.6 million (due to the additional general conditions and recurring setup costs), while also delaying delivery of the full benefits of the retrofit. These figures are high, and we explore methods to reduce them, but the costs of inaction across the building sector are far higher and incremental approaches to energy efficiency are unlikely to meet our climate action goals and may not improve the valuation of the building enough to warrant the effort.

In the pages that follow, we outline strategies selected to minimize disruption to the occupants. However, the project would still require both equipment and finish work in every major room of the building, including extensive work in the common areas and at the building exterior. While many buildings perform efficiency

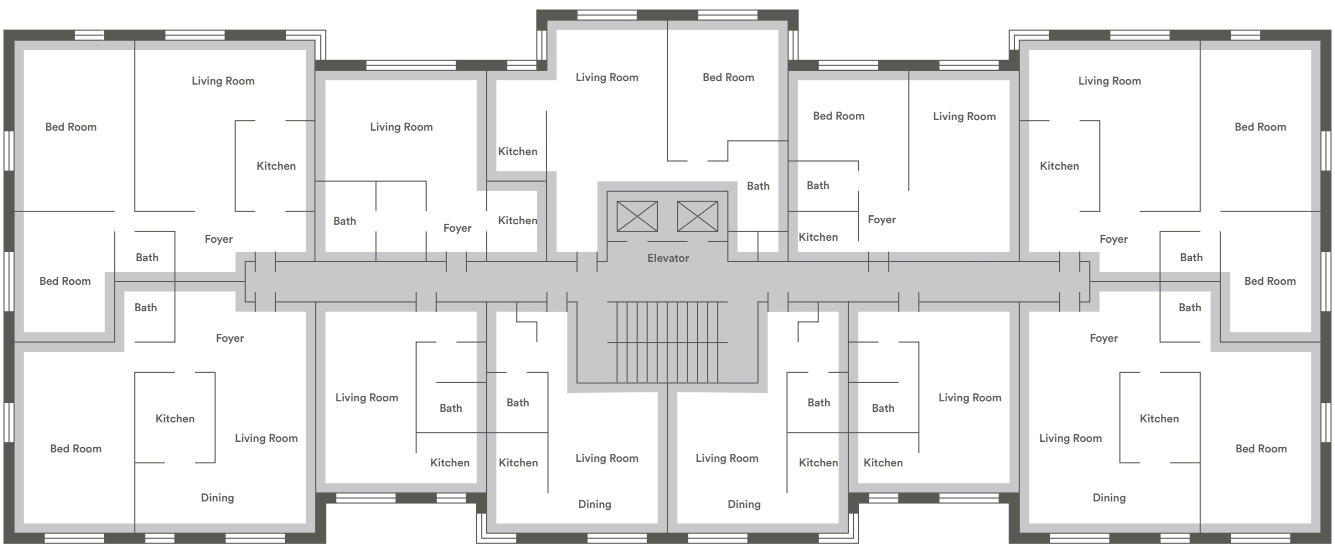
Figure 1: The subject building faces many challenges common to a wide variety of New York City buildings, including masonry exterior walls with no insulation, aging windows and merely adequate ventilation.

upgrades to individual systems, there are limited examples of occupied buildings that perform the type of integrated retrofits delivering the level of greenhouse gas reductions needed for most cities to meet their climate action goals. Extensive, holistic upgrades to existing buildings can deliver raw efficiency along with a high quality living environment, and can enable a future powered by renewable energy along with resiliency in the face of future climate fluctuations and crises.

As Amory Lovins of the Rocky Mountain Institute has stated, "The good news about climate change is that it is cheaper to fix than it is to ignore."[3] The challenge faced by virtually every community is how to connect the individual costs of upgrading buildings to the broader societal benefits of avoiding climate catastrophe, as well as developing strategies to cope with those impacts we will not be able to avoid. This report outlines the retrofit strategies required for one building type in New York City to meet the obligations imposed on us by the specter of global climate change. We hope this is the starting point for a deep discussion about how we can deliver the benefits outlined in the most efficient ways possible, and how we can incentivize as many buildings as possible to undertake them.

The project team selected an existing building with features and challenges common to many high-rise multifamily buildings in the region.

Figure 2: Typical Existing Floor Plan



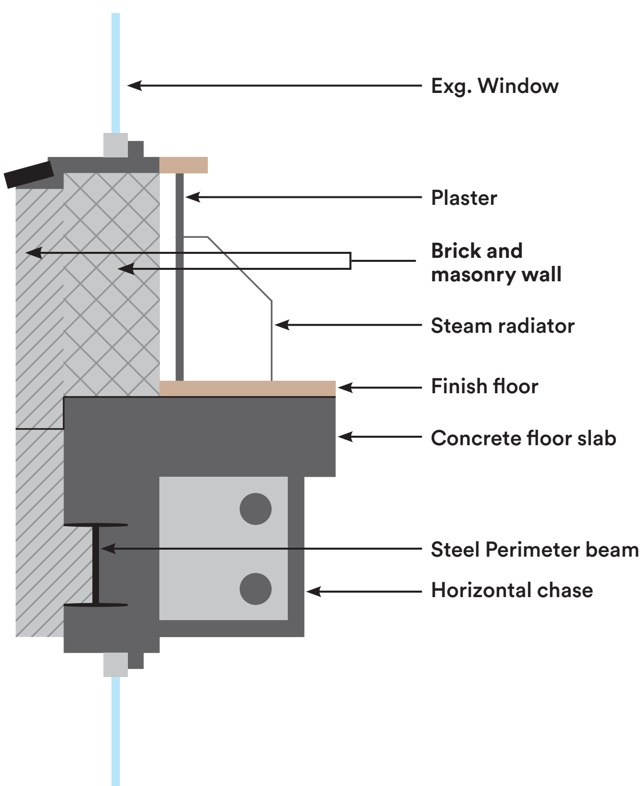
Each of the 15 floors includes 11 apartments except the ground floor with 9. Apartments range in size from studios to two-bedroom units, gathered around a central corridor.

This study describes the feasibility of upgrading an existing multifamily building in New York City to meet the Passive House standard for retrofits. The building selected for study is a 15-story, market-rate residential building on a small campus of nearly identical buildings in Brooklyn. Constructed in 1950, the building has masonry exterior walls that enclose 163 apartments across 123,000 gross square feet. The tower is typical of a large swath of buildings in New York City (as well as many other regions) and has many of the most common challenges that will be encountered by anyone looking to perform a deep retrofit of an occupied multifamily building. The owner of the property generously made drawings and other information about the building available but wished to remain unidentified in the report.

Figure 3: Existing Building Systems Assessment

Elements	Issues
Exterior walls Simple masonry. 4" face brick bonded to 6" concrete block. Plaster interior surface.	No insulation No air barrier Major thermal bridges at perimeter floor beams High long term maintenance costs
Windows Aluminum, double-hung frames (no thermal break), double-paned glazing with small metal spacers	Little thermal resistance High air leakage Major comfort issues Condensation risk Poor solar heat gain properties
Heating Two-pipe steam system served by duel-fuel boiler in basement (serves 2 other buildings.) Includes 25 riser pairs and simple radiators in each major room.	Poor responsiveness Overheating common High short-term maintenance costs High replacement costs
Cooling Window AC units, located in most major rooms	Poor thermal performance Creates drafty conditions Major thermal bridge Noisy, inefficient
Domestic Hot Water Heat exchange at steam boiler with constant recirculation loop	Heavy energy losses from circulation loop Requires running steam boiler in shoulder and cooling seasons
Ventilation Exhaust only at kitchens, bathrooms and corridors. Each type collects under the roof to meet at one fan.	No direct fresh air introduction System is not balanced, drives infiltration from exterior and adjacent units Energy intensive

Figure 4: Existing Wall Section



The existing exterior walls contain no insulation, and the steel perimeter beams at each floor aggravate the situation, providing a clear pathway for heat to escape in winter, compromising comfort and encouraging interior condensation. The study proposes that the steam radiators be removed and most of the distribution piping abandoned.

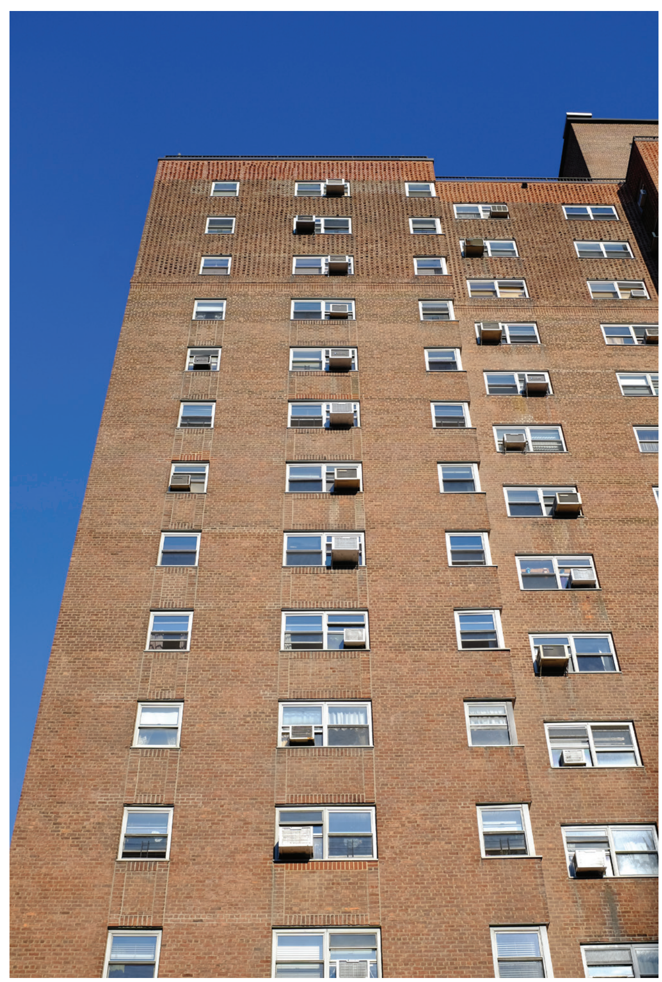


Figure 5: Like many buildings of this era, the window to wall ratio is low, in this case 21%.

Our study connects the progressive goals of our City and State governments with specific strategies for an individual building.

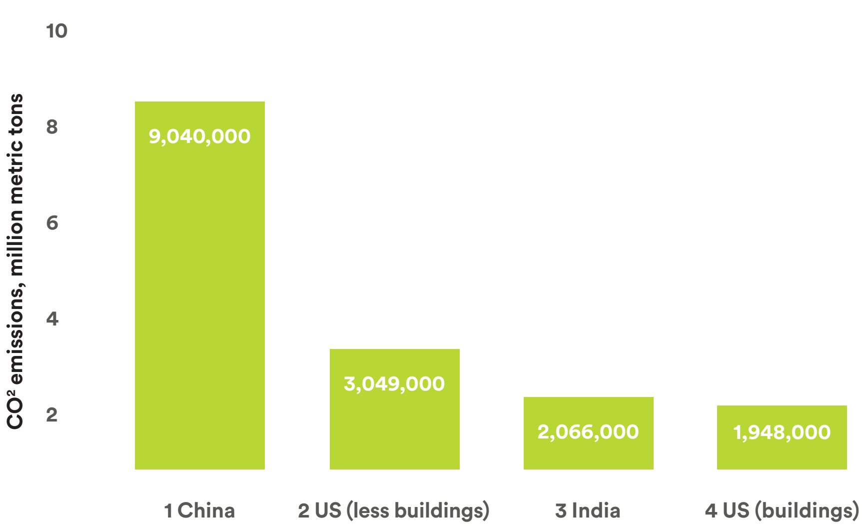
New York City has addressed the challenges posed by gobal climate change through a mixture of long term planning and the implementation of specific programs. As noted earlier, buildings account for roughly 70% of New York City's total carbon emissions.[4] Although a higher percentage than most US cities, nearly 40% of GHG emissions in the United States are from buildings; if US buildings were a country, they would be the fourth largest global emitter of GHG emissions, behind only China, the rest of US emissions, and India.[5]

As early as 2007, the City of New York identified buildings as a critical sector in their climate action plan, PlaNYC.[6] This plan resulted in the development of the Greener, Greater Buildings Plan (GGBP, 2009) which required large buildings to benchmark their annual energy and water use, and to undergo a whole building energy audit once every ten years. The GGBP also required commercial spaces to submeter energy and upgrade their lighting systems to current code, and established, for the very first time, a building energy code for the City of New York (with more stringent standards than the New York State energy code).[7]

In 2015, the City reaffirmed its focus on buildings with the release of OneNYC. The current climate action commitments outlined in OneNYC revolve around an aggressive goal of reducing citywide carbon emissions 80% by 2050 ("80 × 50"), using 2005 as a baseline.[8] This aggressive plan envisions nearly all of the roughly one million buildings in New York City undergoing energy efficiency retrofits by 2050. The Mayor's Office of Sustainability has committed City agencies to this effort, and the Administration and City Council have enacted new laws and implemented a series of initiatives designed to plot the long-term road map for such reductions, including analysis of pathways for both public and private buildings.

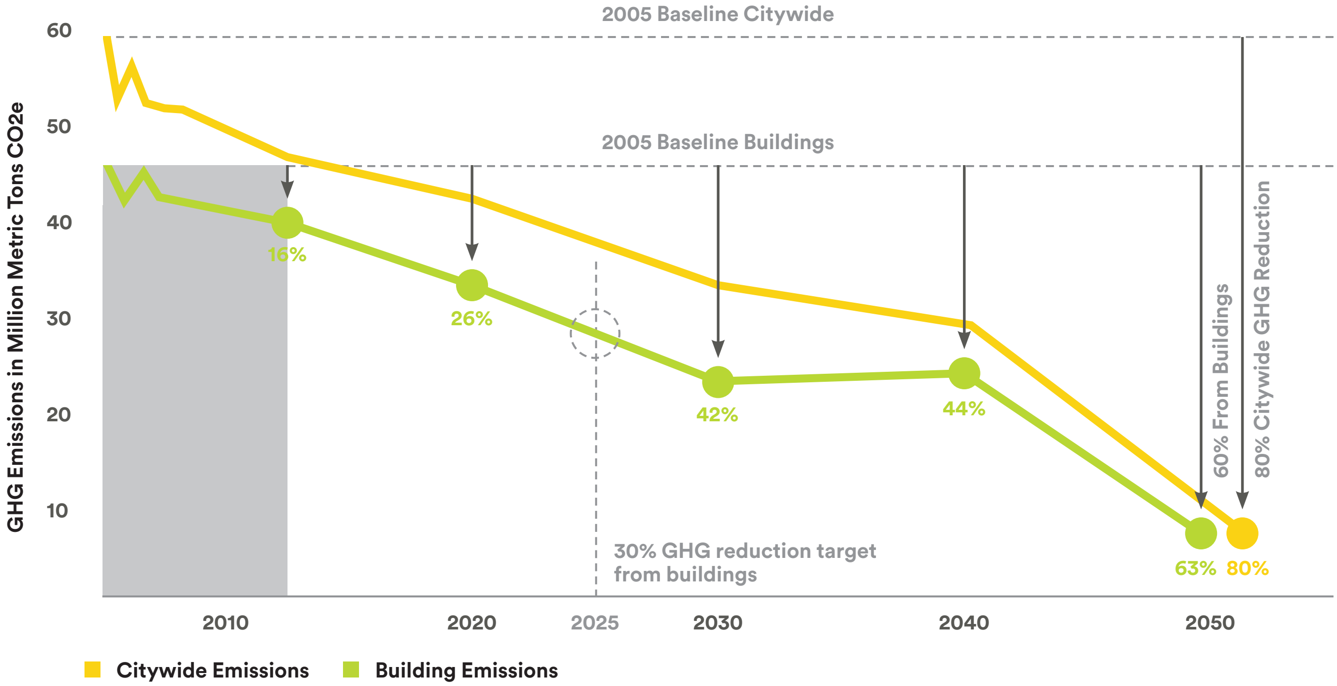
A major component of the City's efforts is the New York City Retrofit Accelerator, a program connecting private sector buildings with resources and advisory services to realize energy efficiency projects. The program includes a High Performance Retrofit Track to promote deeper retrofits of buildings than typical (See NYC Retrofit Accelerator sidebar for more information). Public sector efforts by the City also include the passage

Figure 6: Total CO2 Emissions, by Country (2015)



If US buildings were a country, their CO2 emissions would rank 4th in the world behind only China, the rest of US emissions, and India.[5]

Figure 7: NYC's Pathway to 80 × 50



To meet the 80 × 50 goal, the CO2 emissions of all NYC buildings must be reduced by more than 60%. The challenge moving forward is connecting this citywide goal to actions within individual buildings[2]

of two 2016 laws that require City projects meet LEED-Gold standards and be designed to use no more than 50% of the median energy use of similar buildings. Based on the benchmarking data compiled by the City, this "low energy intensity building" target is the first of its kind in the country. These laws also mandate that the City develop a plan to ensure that capital projects from 2030 forward use no more than 38 kBTU/sf/year (for new construction) or 42 kBTU/sf/year (for renovations)- numbers that match Passive House requirements.

These initiatives to improve the energy performance of City buildings are complemented by increasing the stringency of New York City energy codes in an effort to drive the performance of new construction and major renovations. Stretch codes were recently mandated for the 2019 and 2022 code cycles, transitioning to a code based on whole building energy use targets in 2025. Legislation is pivoting to focus directly on the building energy use, with bills currently under consideration that would limit fossil fuel use in existing buildings relative to size and occupancy type. If they become law, the proposed mandates would take effect in 2030, impacting thousands of buildings across every borough of New York City.

New York State has also made significant commitments to combating climate change. The signature State level goal is an 80% reduction by 2050, with an interim goal of a 40% reduction in emissions by 2030 (baseline of 1990). This plan includes an aggressive efficiency milestone in 2025 that should keep the State ahead of its original pace to drawdown emissions. The goals are supported by specific, heavily resourced programs like NY REV, which aims to radically transform the generation and delivery of electricity statewide, and RetrofitNY, which seeks to create a market for holistic, rapidly

Base Building in Context

In 2016, the City of New York published the One City: Built to Last Technical Working Group Report[9] outlining available pathways for retrofitting NYC buildings to meet the "80 X 50" target set down by Mayor De Blasio. This report divided the buildings of the City into more than 20 typologies. The building selected for this study fits within the "Multifamily, Post-war (to 1980), greater than 7 stories" typology, which includes, in total, 322 million square feet of building area, more than 5% of citywide building area and 15% of multifamily buildings. A rough estimate indicates that this segment houses nearly 1 million people.

State Wide Efficiency Focus

The keystone of New York State energy efficiency measures is a commitment to an 80% reduction in overall carbon emissions by 2050 (and 40% by 2030). The State has recently made a further commitment to further reducing energy use by 185 trillion BTUs by 2025, a 40% improvement on the original 2030 target. This 2025 target is described in a white paper titled New Efficiency: New York, available here: nyserda.ny.gov/About/Publications/New-Efficiency

New York State has also committed significant resources to their RetrofitNY program, designed to pair scalable, holistic retrofit solutions with large portfolios to create a volume market for rapid building upgrades that approach or exceed Passive House levels of performance. Modeled on a European program called 'Energiesprong' which industrialized the process of re-cladding small buildings with modular units that contained new heating, cooling and ventilation systems- and installing them in just a few days. RetrofitNY hopes to connect design and construction teams with large portfolios of buildings and provide assistance in the development of repeatable, rapidly deployable solutions tailored to the northeast market. As you will see, the RetrofitNY program has particular relevance to the findings of this report.

Details available here:
https://www.nyserda.ny.gov/All-Programs/Programs/RetrofitNY

NYC Retrofit Accelerator

The NYC Retrofit Accelerator was created to accelerate energy efficiency retrofits in privately owned buildings. The program employs a team of "efficiency advisors" who assist building owners, managers and other decision-makers in undertaking retrofit projects. Efficiency advisors provide assistance with developing a scope of work, selecting contractors to perform the work, identifying financing and incentives, and verifying energy and water savings.

The program includes a High Performance Retrofit Track (HPRT), designed to begin piloting the deep energy retrofit paths identified in the City's Buildings Technical Working Group. The HPRT offers specialized assistance to building owners and decision-makers to develop 10-15 year capital plans that sync retrofits with the building's capital replacement schedule. HPRT projects are expected to achieve 40-60% reductions in energy savings from a typical building.

More information is online at:
www.nyc.gov/retrofitaccelerator.

deployable building retrofits.

The direction of City and State policies are leading to a future in which much energy use in buildings is electrified, while other policies and programs are focused on greening grid energy sources and introducing the flexibility required to support distributed generation. The findings of this study will support City and State efforts while providing relevant building owners or managers with guidance on the feasibility of transforming their asset to realize deeper energy conservation.

Market Challenges

The policy measures outlined above are in place to overcome significant structural challenges in the market. Building owners and managers routinely miss opportunities for energy savings during major improvements of systems. Many building owners do not have long-term capital plans in place, and those who do rarely consider energy efficiency projects. Decisions about major equipment replacement tend to occur during emergencies when the most expedient option is typically selected, with limited regard for long-term utility costs or other benefits of high performance options. In some cases, mature real estate organizations have capital planning in place, but even these often do not mix capital and operating expense budgets, severely limiting their ability to benefit from efficiency upgrades.

Reducing energy consumption saves money, but energy efficiency projects compete for capital dollars with many other opportunities to increase the value of a given asset. For an existing building, these dollars are particularly scarce and might be spent upgrading lobbies and common spaces, or correcting maintenance issues. It can be difficult for energy efficiency retrofits to compete with these more immediately tangible improvements. The situation is exacerbated by the variable nature of retrofit projects. There is no simple answer to the question: how much energy will an efficiency retrofit save? There are as many answers as there are projects, and decision makers often perceive this variation as risk. Additionally, most efficiency projects are proposed as individual measures (replacing a single piece of equipment or upgrading a single system), making it difficult to promote energy efficiency at significant scale.

This study provides guidance for a specific building type to encourage capital planning that supports deeper retrofits. Such plans have the potential to shift the expectations of energy efficiency retrofits from a burden to an opportunity, encouraging building owners to remain competitive as more and more efficient projects come on line to meet our steadily progressive energy codes.

Following the Passive House criteria for retrofits, called EnerPHit, ensures ensures a building with high quality interiors and low utility bills.

Passive House

The Passive House standard is a set of design principles and a voluntary standard for energy efficient buildings created by the Passive House Institute (PHI). Buildings adhering to the Passive House standard are well insulated and relatively airtight, use dramatically less energy, often rely on renewable energy sources, and are more resilient in the face of power outages and extreme weather. They are also extremely beneficial for the occupants, providing excellent indoor air quality and comfortable temperatures along with balanced, highly filtered ventilation. The Passive House standard relies on several fundamentals:

- Insulation of the building envelope (optimized to the location and project) to minimize heat transfer
- Windows that are carefully specified, positioned and shaded to provide the appropriate amount of heat loss or gain depending on the season
- An airtight building envelope
- Reduction of thermal bridges
- Highly efficient mechanical ventilation with heat or energy recovery

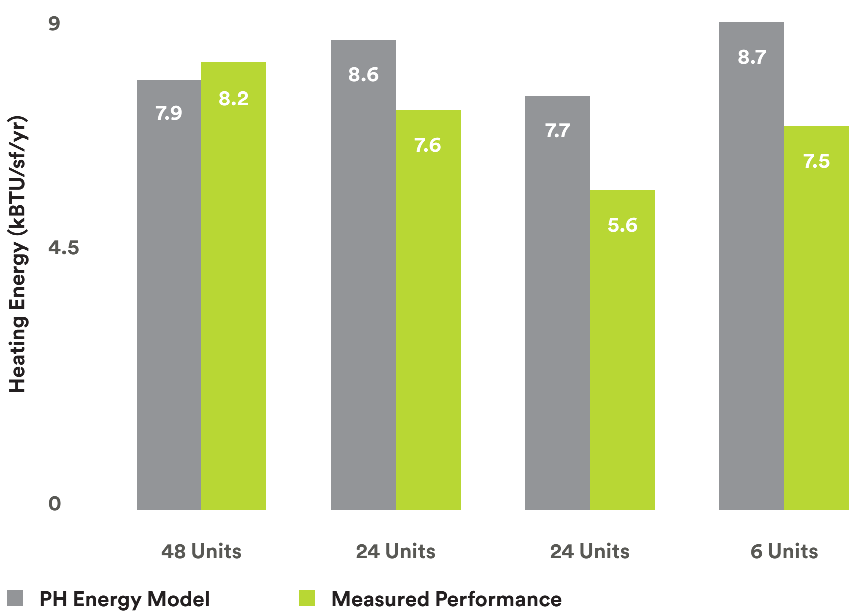
New construction and major renovation projects utilize the 'Classic' Passive House standard, which includes a maximum energy demand for heating or cooling of 4.75 kBTU/sf/yr, a total primary energy demand maximum of 38.0 kBTU/sf/yr, and airtightness of 0.60 air changes per hour (at 50 pascals of pressure.) Retrofit projects can use the 'EnerPHit' standard, which relaxes these requirements and provides both prescriptive and performance paths to certification, outlined in Figure 11.[10] Passive House has a strong track record of delivering savings close to those anticipated—especially regarding energy for heating and cooling—further reducing both perceived and actual risk.[11]

EnerPHit

The Passive House standard for retrofits, EnerPHit, relaxes the airtightness and energy demand targets compared to the 'Classic' Passive House standard for new construction, acknowledging that there is little that can be done about the massing of an existing building, the location

Figure 8: Passive House interiors are typically among the most comfortable available in the marketplace, with excellent air quality due to the balanced and highly filtered ventilation, and much improved acoustics because of the high-performance windows and appropriately insualted exterior walls.

Figure 9: Measuring Passive House Performance



Studies find that most Passive House projects use less energy than estimated in their energy models, especially heating energy. All but one of the multi-unit refurbishments monitored above used less energy for heating than estimated in the PHPP software.[11]

and size of its windows, existing thermal bridges, and other factors. EnerPHit also provides two certification pathways. The Energy Demand Method is largely identical to the basic Passive House standard, except the demand limits fluctuate based on climate zone (see Figure 11). The Component Method takes a prescriptive approach in which the individual components need to meet specific requirements depending on climate and location but not overall heating or cooling demand limits. These prescriptive requirements can differ significantly from those that would be calculated using the Energy Demand method. In both cases, an energy model (using the Passive House Planning Package, or PHPP, software) is developed to determine specific parameters for each project, based on climate, orientation, and other building characteristics. EnerPHit also provides a long-term planning tool that allows the project team to package various upgrades into phases, indicating the ways in which these upgrades impact one another and how much each phase can be expected to save, providing a basis for simple capital planning. In this study we have focused on the EnerPHit Energy Demand Method.

Comfort and Quality, plus Savings

Passive House is organized around occupant comfort, rather than focusing solely on energy efficiency, with principles designed to produce the healthiest, most comfortable interior while using only a fraction of the energy consumed by a typical building. This is an important distinction, as many of our existing buildings are not particularly comfortable–they are often too hot or too cold with less than ideal ventilation. Passive House provides superior air quality through highly filtered air at appropriate temperatures and humidity levels, ensures comfortable temperatures on the interior surfaces of exterior walls and windows, and dramatically reduces the potential for interior condensation and the mold that often results. For buildings with significant interior air quality or thermal comfort issues, these benefits alone may make a Passive House retrofit attractive. The measures required to meet these comfort requirements often include recladding the exterior and providing new, more responsive heating, cooling and ventilation systems—significantly transforming the building as a place to live or work.

In the past, some energy efficiency initiatives have addressed occupant comfort only obliquely, with the needs of the occupants acting as a kind of backstop to attempts at drawing down energy use. The Passive House focus on providing the greatest comfort for building occupants remains a fundamental

What's In a Name?

The concept of a Passive House is sometimes confused with the "passive solar" houses popularized in the 1970s. However, Passive House projects have active heating, cooling, and ventilation systems, and are 'passive' only in the sense that the bones of the building—the low maintenance parts such as an optimized envelope and high performance windows—do much of the work before the higher maintenance mechanical systems are engaged to temper the interior conditions. Because of its name, and because the Passive House standard was first applied to detached houses, it is often assumed that the standard is only applicable to small residential buildings. In fact, it applies to the vast majority of building types, from civic and institutional projects to commercial and large multifamily structures. Though developed in Germany, the Passive House standard is applicable globally and projects have been certified in nearly every climate zone from equatorial to arctic.

Figure 10: Passive House Standard Criteria

	Heating Demand*	Cooling Demand* (+latent)	Air-tightness (ACH @50 pascals)	Primary Energy Demand*	Renewable Primary Energy Demand*	Renewable Energy Generation*
Passive House Classic	4.75	4.75	0.6	38	19	-
Passive House Plus	4.75	4.75	0.6	-	14.3	19
Passive House Premium	4.75	4.75	0.6	-	9.5	38
EnerPHit (existing buildings)	4.75–11	9.75	1.0	varies	38	varies

*kBTU/sf/yr

Figure 11: EnerpHit criteria

Climate Zone (according to PHPP)	Heating Demand Limit (kBTU/sf/yr)	Cooling and Dehumidification Demand Limit	Opaque Wall Insulation (r-value) Exterior	Opaque Wall Insulation (r-value) Interior	Windows U-Value	Ventilation Min. Heat Recovery	Ventilation Min. Humidity Recovery
Arctic	**11.0**	**Equivalent to Passive House requirement for new construction**	**63**	**23**	**0.08**	**80%**	**-**
Cold	**9.5**		**47**	**19**	**0.11**	**80%**	**-**
Cool-temperate	**7.9**		**38**	**16**	**0.15**	**75%**	**-**
Warm-temperate	**6.3**		**19**	**11**	**0.18**	**75%**	**-**
Warm	**4.7**		**11**	**8**	**0.22**	**-**	**-**
Hot	**-**		**11**	**8**	**0.22**	**-**	**60%**
Very hot	**-**		**23**	**13**	**0.18**	**-**	**60%**

Figure 12: Passive House Ventilation Criteria

	Passive House	Typical / Code
Heat recovery efficiency	**>75%**	**50%**
Watts per CFM	**<0.77**	**-**
Coefficient Of Performance	**>10**	**-**
Leakage (@ ERV)	**<3%**	**-**
Sound	**<25 dBA**	**-**

The Passive House standard includes a variety of performance requirements for ventilation systems, many of which are either less stringent or not addressed in US codes.

(and fundamentally positive) distinction that recommends this approach.

In addition to the energy demand and airtightness figures above, the Passive House standard includes specific interior comfort criteria that determine window performance and dictate construction detailing at locations of potential thermal bridging, such as the window installation details. More details on thermal comfort are included later in this report.

There are also efficiency criteria for the ventilation systems, mitigating against simply adding fresh air without regard for the energy costs of doing so. To meet these criteria, Passive House projects must utilize heat- or energy-recovery ventilation systems. Beyond the efficiency of heat recovery the requirements include a cap on the amount of energy used to deliver each unit of air (in cubic-feet-per-minute, or CFM), the leakage within the unit itself, and the sound experience by the occupants, the last a rather unique criteria that speaks to Passive House concerns for the comfort experienced by the occupants and not just the hard numbers of energy use.

retrofit criteria

Figure 13: Design Condition Assumptions

Design Condition	Winter	Summer
Outside	**14.4 F**	**70 F (wet bulb) / 86.8 F (dry)**
Interior	**68 F / 25% RH**	**77 F / 50% RH**

Design conditions assumed for the purposes of studying strategies in the PHPP energy modeling software.

Figure 14: Passive House Performance Criteria vs. Existing Conditions

	PH Criteria	Proposed	Existing	Delta
Heating energy demand*	**6.34**	**6.33**	**35.11**	**82%**
Cooling energy demand*	**5.71**	**4.66**	**5.8**	**20%**
Primary Energy Demand*	**39.93****	**36.58**	**99.44**	**63%**
Primary Renewable Energy Demand*	**60/45/30**	**30.17**	**123.14**	**75%**
*kBTU/sf/yr				
**varies with project parameters				
Airtightness (ACH 50)	**1.0**	**1.0**	**5.0**	**5X**
Window U-value (average)	**0.18**	**0.144**	**0.8**	**5X**
Walls (R-value)	**-**	**10.0**	**2.4**	**4X**

Comparison of i) the criteria to meet the EnerPHit standard, ii) the estimated performance of the proposed retrofit, and iii) the existing conditions, where known.

Figure 15: Thermal Bridging Performance vs. Existing Conditions

Thermal Bridge	Before*	After*	Delta
Parapet	**0.55**	**0.17**	**3X**
Perimeter Beam @ Floor Slabs	**0.20**	**0.04**	**5X**
***BTU/(h-ft-F)**			

Teams pursuing Passive House must demonstrate that the primary thermal bridges through the envelope are mitigated to protect against interior condensation, heat loss and thermal comfort problems inside. Two examples are included here.

retrofit strategies

Multiple strategies have been explored in each category to determine the most effective solution that limits disruption to the occupants.

To meet the Passive House-EnerPHit criteria outlined previously, the project team analyzed available options for each major category of improvement: envelope (insulation, airtightness, and windows), heating and cooling systems, ventilation, and domestic hot water systems.

Envelope

A high performing envelope is the foundation of the Passive House standard, with a significant emphasis on airtightness, the right amount of insulation, and high performance windows and doors.

Airtightness

EnerPHit Criteria	**1.0 ACH**
Existing	**5.0 ACH**

Proposed
New airtight layer at façade, carefully detailed window install, correct shaft issues

It is assumed that major points of infiltration through the existing building exterior are the windows (including the perimeter condition, the operable sash connections, and the window AC units) and the roof level openings at the elevator shafts and fire stairs. The introduction of properly installed, high performance windows will have a dramatic impact on the airtightness of the building as a whole. If an exterior-insulation-and-finish-system (EIFS) is applied to the exterior the adhesive itself will act as an air barrier across the opaque wall surface. A series of remedial measures would improve the airtightness of the shafts, fire stairs and existing duct risers.

Insulation

EnerPHit Target	**R-10**
Existing	**R-2.4**

Proposed
Install new exterior insulation system

Walls: As with any large multifamily building, the building under consideration possesses a low ratio of exterior envelope (walls, windows and roof) to occupied interior space. Coupled with the limited area of windows (only 21% of the exterior walls), this produces a building whose loads are not dominated by envelope losses or gains. As such, our analysis finds that only an additional R-10 must be added to the exterior walls. This translates

The development of US energy codes are driven by two primary factors that obscure the advantages of high performance components and systems. The first is that our codes focus on the performance of individual elements rather than their holistic impact on overall performance of the building, and the second is using the concept of diminishing returns to determine cost effectiveness of individual components.

First, the performance requirements of various building components, whether these be window units or the insulation of exterior walls, are evaluated on a component by component basis with little regard for how these choices might impact one another. For instance, all other things being equal, the selection of extremely high performing windows may allow a project to install less insulation to meet the project's demands, or vice-versa. Currently our energy codes provide prescriptive criteria for both, without regard to how they impact one another. Under this paradigm, you don't get to reduce your levels of insulation because of your high performance windows. Despite the fact that higher performing elements might pay for themselves many times over across their life span while providing far superior comfort, our prescriptive code paradigm masks their cost effectiveness and reduces the chance that they will be considered.

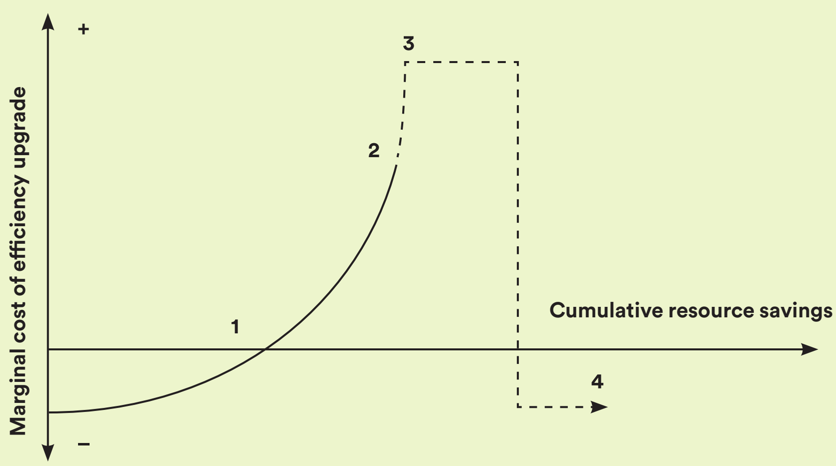
Second, the performance criteria of specific components are generally selected by determining a point of diminishing returns. Take insulation as an example: the first few inches of insulation in an exterior wall assembly are the most critical inches. Moving from a wall with R1 to an wall with R5 provides a huge step forward in performance, both in terms of comfort and saved energy, for very little cost. Moving from R5 to R10 you begin to see diminishing returns on the dollars spent for each unit of increased performance. It is at this point that codes professionals typically determine that it is no longer cost effective to increase the performance of the component in question, and set the prescriptive requirements for that element. This criteria is perfectly sensible with regard to the individual component in question, but discourages consideration of those occasions when increasing the performance of a particular component might reduce spending in other areas. In our insulation example, imagine if rather than providing just the code mandated R 10 wall, providing an R 30 wall allowed you to significantly downsize your heating system. In that scenario, increasing the amount of insulation may actually result in spending less money.

The opportunity costs of this paradigm in terms of carbon emissions is significant. Sometimes increased performance can reduce first costs.

Certainly, there is little about our codes that precludes project teams from pursuing holistic solutions that take advantage of the type of synergies described here. And the role of our codes is to act as a backstop, to determine the minimum that must be provided, not to establish industry leadership. But our codes are the central reality of the building industry, setting the tone for virtually all design and construction decisions.

Passive House has been designed to take advantage of the interaction between envelope performance and the heating and cooling systems. The fact that Passive House is seen as such a revelation by so many in our industry speaks to the manner in which our current code paradigm has quietly shaped the way we look at decisions about building performance. Even if something like the full Passive House standard is not adopted as our energy code, it will be a huge improvement if the principles embedded in the standard become our typical approach to design decisions, altering both the cost and performance of our buildings positively.

Postscript: This piece owes a great debt to the work of Amory Lovins of the Rocky Mountain Institute. For a deeper exploration of these concepts we highly recommend *Natural Capitalism: Creating the Next Industrial Revolution* which he co-authored with Hunter Lovins and Paul Hawken.



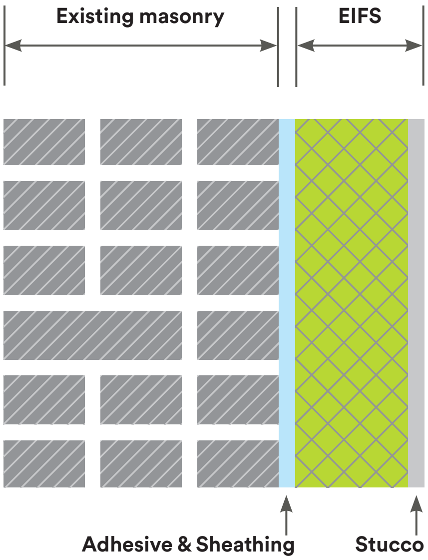
1 The greatest resource savings of a given component are achieved with the first upgrades to performance, for instance, going from single to double glazed windows.

2 Our energy codes typically set performance requirements based on the moment of diminishing returns—the point at which the direct returns per dollar spent on improved performance declines.

3 In certain scenarios, increasing performance of one element can have dramatic impacts on efficiency. A high performance window, for instance, might allow a project to forego providing heating at the window interiors.

4 Taken together, the more expensive window has resulted in eliminating the cost of the heating system—so the higher performance option is less expensive.

Figure 16: EIFS Detail



The proposed EIFS system would likely include a layer of sheathing fastened to the existing masonry, with the insulation adhered directly to the sheathing. The adhesive acts as an air barrier.

to 2” of R-5 XPS insulation, or 2.5” of R-4.2 rigid mineral fiber board. Many people assume that pursuing Passive House requires adding a large quantity of insulations in walls and roofs, but this is typically the case only in smaller buildings with a high ratio of exterior surface to interior space. Conventional energy codes usually require the same amount of insulation in both large and small buildings, whereas Passive House calculates the appropriate amount of insulation needed (assuming other criteria like airtightness and window specifications are met.) In fact, because this specific building has a limited window area and lacks the more egregious thermal bridges (like balconies), the wall R-value required by Passive House is actually less than current energy code. This is not a particularly common set of circumstances, but illustrates the degree to which Passive House tailors requirements to the specifics of the project.

Two basic strategies offer themselves to provide the additional insulation required to meet the EnerPHit standard: an Exterior Insulation & Finish System (EIFS), or a ventilated rainscreen, both of which require scaffolding the entire building exterior.

EIFS: Installation of an EIFS system requires mechanically fastening a layer of exterior sheathing to the existing brick to produce a clean, stable substrate. (If the existing brick is sufficiently stable this sheathing layer can be omitted and the insulation can be installed directly against the brick.) The required layers of rigid insulation are then adhered directly to the sheathing without mechanical fastening. (Figure 16) In this assembly the adhesive is actually the air barrier. A mesh-reinforced multi layer coating resembling stucco (typically proprietary) is applied over the insulation to finish the new facade. (See Figure 17)

Insulation needs to return at the jambs and heads of each window opening, with a special detail for the sills, presumably in metal. It also needs to encapsulate the parapet, including the top and rear faces, with a metal coping cap over the assembly. This is the least expensive exterior insulation option, but these systems have a history of moisture problems

Figure 17: EIFS typically utilizes expanded polystyrene board insulation. The product shown here utilizes recycled wood fibers, providing the requisite thermal properties with far lower life cycle costs.

related to fine cracks that can develop in the stucco finish, allowing water to seep behind this outer layer where there is no system to allow the moisture to drain back out of the wall assembly. Regardless, these commonplace EIFS systems represent the most cost-effective means of improving the insulating properties of the wall while limiting air infiltration.

Rainscreen: These systems are more expensive than EIFS systems, but can produce an extremely durable façade system with a wide variety of aesthetic options, most of which significantly increase curb appeal. (Figure 18) Rainscreen systems require frequent points at which the faced system connects mechanically to the existing building structure. These penetrations are costly, but also interrupt the otherwise continuous layer of exterior insulation. This requires careful detailing and may result in the need for additional R-value of insulation to compensate for the penetrations in the insulation layer. (Though many systems are now available that include elements with low thermal conductivity, like fiberglass.) Rainscreen systems allow for the installation of façade components (insulation, air barrier, sheathing, etc.) in the correct order and in a manner allowing for easier long term maintenance. (Figure 18) Properly constructed rainscreen systems should not suffer from the moisture problems often associated with less expensive façade systems, like EIFS.

Roofs: A total of R-23 is needed at the roof, easily reached with 2” of XPS insulation board, and not dissimilar to the insulation board that exists currently. This can easily be included when the roof membrane requires replacement. Any roof membrane replacement program should be prepared to accommodate other complementary uses for the building roof area, including green roofs (to supplement insulation, reduce the heat island effect, improve stormwater performance and provide wildlife habitat), as well as the potential installation of photo-voltaic systems. Insulation will also be required on the inside face of the parapet above the roof.

Windows

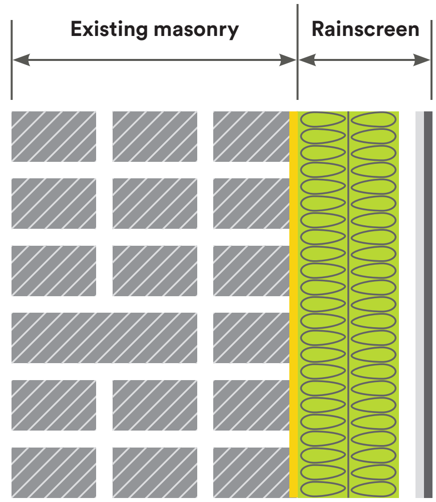
EnerPHit Target	**U=0.18**
Existing	**U=0.80**

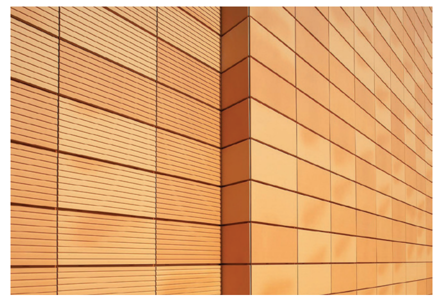
Proposed
Replace existing windows with PH-certified, triple-glazed windows, with appropriate install details

Passive House requires careful selection of high performance windows to ensure interior comfort and to optimize heating and cooling demand. To maximize comfort and reduce the potential for condensation, these windows often require triple-glazing, though not always in transitional spaces such as lobbies or common areas. Passive House windows meet stringent standards for airtightness and thermal bridging with continuous gasketing, robust hinging and locking mechanisms, and frames incorporating extensive thermal break materials.

Passive House determines the window performance requirements based on several

Figure 18: Rainscreen Detail





While more expensive, a rainscreen system provides a far more attractive and durable exterior facade that should not suffer the maintenance challenges often experienced with EIFS products.

Figure 19: Available Passive House Windows

Frame	Mtl.	U, total	U, Frame	U, spacer
Schuco	Alum.	0.144	0.176	0.031
Heroal	Alum.	0.13	0.13	0.022
Schuco	uPVC	0.114	0.134	0.016
Munster	uPVC	0.13	0.15	0.022
Aluplast	uPVC	0.14	0.19	0.022

Several manufacturers offer products in the US that meet Passive House requirements, a market that has been growing significantly each year.

Figure 20: The primary Passive House window criteria are as follows:

Assumptions

Winter design temp	14.4 °F
Installation PSI value**	0.023

Window Criteria

U-glazing*	0.115
U-frame*	0.155
Glazing edge**	0.020
Solar Heat Gain Coefficient	0.325

*BTU/h/ft2/F
**BTU/hr-ft-F

The following table compares the U-value requirements of the Passive House windows with that of the existing and that mandated by current code.

PH Window U-value	0.18*
Existing U-value	0.8
Delta	5X
Code U-value	.55**
Delta	3.4X

*Assumes carefully detailed installation that mitigates thermal bridging at window perimeter. (A poorer installation would require a more stringent U value.)

**Code U values do not take installation conditions into account.

Figure 21: Existing Window Although the frames of the proposed Passive House windows are larger than the existing, because the retrofit would allow for the elimination of window AC units the daylight area of the windows are effectively increased by about 15%.

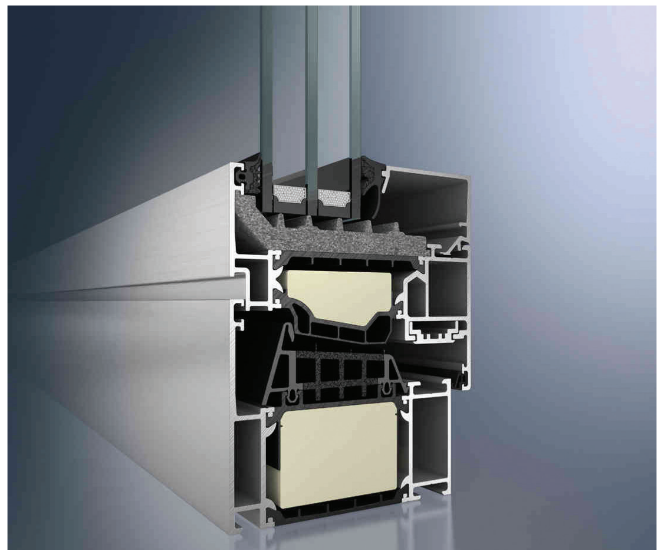


Figure 22: Proposed Window Passive House certified windows benefit from generous thermal breaks within the frame, typically include triple glazing, and, perhaps most importantly, include gasketing and hardware that ensure airtightness.

factors, including the size of each window opening, the interior conditions and thermal bridging characteristics of the window installation. Another primary driver is the winter exterior design temperature assumed within the PHPP software. The thermal comfort requirements for New York (in the PHPP) are currently based on an exterior design temperature of 14°F. EnerPHit allows some exemptions if heat is delivered at the window surface. The required window criteria for a project is partially dependent on assumptions about the thermal properties of the installation itself, since the performance of a window is directly impacted by the local context. Standard energy codes do not calculate the losses associated with varying installation details.

The availability of Passive House certified windows in North America, while limited, is increasing steadily. To reach the US market, windows must not only meet Passive House standards but must also fulfill National Fenestration Rating Council (NFRC) and other US certifications. Many manufacturers of Passive House certified windows specialize in wood frame units, which are the norm in Europe, even in multi-story buildings. Here in the US, wind load requirements typically

Passive House windows differ significantly from typical windows, with far higher performance regarding both energy use and human comfort.

US energy codes view window performance primarily through the prism of heat transfer of the total window unit, without isolating the performance of individual components (the frame itself vs. the glazing unit, for instance) and with only nominal limits on air leakage. While this certainly simplifies the testing and selection of windows, it produces energy and comfort compromises by allowing one component with relatively strong performance to obscure poor performance in other areas. The components of window units that directly impact performance include i) the frame itself and the makeup of any thermal break, ii) the operating sashes and their hinging and locking mechanisms, iii) the spacers (often aluminum) at the edge of insulated glazing units (IGUs), iv) the gas (often air, sometimes argon) between glazing panes, and v) the number of panes of glass. Each of these can impact the other quite directly. You may have an aluminum frame with an excellent thermal break, but aluminum spacers in the IGU can effectively bypass the thermal break, increasing the potential for condensation and amplifying discomfort for those near the windows.

A typical code compliant window, for example, will require that the interior surface be conditioned by a heating or cooling system at certain times of the year to avoid condensation and mitigate discomfort. A high-performance window, however, might eliminate the need for that perimeter heating and cooling system, but this cost reduction is rarely considered when we evaluate the cost effectiveness of the window.

Additionally, testing for U-values in the US is done with equal pressure on either side of the window unit, a lab condition that is effectively never encountered in real life. Pressure differences are often quite severe and air leakage (around the window glazing, at hardware locations, or at the sashes) bypasses the performance of the individual window components. This convection heat transfer actually increases the conductive heat transfer. Not only is heat lost (or gained) via the air itself, the leakage increases opportunities for condensation and discomfort. Under our current testing procedures, a poorly designed leaky window can have the same total U-value as a highly airtight unit. The former will perform far worse than the latter, but the consumer has no reasonable means of telling the difference between them. Many window experts would go so far as to say that the airtightness of a window unit is more important than the U-value, but our energy codes do not requiring testing that would inform decisions on this basis.

Enter Passive House

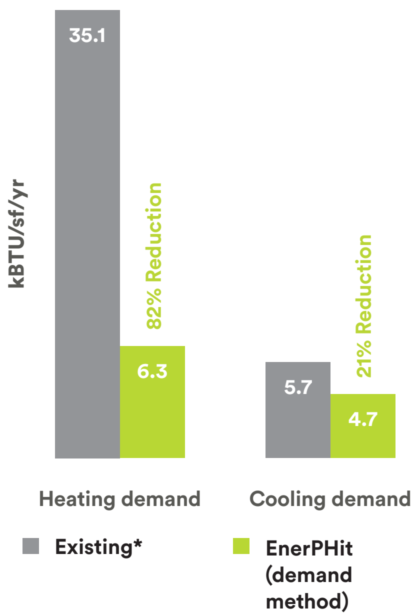
Passive House tackles window performance by looking primarily at their contribution to interior comfort, and with regard to heat transfer they assume windows should provide energy balance. As such, the window criteria in Passive House includes individual U-values for both the frames and the glazing components (not just the total U-value) and they include stringent airtightness requirements.

Here in the US we see windows as a breach in the envelope, with the performance of the window unit mitigating (slightly) the energy losses through the opening. One goal of Passive House is to configure the placement, area, performance and installation of windows such that the heat losses are lower than the annual solar heat gains through the glazing, meaning that the windows reduce total heating demand rather than increase it.

A fundamental element of this perspective is basing window performance requirements on the specific climate impacts of the location. Our energy codes already do this to some extent, requiring different U-values for different climate zones around the country. But Passive House takes this to a far more granular level, using the peak temperature extremes in a specific location to determine the overall U-value of the window units and using interior comfort as an additional consideration beyond heat loss. Passive House starts by asking that the interior surface of the window never be more than seven degrees Fahrenheit different than the air temperature of the room (the threshold at which people feel discomfort because of radiant heat transfer.) The window and glazing U-values are set to ensure this delta is not reached on the coldest day of the year. As a result, a person wearing a thin shirt can sit next to a Passive House window in winter, and not feel a chill.

Although double-glazing may be sufficient in common areas and hallways—places where occupants are rarely sedentary near the glass for long periods—triple-glazing is typically required for Passive House projects. But Passive House certified windows are more than just triple-glazed, they meet stringent standards for airtightness and thermal bridging with continuous gasketing, robust hinging and locking mechanisms, and frames that incorporate extensive thermal break materials (Figure 22). It is probably true that the airtightness, thermal breaks and other measures are as important to the overall performance of Passive House windows as the triple glazing. In general terms, it is better to have a tight window than a low U-value, but best to have both.

Figure 23: Heating and Cooling Reductions



* Based on energy modeling, calibrated to utility bills

Upgrades to the building envelope, including new exterior insulation, airtightness and high-performance windows, result in a 80+% reduction in heating demand and 20+% cooling demand.

necessitate aluminum frame units, or polymer based frames with metal reinforcement. Figure 19 lists several of the windows that currently meet both the Passive House criteria and other requirements for this project, including the Shuco unit modeled and priced for the feasibility study.

Phasing: There are effectively two options for window installation. The most effective method is to install new windows from the exterior when the exterior insulation system is installed, thus utilizing scaffolding once and limiting disruption to the tenants. However, if the building owner wishes to delay the expense of implementing exterior insulation, it is feasible to install new windows from the interior, realizing significant comfort and energy cost benefits. Because the new high-performance windows so dramatically reduce air infiltration, best practice suggests installing a balanced ventilation system as soon as possible after the window installation, to ensure that the tighter envelope doesn't create unhygienic conditions. Careful positioning of the new window will be critical to avoid thermal bridges when all phases of the retrofit are complete.

Phased Retrofits and Window AC: Passive House window performance criteria essentially precludes the use of double-hung windows. The "meeting rail" connection between the upper and lower sashes and limited engagement offered in the sliding track at the jambs is simply too weak to meet the airtightness and thermal break requirements essential to both human comfort and energy savings. Assuming that a window replacement program will occur prior to the conversion of the heating and cooling system, provisions must be made to accommodate window AC units in the period between new windows and new cooling systems. Because Passive House windows are typically of the casement or tilt/turn type, the windows may need to be designed to accept a window AC unit for several years, with the void replaced by triple glazing when a new cooling system is finally in place. There is no technical impediment to this, but window manufacturers do not currently offer units specifically suited to this purpose and will need a strong market indicator before they are likely to invest in the required research.

Heating & Cooling

Once improvements to the envelope are complete, heating and cooling demand is dramatically reduced. (Figure 23)

Heating

EnerPHit Estimate	**6.3 kBTU/sf/yr**
Existing	**35.1 kBTU/sf/yr**

Proposed
Remove steam radiators, install VRF system with rooftop condensers and cassettes in each major room

The heating demand reductions of more than 80% allow for either scaling back the existing steam delivery system or replacing this system with something providing far smaller capacity and far greater efficiency.

Our analysis indicates that the heating demand is so low that the heat produced by the steam risers, not including the radiators, is sufficient to meet the overall heating demand for a significant portion of the year. Put another way, with a fully improved envelope, even with the radiators turned off apartments will experience periods of overheating in the shoulder seasons solely due to the heat from the risers. Given the size and quantity of the steam risers in the building, the heat output of the risers could meet 40% of the annual heating load of the fully improved envelope, which is over 50% of the heating season. The potential for overheating will necessitate a steam riser control system to prevent overheating even when all apartments have the radiators off because the room temperature set point is satisfied.

Phasing out the steam heating system is further complicated because the steam system that serves the building is actually a small district system, serving a total of three buildings. A building by building conversion will be required to achieve the full efficiency of the retrofit upgrade. For the purposes of this study, we assume the full conversion of this building includes the removal of the steam boiler system.

Cooling

EnerPHit Estimate	**4.7 kBTU/sf/yr**
Existing	**5.7 kBTU/sf/yr**

Proposed

Remove window AC units, install VRF system

The cooling demand reductions, while more modest, will result in significant electricity savings. Changes to the cooling system however, are not driven primarily by cooling demand but by the fact that window air conditioning (AC) units do not meet the comfort and envelope criteria of Passive House. With regard to comfort, window AC units and the assemblies required for their installation represent significant thermal bridges, impairing thermal comfort and raising the risks of condensation. The airtightness of these units is also substandard, and even if the units are provided with a carefully designed thermal jacket in the winter months, their installation almost universally results in a porous element in the exterior façade. They are also not particularly efficient. (See also “Phased Retrofits and Window AC” above.) These issues require the introduction of a cooling system other than window units.

Through-wall, packaged thermal air conditioning units are another common solution in New York and around the United States. While these represent an improvement over window units, the same issues regarding thermal bridging and airtightness preclude a PTAC system from meeting the requirements of Passive House. (In the Optimal Plan later in this

Heating & Cooling Options

The study assumes that heating and cooling demands are met by the introduction of a Variable Refrigerant Flow system, described elsewhere in this section.

Converting the existing steam system to a hydronic system is a common upgrade for buildings of this type and, while possible, it seems a less attractive option when the various challenges are considered. Among the most attractive aspects of a steam-to-hydronic conversion is the potential to use the existing distribution piping (though not the radiators) to serve the interior spaces. However, since chilled water would be delivered in the 40-50 F temperature range, all the piping would need to be insulated to avoid condensation. Opening the pipe chases in every major room in the building to insulate this piping would be costly and seems an untenable level of intrusion while the building is occupied. The other option would be to run new hydronic piping on the exterior of the building, similar to what is proposed for the refrigerant lines. In either case, the existing radiators would need to be replaced with appropriate fan-coil-units.

The most effective centralized solution would likely be an air-to-water heat pump (AWHP) plant that delivered hot and cold water to the selected distribution system. While there is not currently a well developed market of heat pumps at the scale of this application it might be feasible to install a high efficiency boiler and rooftop chiller system now and replace it with an AWHP plant when they are available. Refrigerant leakage is a major contributor to climate change and one of the primary advantages of a central AWHP plant is that the refrigeration system would be packaged and the refrigerants charged in the factory, greatly reducing concerns about leakage when compared to a VRF system.

A third option might be the provision of water source heat pumps in each apartment connected to a condenser water loop whose water is heated by a central AWHP plant and cooled by a heat rejection plant like an evaporative cooling tower on the roof. In addition to the significant hydronic piping required, the units in each apartment would each take up about four square feet of space.

Given the above issues, refrigerant leakage concerns notwithstanding, at time of writing a new VRF system seems the most effective solution.

section we discuss the significant potential for high-performance packaged units to improve the viability of deep retrofits.)

Another option is to convert the steam system to a hydronic system, which entails replacing the steam boiler with a hydronic plant, replacing the steam radiators in every room with Fan Coil Units, and introducing a new cooling tower assembly, presumably on the roof. This is a somewhat common upgrade for post-war buildings, but it is expensive and complicated to implement and, all other things being equal, often costlier to operate (due to pump and fan energy, among other things) than the other primary option, a Variable Refrigerant Flow (or VRF) system, detailed below.

The overheating issues described above essentially preclude the continued use of the steam system, and the existing window AC units do not meet Passive House requirements. To meet the heating and cooling demands of the project we elected to study the installation of a new VRF system. See the Heating & Cooling Options sidebar for more details on this choice.

Variable Refrigerant Flow Systems (VRF)

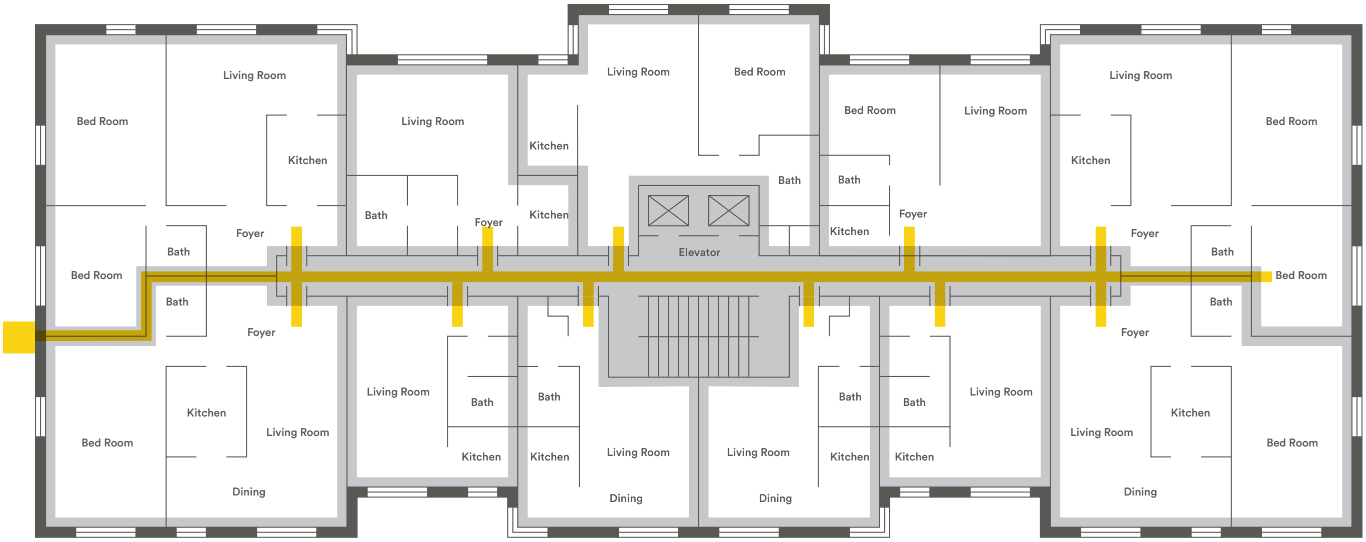
Commercialized in the 1980s, VRF systems use refrigerant as the medium for cooling and heating. A compressor and heat exchanger are located in an outdoor unit. Refrigerant is distributed throughout the building to fan-coil units (FCUs) where the refrigerant heats or cools air as needed. The ability of the system to operate at varying speeds allows for efficiency and greater control of interior temperature.

The terms most commonly used to describe refrigerant-based air conditioning systems can be a little confusing. The term “VRF system” typically refers to larger systems with expansion valves at the FCUs that allow for longer piping runs, a greater number of FCUs on each refrigerant loop, and in some cases, heat recovery. Although VRF systems are, technically, “heat pumps,” this term usually refers to smaller systems utilizing variable speed compressors. Often found in homes or small commercial spaces, these systems are also often referred to as “mini-splits,” “ductless,” or “ductless mini-splits.” Whatever the terminology, the fundamental technology of these various refrigerant based systems remains essentially the same.

VRF systems have several benefits compared to more traditional systems, offering a much higher level of control than ducted systems, and they can be much quieter. Standard hydronic systems also provide a high level of control, but pump and fan energy to operate them can be

Figure 24: Similar to "mini-split" systems, VRF systems utilize interior cassettes to deliver heating and cooling. A unit similar to the one shown here would sit above the window in each major room, replacing the steam radiators and window AC units.

Figure 25: Distributed VRF Diagram



In a distributed VRF arrangement, a small tower would be constructed at one end of the building to house condensing units serving each floor. Refrigerant lines would run above the ceiling in the hallway and serve cassettes mounted above each foyer. Small ducts would deliver tempered air to adjacent rooms.

excessive, making those systems less attractive from an energy efficiency perspective.

In Passive House projects, a common problem is that the smallest heating and cooling units available are far larger than is necessary. Even VRF systems are somewhat too large in most cases, although they do offer the lowest capacities on the market when compared to other options providing both heating and cooling.

In buildings that may experience the simultaneous need for heating and cooling due to differences in internal gain or excessive solar gains in some areas, VRF offers the ability to recover heat from one side of the system and provide it to the other. This heat recovery option improves the performance of the system but typically requires additional controls and, in some cases, extra refrigerant lines. This type of system is ideal for office spaces with differing uses spread around the building and for hotels where occupants have varied temperature requirements. Heat recovery is not included in this proposal.

In the subject building, a

Refrigerants

While Variable Refrigerant Flow (VRF) systems such as the one described in this report offer high efficiency and other important benefits, there remain concerns about the significant global warming impact of the hydroflourocarbon (HFC) refrigerants utilized within these systems. Although refrigerants that severely deplete ozone have been largely phased out since the 1987 Montreal Protocol, their replacements—mostly HFCs—are very potent greenhouse gases. Recognizing this impact, in 2016 roughly 200 countries signed the Kigali Accord, a commitment to dramatically reduce the use of HFCs by 2050. Kigali was a remarkable show of global unity, but HFC replacements are proving difficult to find.

Those looking to utilize VRF systems must contend with the possibility that the specific refrigerant the system is designed for might be phased out, and that the replacements might require new refrigerant lines or other equipment replacement—an expensive and disruptive prospect. Leakage of HFCs can occur during installation, commissioning and disposal of the systems, so training installers is critical moving forward. How critical? If the leakage is high enough, the global warming impact of the HFC could potentially outweigh the benefit of not burning fossil fuels over the life of the system.

VRF systems have a prominent role to play as we drive toward electrification of the built environment, but ensuring they are installed and maintained appropriately and that there is a smooth transition to refrigerants with low global warming impact will be incredibly important if we are to meet our climate action goals.

A fuller treatment of this issue is available here:
https://www.buildinggreen.com/feature/cost-comfort-climate-change-and-refrigerants

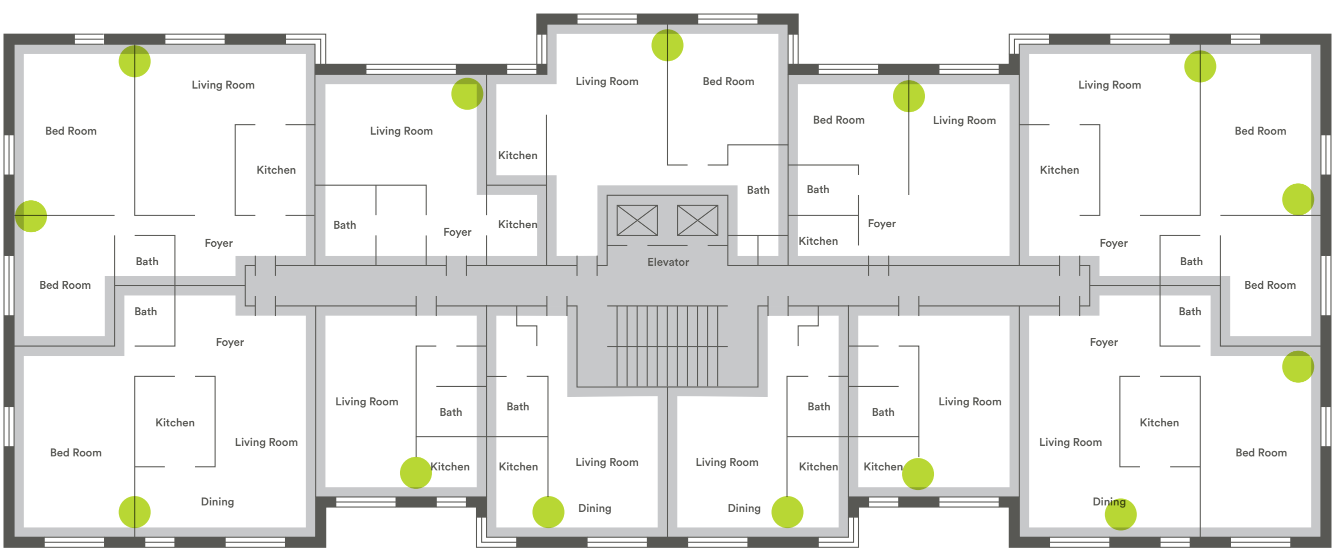
VRF cassette would replace each existing steam radiator, with the cassette mounted over the window above the existing radiator (Figure 24). This arrangement frees up a portion of floor area. Coupled with the removal of the window AC units and the high performance of the windows themselves, it will now be feasible to sit comfortably directly next to these windows in all seasons. Assuming this configuration frees up space next to each window that is the width of the window and 3 feet deep, the retrofit adds roughly 4,000 square feet to the usable area of the building.

There are two primary options for deploying a VRF system: distributed or centralized.

Distributed VRF: In a distributed arrangement, condensing units are designed to serve specific zones, presumably one or two floors, and located throughout the building. Unfortunately, in the subject building there are no extraneous mechanical or common area spaces that might be repurposed for such units, and creating such space with access to the exterior would require significant reductions in one or more apartments, which seems untenable. Another distributed option is to build a small footprint tower at one end of the building to carry condensing units. An obvious location for such a tower is the north façade of the building. The new tower would likely be clad for aesthetic purposes but would not need to include conditioned space. The condensing units in this tower would deliver refrigerant along the spine of each floor to serve a ceiling-mounted VRF unit in the foyer of each apartment (Figure 25). This option would be relatively expensive, given the need to build the small mechanical tower, and the interior runs of refrigerant (including those through the northernmost apartments from the condensing tower to the interior corridor) would be extremely disruptive to the occupants.

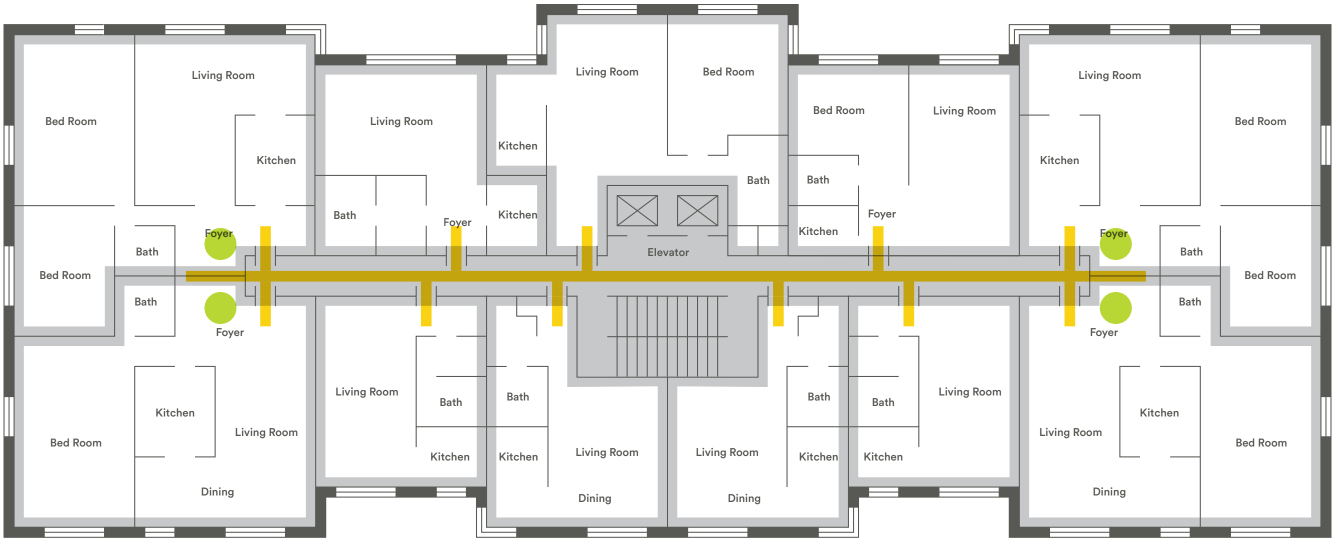
Centralized VRF: In a centralized arrangement, large condensing units would be located on the roof serving interior VRF units via vertical refrigerant runs. There are

Figure 26: Centralized VRF, Option 1: Replace Existing Risers



The existing steam risers serve each major room in the building and could be removed and replaced with vertical refrigerant lines, although this would entail opening these chases from floor to ceiling in every major room.

Figure 27: Centralized VRF, Option 2: New Central Shafts



In this scenario new shafts are created at each end of the hallway, elimianting some closet space in the four end units while providing easy access to the hallway for distribution.

three options for locating these refrigerant risers, listed from most disruptive to least:

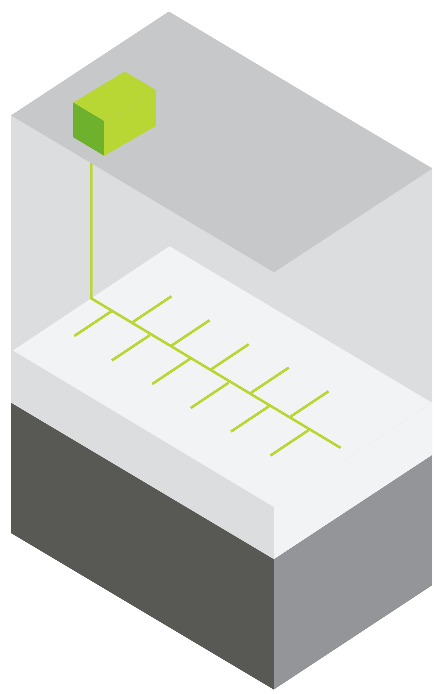
1. In existing steam riser locations
2. In new central shafts adjacent to the corridor
3. On the exterior of the existing façade

Replace existing steam risers: The idea of replacing the old heating risers with new ones is appealing, as they are evenly distributed around the perimeter of the building, adjacent to each radiator which will be replaced with a new fan coil unit (FCU.) (Figure 16). However, this work would be extremely disruptive to the apartments as the chases containing the existing steam riser would need to be opened in every major room of every apartment on every floor. It is highly likely the old steam riser piping would require removal. This sort of significant construction throughout the building seems untenable, though it is technically possible.

New central shafts: In this scenario (Figure 27), the vertical refrigerant lines would be located in two newly created shafts at either end of the central corridor. As luck would have it, there are 6-foot deep closets at each end of the corridor. Without understating the disruption this would cause for the four apartments that would be impacted, one can imagine that a small portion of these closets might be considered a reasonable sacrifice for a modern heating and cooling system. If the chases are the full width of the corridor (4'-8", also the depth of the back to back closets) the chase would only need to be 6" deep. If one assumes 4" shaft wall the closets will have lost only 10" of width. From the risers, horizontal lines would run along the ceiling of the corridor, feeding fan-coil units mounted at the foyer ceiling of each unit (Figure 29). Reaching bedrooms and other ancillary spaces would be difficult, requiring either running refrigerant to cassettes serving those spaces, or ducting tempered air from the entrance ceiling units.

Both scenarios represent significant disruption to every

Figure 29: Centralized VRF, Option 2 Schematic



New central shafts would allow the rooftop units to directly serve distribution in the hallways at each floor.

Figure 33: Centralized VRF, Option 3 (preferred) Schematic

In this option each rooftop condenser unit serves a "stack" of cassettes, one per floor. Vertical distance restrictions require that separate supply and return refrigerant lines serve the lower and upper floors.

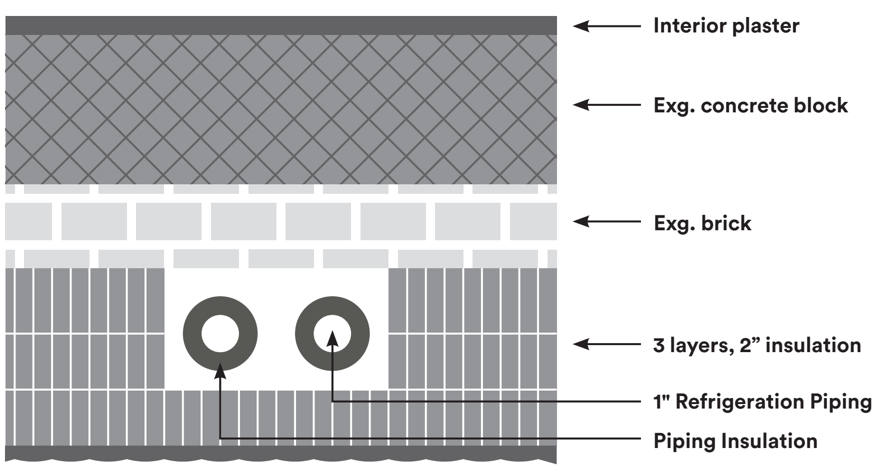
room in every apartment, especially in the most congested areas of the plan—the kitchen and bath spaces adjacent to the corridor. Although this scenario requires a single supply and return riser for each floor rather than for each stack of cassettes, the increase in horizontal piping required means that more material is required than the other options. Another barrier to this scheme is headroom in the hallway. The most viable ventilation option will include a wide duct along the ceiling of the hallway, leaving little space for refrigerant piping, and necessitating crossovers that would certainly drop below comfortable levels.

Exterior risers: The most plausible scenario is to run vertical refrigerant lines on the outside of the building with each supply/return pair of risers fed by a rooftop condensing unit (Figure 30). The new VRF cassettes would be located above the major windows in each apartment and to avoid crossover of lines on the façade, a supply and return would run vertically on opposite sides of the windows. The primary restriction of this system is a 160' foot limit on the vertical distance of any cassette from the condenser, as well as a 100 foot limit on the vertical distance between any cassettes served by single riser. Due to this, each "stack" of cassettes would be divided into upper (floors 8-15) and lower (floors 1 to 7) portions with separate supply & return risers. (See Figure 33) Small penetrations through the existing masonry would be required at each cassette location, to minimize interior refrigerant runs.

VRF & Recladding

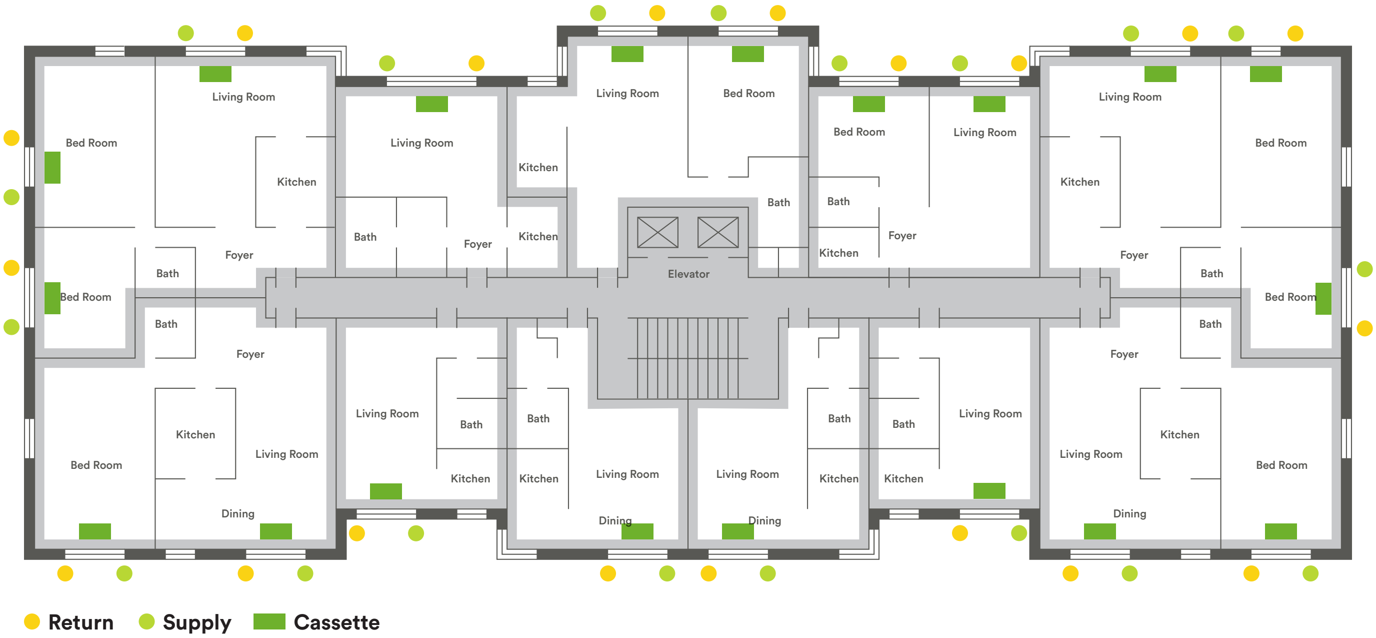
One consequence of the exterior riser arrangement is that the refrigerant lines would have to be installed in the same phase as the exterior recladding system (whether EIFS or rainscreen.) In either case, 4" of additional insulation would be added to provide depth for the insulated riser lines, with the 2" of insulation required to meet Passive House over that. (See Figure 32) With this arrangement, a rainscreen cladding system would be highly preferable to an EIFS system:

Figure 32: Refrigerant Lines Detail



Installing the refrigerant lines on the exterior requires additional insulation to maintain a flat façade (and to maintain the continuous 2" required to meet Passive House.) The need to remove and patch EIFS to service these lines recommends the rainscreen recladding over the EIFS.

Figure 30: Centralized VRF, Option 3: Risers on the Exterior



The preferred VRF option limits interior construction by placing the new refrigerant lines on the outside of the existing masonry walls and directly accessing the new cassettes over each window.

any future work on the buried refrigerant lines could be done without permanent aesthetic impact because the visible cladding is removable. With an EIFS system, any future work would require cutting away the stucco exterior and re-patching, with predictably poor aesthetic results.

Ventilation

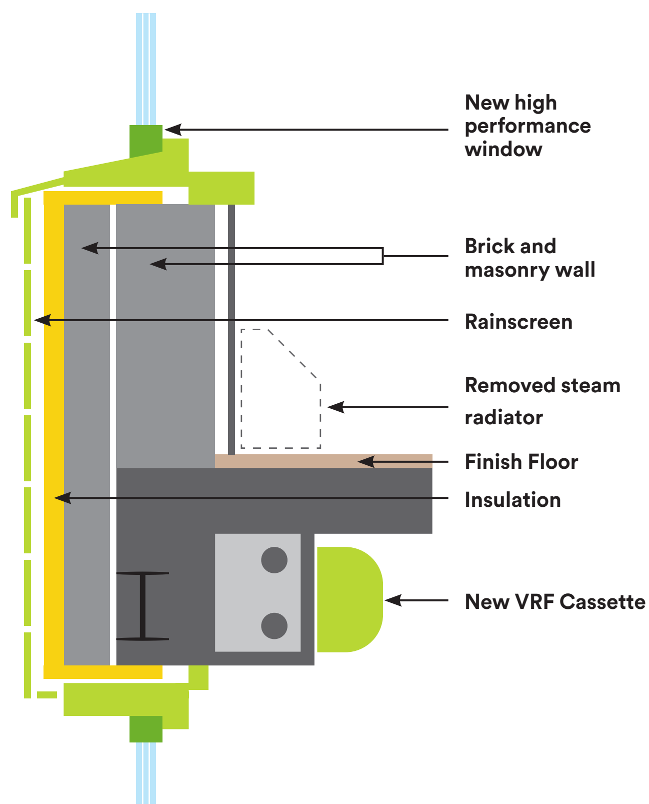
EnerPHit Criteria	**75% efficient (energy recovery), humidity control**
Existing	**No heat recovery, no humidity control**

Proposed

Convert existing exhaust system to balanced system utilizing rooftop energy recovery ventilation units

Ventilation represents an underappreciated component of the quality of interior spaces. The need for balanced and properly filtered fresh air receives far less attention than heating and cooling systems but has just as significant

Figure 28: Proposed Wall Section



The fully retrofitted envelope includes new recladding with sufficient insulation as well as high-performance windows, while the new VRF cassettes are installed above the window in each major room.

Figure 34: Existing Ventilation Plan

Kitchen Bathroom Cooridor

Most ventilation systems of this era perform only adequately, relying heavily on infiltration from the exterior (and adjacent apartments) to make up air exhausted from kitchens and bathrooms.

Figure 31: VRF Scenario Matrix

		Pros	Cons
1	Replace Steam Risers	Tenants: No loss of interior square footage Phasing: Strong flexibility Efficiency: Close proximity to FCU units	Tenants: Major disruption to every major room in every unit
2	New Interior Chase	Tenants: Somewhat limited in-unit disruption (except end units) relative to scenario 1 Phasing: Not dependent on other phases needed	Tenants: End units (4) lose 10" of closet space Tenants: New ceiling mounted FCU locations Tenants: Piping/Ducts needed to rooms off corridor
3	Exterior Risers	Tenants: Least interior disruption Tenants: FCUs in same location as exg. Radiators Materials: Less linear feet of refrigerant piping	Cost: 4" additional exterior insulation (for flat facade) Phasing: Vertical risers must be installed with exterior insulation

an impact on the comfort and health of occupants. Despite this, many live or work in spaces with less than ideal ventilation, and some significant portion of buildings have ventilation systems that are almost entirely non-functional. The multifamily residential market is dominated by exhaust-only ventilation systems that draw air out of kitchens and bathrooms and exhaust it to the exterior, often at the roof. To replace the volume of air pulled out of the building by the exhaust, these systems rely on fresh air that is typically provided at the corridors as well as random infiltration through the windows and gaps in the exterior envelope. (Many post-war buildings have corridor exhaust as well, and no mechanical supply air at all.) This infiltration air is often the source of moisture that leads to mold formation and can be the source of asthma-inducing contaminants like PM 2.5 and ozone. Common areas such as corridors usually have separate supply air systems.

Figure 35: Energy Recovery Ventilation units similar to this Swegon unit would serve the new ventilation system, resulting in highly filtered, balanced fresh air delivery at a minimal energy cost.

Engineers often argue that pressurizing the hallways prevents smells from transferring from the apartments into the corridors and thereby bothering the neighbors. However, negative pressures in apartments often result in air being drawn between these areas through common walls, spreading odors and reducing both the effectiveness of the system and the comfort of the occupants.

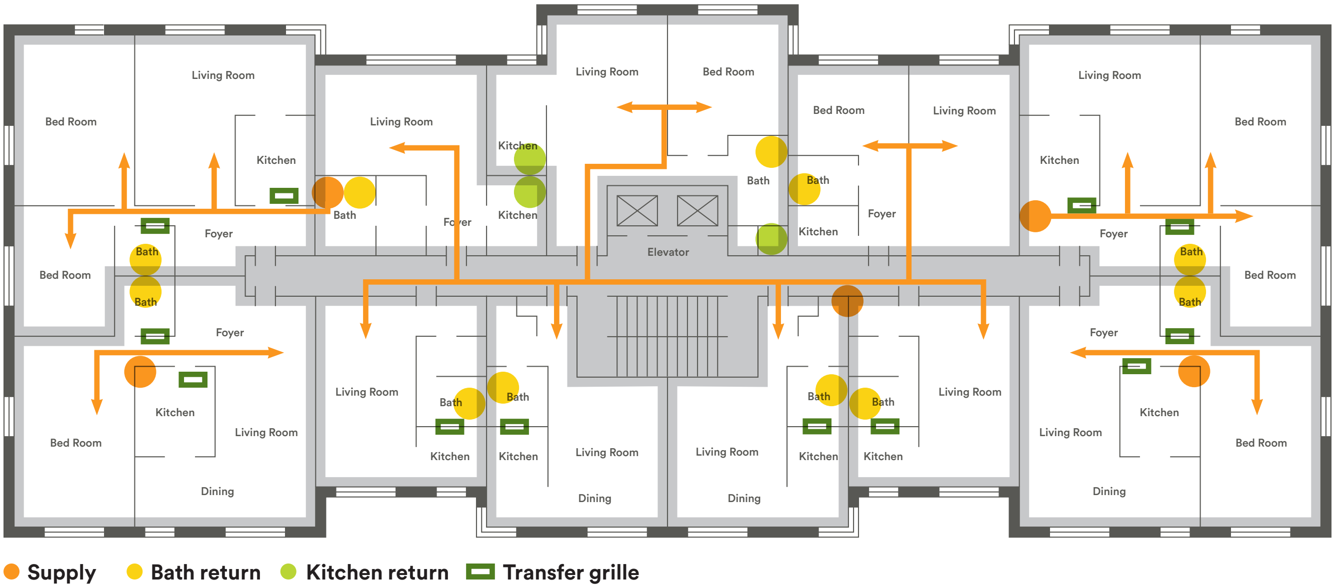
The Passive House standard requires balanced ventilation that delivers properly filtered supply air directly to habitable spaces, while stale air is removed from kitchens, baths, and laundries. This approach is made possible in part by the airtight envelope which in addition to benefits mentioned elsewhere (improved air quality, air temperature, and acoustics) ensures the balanced ventilation draws little air via infiltration from the exterior or adjacent apartments. Passive House ventilation systems must also be at least 75% efficient, which necessitates the use of energy or heat recovery units (ERVs/HRVs) to handle temperature and moisture differentials in the supply and return streams.

Existing Ventilation System

The existing ventilation strategy of the subject building is typical for the type and age of the building: stale air from the kitchens and baths in the apartments, as well as the corridors, is exhausted out of the building and fresh air is supplied to the corridors on each floor. Vertical duct risers located throughout the building extend from the lowest floor up to the underside of the roof where they combine and then connect to three roof-top fans: one for the kitchen exhausts, one for the bath exhausts and one for the corridor exhaust air (Figure 34). In older, less airtight buildings, exhaust-only systems have been shown to provide adequate (but not excellent) ventilation if properly designed and air sealed—though it must be stressed that most ventilation systems of this post-war era are neither designed or maintained properly. However, exhaust-only systems in a building retrofitted to Passive House airtight standards will be unable to provide the desired fresh air from the exterior and instead will pull air from neighboring hallways and apartments.

Conceptually, there are three distinct options for providing ventilation: decentralized, semi-

Figure 36: Floor Plan: Central Ventilation



In the proposed scenario the existing ventilation shafts are repurposed, converting the system from exhaust-only to balanced. Rooftop ERV units serve the new supply risers, and transfer grilles allow the reufrbished exhaust lines to extract from each room.

decentralized and centralized.

Decentralized ventilation: Individual ERVs/HRVs are provided in each apartment, usually requiring two penetrations through the exterior wall per apartment.

Finding a location for the ventilator can be difficult, especially in an existing building in NYC where every square foot of space is valuable. Maintenance is often a concern with this approach because the filters in each ERV/HRV need to be replaced or cleaned at least twice a year.

Semi-decentralized ventilation: A single ERV services all the apartments on one floor. Advantages include ease of access for maintenance and elimination of problems that can result from stack effect in the building. The primary disadvantage is the need for a large mechanical space on every floor.

Centralized ventilation: ERVs on the roof or at the base of the building (Figure 35) serving stacks of floors through central ventilation shafts (Figure 36). A more popular option for multifamily highrise projects, this arrangement results in the fewest number of ventilators, preserving valuable floor area and easing maintenance. Reusing an existing central system will save significantly on duct installation costs.

The ventilation shafts in the building under study can be repurposed and the system converted from exhaust only to balanced. For the purpose of this study, a centralized scheme has been explored.

Figure 34 indicates the location of the existing ventilation risers in the building. The kitchen and bathroom risers were originally sized to exhaust 50 cfm from each bathroom and kitchen. The corridor supply shaft was sized to provide the code required 0.5 cfm per square foot of floor area for that space which equates to approximately 250 cfm/floor. The proposed design is illustrated in Figure 36.

At the four apartments at the ends of the building, the kitchen exhaust riser will be converted to a supply riser. Transfer grills will move air from the kitchen to the bathroom exhaust to help remove moisture and odors from the apartment. Small soffits can be constructed to hide the new supply ducts which can be run down the foyers.

The seven apartments in the middle of the floor will receive supply air from the corridor supply shaft. A main trunk line approximately 6" x 24" can be run down the corridor and small 4" ducts can be used to penetrate into each apartment to supply approximately 45 cfm to the living rooms and bedrooms to balance out the exhaust flows. The total flow rate needed for the 7 center apartments is approximately 315 cfm which should be possible to achieve through the existing corridor riser. Thorough duct sealing will be required using an aerosolized product along with constant air-flow regulating (CAR) dampers at each register to ensure that the proper flow rates can be achieved throughout the building.

To handle the ventilation, this study assumes that three Swegon Gold rotary heat exchangers (1 size 50, 2 size 14) replace the existing rooftop exhaust fans. Ducting just under the roof will need to be reconfigured such that the exhaust and intake flows through each ERV are within 10% of each other.

Interior Insulation

As the building is freestanding and fully occupied, this analysis focused on the feasibility and benefits of installing new windows and applying insulation from the exterior. Although scaffolding a building of this scale is costly, it presents the most likely option because the impact on the tenants is limited and because it results in the highest performing building with least number of complications. The team analyzed the feasibility of insulating the building from the interior, and while possible, it raises the following concerns.

If insulation is applied in the interior, both the perimeter beams at floor level and the interior partitions that meet the exterior wall represent major thermal bridges that impact the heating and cooling demand as well as the comfort criteria. Because of these bridges, even adding R-50 of interior insulation (equivalent to 10” of XPS insulation board) will not allow the building to meet the demand criteria. As a result, any interior insulation strategy is possible only if the component method is followed.

To satisfy the component method interior insulation of R-13 is required. Achieving this with conventional insulation materials is not tenable given the 4-5” loss of interior space. Non conventional options include Aerogel, an advanced insulation product used in petrochemical industries for many years and recently adapted for the building industry. This product is essentially a gel that has had its liquid component replaced with 90% air, by volume. It is highly insulating, providing roughly R-10 per inch. In the UK the material is offered in a thin, rigid board with a layer of plasterboard adhered to it, ideal for retrofit applications because after being adhered to an existing interior wall, one can simply apply a layer of joint compound and paint. In this particular case, adding just one layer of 30mm (1.2 inch) Aerogel board would provide enough insulation to meet the EnerPHit component method criteria.

Another future option might be vacuum insulated panels (VIPs). Only recently available in commercial volume, these panels achieve up to R-50 per inch so only a 1/2 ” panel is sufficient. However, VIPs are mylar wrapped and if they are punctured (either during construction or later in life), the insulating properties fall to effectively zero.

Despite satisfying the component method requirements, interior insulation does not resolve the thermal bridges that remain at the floors and interior partitions. The thermal bridge at the floor could be improved by introducing a wedge of rigid insulation where the ceiling meets the exterior wall. If installed two inches deep at the exterior wall, and tapered over 20 inches to just ¼ inch, the surface temperature of the floor above will be moderated sufficiently to avoid most condensation issues. Windows need to be installed with thermablock material at the perimeters, reducing thermal bridging at each opening. If thermablock is not used at the window install, then tempered air would need to be introduced at the windows to avoid condensation.

Domestic Hot Water

EnerPHit Estimate	**6.8 kBTU/sf/yr**
Existing	**14.1 kBTU/sf/yr**

Proposed

Replace existing steam heat exchanger with high efficiency boiler

The study assumes that the existing steam heat exchanger for domestic hot water (DHW) is replaced with a high efficiency gas-fired boiler connected to the existing distribution system.

Renewable Energy

Although this analysis does not include costs or payback calculations for the provision of solar photovoltaic panels (PV) the Passive House energy modeling software (called PHPP) does allow for easy modeling of contributions from on-site renewable energy generation.

Using this module within the PHPP, we can determine that installing PV on the elevator tower above the roof and across 60% of the roof area comes to 3,500 square feet on the elevator tower and 1,700 square feet on the flat roof of PV panels. These are estimated to produce 52,000 kWh/yr or 178,000 kBTU/yr per year, roughly 16% of the existing building electricity demand and roughly 21% of the retrofitted building electricity demand.

Recognizing the drive to net-zero energy buildings, Passive House now includes two certification levels for the provision of renewable energy, Passive House Plus and Premium. For the case study building Passive House Plus certification would require 19.05 kBTU/sf-yr, or 38.04 kBTU/sf-yr for Passive House Premium. The figures outlined for this project come to 22.05 kBTU/sf-yr, which would qualify the project for Passive House Plus certification. (The same figures apply for EnerPHit projects.)

Other options include utilizing air to water heat pumps (AWHPs) for DHW, but these are not currently a standalone option for a building of this scale in this climate. Although highly efficient and widely used in single family homes, AWHPs have a lower output than boilers and the units available in the US cannot meet the simultaneous demands of a building of this scale. In fact, it is common for AWHPs in larger buildings to be paired with a traditional boiler for use during winter (when AWHP output decreases) or at peak demand periods.

However, as the carbon intensity of the grid decreases, the carbon reduction potential of AWHPs grows and it is anticipated that systems that can service buildings of this scale will be developed for the US and other markets. One of the more promising recent developments has been the introduction of CO_2-based heat pump systems that utilize a “split-system” arrangement with an outdoor compressor, improving efficiency dramatically and alleviating issues related to interior AWPHs cooling interior spaces even in winter. Smaller multifamily buildings can stack these CO_2-based split systems in modules to meet demand.

Lighting

The modeling assumes that all lighting, currently a mixture of compact or linear fluorescent lamps, is replaced with appropriate LED technology. Occupancy controls in common areas and back-of-house spaces are assumed, to reduce lighting levels during unoccupied periods.

Plugs & Process Loads

Plug loads are modeled as unchanged in the before and after scenarios. In the retrofit scenarios, all appliances are assumed to be EnergyStar rated and elevators to be higher efficiency models.

Summary Of Proposed Strategies

Based on the above analysis, the following set of retrofit strategies are proposed.

1. New windows + roof insulation + airtightness measures (shafts, etc.)
2. Centralized ERV supply & return ventilation system
3. EIFS and sheathing at exterior (incl. airtightness layer, and VRF risers at exterior)
   ALT 3: Rainscreen system in lieu of EIFS
4. Install VRF roof top units, replace steam radiators with VRF cassettes, connect to risers
   ALT 4: High-performance packaged units in lieu of VRF system
5. Replace domestic hot water heat exchanger with high efficiency boiler
6. LED lighting and controls, energy efficient elevators, EnergyStar appliances

These are listed in the proposed order of phasing (see next chapter.)

Optimal Plan (Near Future)

The analysis and proposed strategies listed above are based on products available in the United States today. But a heating and cooling option is available in the United Kingdom and Europe that is both more affordable and represents fewer phasing challenges: high-performance packaged heating/cooling units. Superficially similar to the through-wall packaged-terminal-air-conditioning-units (PTACs) so common throughout the US, these high-performance units utilize heat pump technology to more efficiently deliver heating and cooling. Unlike through-wall PTACs, these high-performance units typically house the 'outdoor' coils in an interior enclosure, obviating the need for an exterior condenser, and only require two 4" exterior ducts and a 1" condensate line opening, massively reducing the thermal bridging, air infiltration and discomfort issues associated with traditional PTACs. The supply and return ducts have self closing baffles. The units have inverter-driven compressors, which tend to be quieter than the constant-speed compressors common to PTACs in US.

In the case of the proposed strategies for our subject building, these units would replace the VRF system, including the rooftop units and entire system of exterior façade refrigerant risers and connections. In addition to significant cost savings, this system would obviate the need to install the exterior refrigerant risers at the same time as the exterior recladding (whether EIFS or rainscreen) is installed. Rather than replacing the entire steam heating system at once, these units could be phased in over time, presumably with each stack of rooms served by a specific steam riser. To ensure the heating demand is easily met, simple resistance heating would also be provided within the newly introduced balanced ventilation system. For heating purposes, these high-performance units would provide supplemental heating directly controllable by the occupants. Further research would be required to ensure that such units could meet the requirements of our cold climate, but they represent a promising potential retrofit solution.

The stages of this optimal plan would be as follows:

1. New windows + Roof Insulation
2. Centralized ERV supply & return ventilation system (w/ in-line heating)
3. EIFS and sheathing at exterior (incl. airtightness layer)
4. **Replace steam radiators with high performance packaged heating/cooling units**
5. Replace domestic hot water heat exchanger with high efficiency boiler
6. LED lighting and controls, energy efficient elevators, EnergyStar appliances

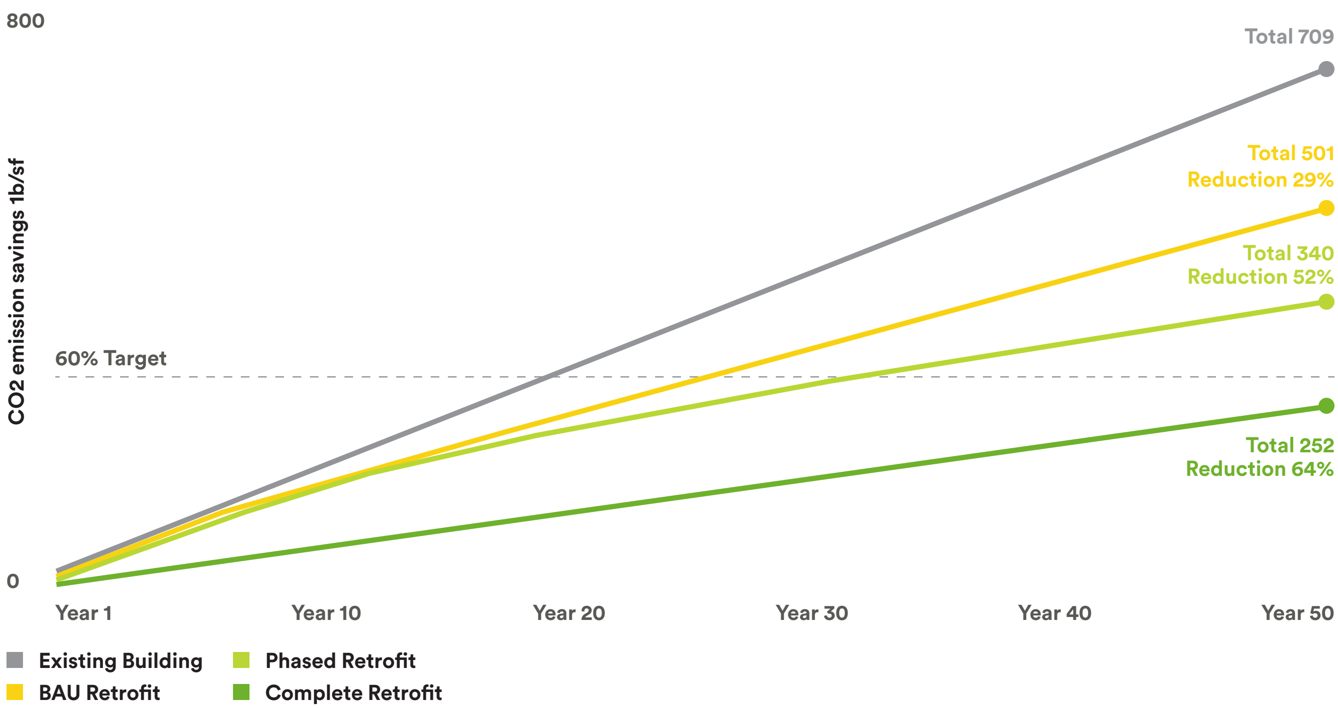
retrofit phasing

Although a full retrofit is the least disruptive overall, phasing has been carefully explored so that owners might align upgrades with financial or other milestones.

Most building owners would likely prefer to implement a deep retrofit of this nature in phases over a significant period of time, perhaps 15-20 years. Each phase requires less capital (and therefore smaller construction loans), and allows the kinks of each system to be worked out over time. (Financing options are described later in the report.)

Phasing the work, however, raises the total project cost by more than 15% due to duplication of general conditions and startup costs. Phasing also significantly delays full realization of operating cost savings and carbon emissions reductions, not to mention the myriad benefits to the occupants. When one considers how quickly

Figure 37: Long Term Impact of Retrofit Scenarios



Although a phased retrofit is a far better option than business-as-usual replacements of equipment, performing the full retrofit in a single phase produces significantly improved outcomes, including earlier enjoyment of the full benefits of the retrofit.

our City and State carbon reduction goals are approaching, the timing of retrofit phasing is far from academic. If the primary motivation for embarking on such an extensive retrofit is the increase in asset valuation, it would make sense to transform the property as quickly as funding will allow.

If an owner does choose to pursue a retrofit in phases, the order is influenced by a number of factors. Window replacement has been selected as the first phase because it is clear from energy modeling that it provides the greatest number of comfort and energy benefits, although the ventilation or exterior insulation phases could occur prior to window replacement. Decisions about phasing will be influenced by the specifics of each building's systems, including their ages and ongoing maintenance costs. If both the window replacement and the exterior insulation occur prior to the ventilation upgrade, there is a significant risk of developing moisture problems. Since the current domestic hot water system relies on the steam system boiler, it makes sense to replace that equipment once it has been made redundant by the introduction of new heating and cooling systems.

Phases

1 **Year 0**
Envelope 1: windows + roof insulation

2 **Year 4**
Ventilation system (balanced ERV system + exhaust)

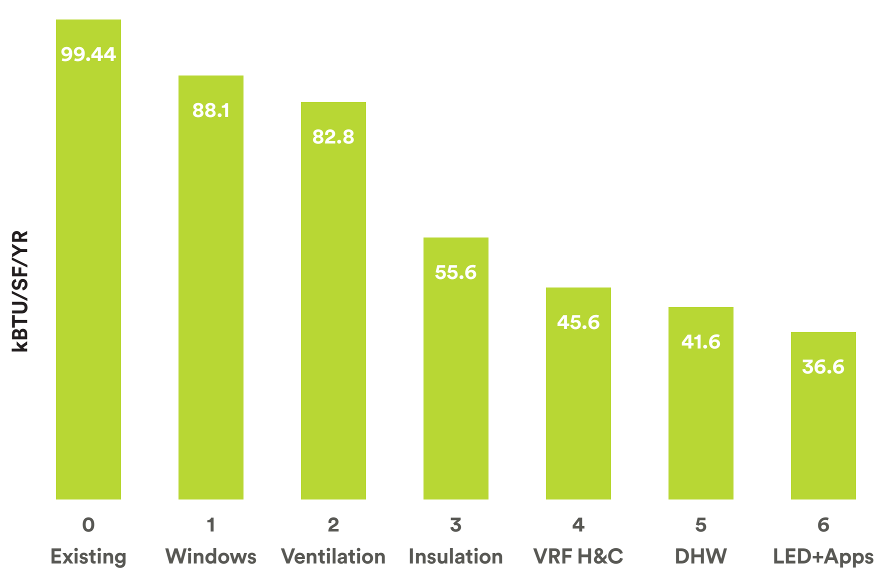
3 **Year 8**
Envelope 2: wall insulation & airtightness

4 **Year 12**
Replace heating/cooling systems with VRF system

5 **Year 16**
Replace domestic hot water boiler with high efficiency model

6 **Anytime**
Upgrade lighting to LED, upgrade elevators, install energy efficient appliances

Figure 38: Energy Reductions by Retrofit Phase



The fully completed retrofit is estimated to reduce total building energy use by 63%, with more than 60% of those reductions the result of new exterior insulation and high-performance windows.

The benefits of a complete Passive House retrofit result in a radical transformation of the building, from improved comfort, air quality, and aesthetics, to more responsive heating and cooling systems, to far lower utility bills.

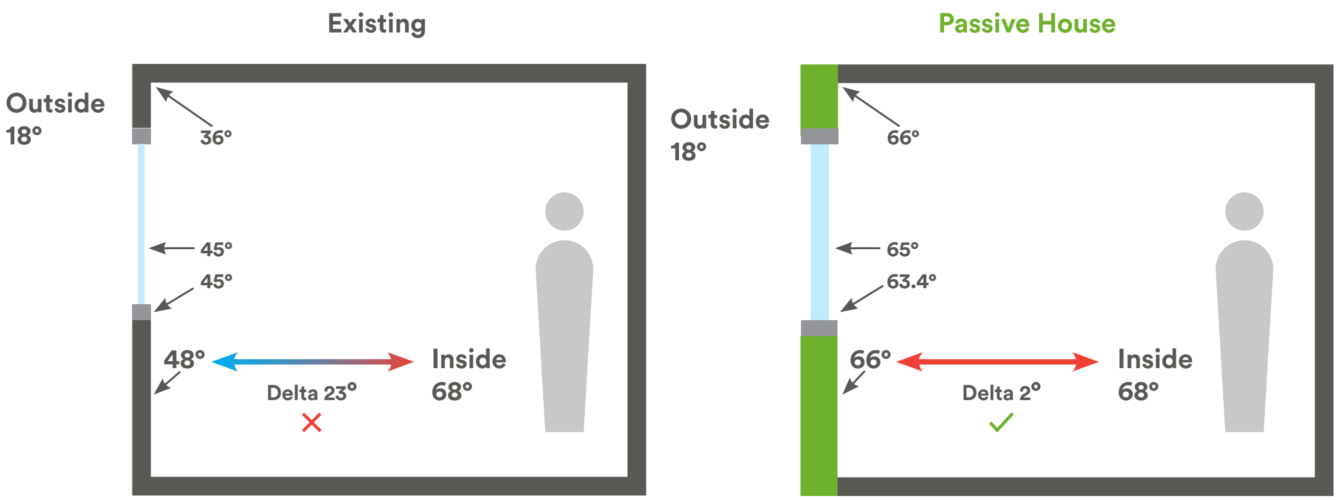
The building industry tends to view the individual elements of energy efficiency projects as distinct entities that must prove their worth in simple payback terms without reliance on other measures. This approach severely limits the ability of the industry to improve the building stock and prepare for the future, and it has a calamitous impact on efforts to reduce carbon emissions.

Passive House benefits derive from the combined result of several highly interconnected measures reliant on one another to produce extremely comfortable buildings that use limited energy. No single measure in Passive House is significantly attractive on its own, but together they transform the building. The benefits achieved are similarly bundled: thermal comfort without high air quality does not represent a successful reinvention of a building, but taken together they can reposition a building, in investment terms, from Class B, or even C, to Class A.

Thermal Comfort: As stated earlier, the improvements in interior comfort are one of the primary advantages of pursing Passive House certification. Most standard buildings suffer from a host of issues that degrade interior comfort, chiefly the poor thermal performance of exterior walls and windows. For instance, the subject building of this study has no insulation within the exterior walls and includes very low performance windows. Standard windows pose major challenges to interior comfort—in winter, standard glazing offers a cold radiant surface while poor installation and degraded seals at the operable elements produce drafts and frequently incubate condensation which can lead to the development of mold. In summer, standard windows offer limited protection from solar heat gain while remaining a source of air infiltration and condensation. The higher performance windows required by Passive House contribute significantly to improved air quality and allow residents to be comfortable sitting next to a window in any season. Since the space immediately next to a poorly performing window on the coldest or hottest days is typically unused, it could be argued that installing Passive House windows increases usable square footage. Exterior wall insulation also improves interior comfort and reduces the threat of condensation, though less dramatically than installing better windows.

Understanding the science of thermal comfort is critical to

Figure 39: Thermal Comfort and Interior Temperatures



Insulating the exterior and installing high-performance windows ensures that the inside surface temperature of the exterior walls remains warmer throughout winter and, most importantly, closer to the interior air temperature. Research indicates that comfort is significantly compromised when this difference is greater than 7 degrees F. We estimate the existing building suffers from a difference nearly 3x this figure.

understanding the importance of insulation, airtightness, and high-performance windows. The difference between the interior air temperature and the surface temperature of the exterior walls and windows drives at least three major components of interior comfort: drafts, radiant temperature and condensation. When the difference in these temperatures is large enough the warm interior hits the cold surface, cools and then falls toward the floor creating a dramatic internal draft—air movement that occupants experience as a chill, even if the ambient air temperature remains constant. You may remember from high school physics that warm objects radiate heat towards cold ones, and this remains true if the objects are humans and exterior walls. If the exterior walls and windows are significantly colder than the ambient air temperature, humans feel chilled near the exterior walls and windows. Research by the Passive House Institute[12] indicates that these draft and radiant temperature discomfort issues generally occur when the difference between air and surface temperature exceeds 7 degrees F. Figure 39 illustrates the difference between the air temperature and the interior surfaces of the exterior walls and windows in the existing building once the Passive House envelope measures are complete.

On a winter day, the existing building produces highly uncomfortable conditions near the exterior walls, with a difference between air and surface temperatures of more than 20 degrees, almost three times the recommended delta, certain to produce significant drafts and radiant chills for anyone near the walls or windows. Passive House is a completely different story, with the exterior insulation and high-performance windows providing a comfortable interior that will not produce internal drafts or radiant chills. Imagine how differently you'd dress when leaving the house for the day if the temperature outside matched the interior temperatures above. If it is in the mid-40s outside, most of us would wear an insulated jacket; if it's in the mid-60s, we'd wear something light or no coat at all. An upgraded envelope offers a clear and dramatic impact on comfort.

A related element of comfort in Passive House projects is the steadiness of the temperature within the spaces. In a typical building, the heating and cooling systems cycle on and off frequently as the envelope loses or gains heat. Residents feel these frequent changes in air temperature (and the drafts created) as discomfort. But the higher performing envelope of a Passive House project means that the changes in interior temperature happen more slowly and less frequently, meaning the heating and cooling system is used less often and the residents experience a more balanced, comfortable interior environment.

Health: Air infiltration and condensation are among the primary vectors for poor indoor air quality. The former can be the source of moisture and myriad pollutants (including carcinogens like PM 2.5) while the latter is the foundation of interior mold growth. Additionally, the balanced, highly filtered ventilation system in a Passive House building provides ample amounts of fresh air. This mixture of reduced pollutants and increased fresh air can provide a far healthier building interior than typical.

Energy Cost Savings: In addition to the raw utility savings outlined in Figure 40, the reduced energy use of Passive House certified buildings also significantly mitigates risk by insulating the owners and tenants from utility cost fluctuations. In the near future it is likely that utilities will look to charge more for energy delivered in peak periods and that energy will be more expensive than in prior years. The impact of both factors is mitigated by Passive House certified buildings.

Net Costs: Figure 41 includes conservative estimates of the costs of each phase of proposed work. These figures include the costs to furnish and install all the required components of each phase, including all general conditions such as scaffolding and protection, together with on site staff. The following costs are also included:

Insurance	**4%**
Overhead	**2%**
Fee	**8%**
Contingency	**10%**

The table includes costs for each retrofit phase, if delivered separately, as well alternates for two of the phases, and the costs of business-as-usual (BAU)

Figure 40: Annual Energy Cost Savings by Phase

		Electricity			Gas			
		kBTU/SF/YR	kWh/YR	$/YR*	kBTU/SF/YR	therms/YR	$/YR**	total ($)
Existing Utility Costs		11	396429	$79,286	64.29	79077	$83,031	$162,316
Utility Cost Savings by Phases								
1	Windows	0	0	$0	10.23	12583	$13,212	$13,212
2	Ventilation	-0.68	-24507	$4,901	6.51	8007	$8,408	$3,506
3	Ext. Insul.	0.21	7568	$1,514	24.36	29963	$31,461	$32,975
4	VRF	0.82	29552	$5,910	7.13	8770	$9,208	$15,119
5	DHW	0.15	5406	$1,081	3.25	3998	$4,197	$5,279
6	Plugs/Appliances	1.94	69916	$13,983	0	0	$0	$13,983
Totals		2.44		$17,587	51.48		$66,486	$84,073
*	Cost kWh	$0.20						
**	Cost therms	$1.05						

Figure 41: Retrofit Construction Costs by Phase

Phase	Est. Cost ($)	Alternates	BAU Costs
Windows/Roof insulation	$4,494,000	-	-$652,000
Ventilation (balanced ERV + exhaust refurb)	$1,447,000	-	-$324,000
Exterior insulation + airtightness	$2,528,000		-$1,150,000
Alt: Exterior rainscreen + airtightness		$1,191,000	
Install VRF system (remove steam/PTACS)	$3,071,000		-$1,261,000
Alt: Install HP Packaged H/C units (remove steam/PTACS)		-$1,054,000	
Replace DHW boiler	$250,000	-	-$250,000
Total costs, phased	$11,790,000 (A)		
General Conditions reduced (if single phase project)	$1,655,000 (B)		
Total, alternates (net)		$137,000 (C)	
Total offset costs			$3,636,000 (D)
Total costs, single project	$10,135,000 (A-B)		
Net costs, phased			$8,154,000 (A-D)
Net costs, single project			$6,498,000 (A-B-D)
+ Alternates, single project		$10,272,000 (A-B+C)	
+ Alternates, multiple phases		$11,928,000 (A+C)	
Optimal Project (net, future)		$6,635,000 (A-B-D+C)	

Phasing the retrofit delays the full benefits of the retrofit while adding $1.6M to the $10.1M cost of doing the work in a single phase. If the BAU costs of equipment upgrades are deducted, the net cost of the retrofit is $6.5M, less than 8% of the current market value of the building.

upgrades that the building might reasonably expect to perform over time. The sidebar on page 44 outlines the scope of the BAU items.

Financing

Simple energy efficiency projects are typically evaluated by the number of years required to pay back the expenditure from utility savings. But this is an insufficient lens through which to evaluate a deep retrofit that transforms a building in almost every capacity. Instead, we should evaluate these projects based on their impact on the total value of the building. At the same time, we should identify mechanisms to connect the overall societal benefits of these projects to the costs borne by the individual building.

Prospects for financing a project of this sort vary wildly due to the great number of variables involved. These include, but are not limited to, ownership structure, current debt service, asset value, liens or other obligations, tax subsidies enjoyed, rental revenue history, credit score and credit history. Owners will need to describe the full suite of benefits to lenders, from energy cost savings, to interior comfort and air quality, to risk mitigation and improved asset value. Opportunities for financing building energy efficiency retrofits include:

Operating Budget/Reserves: Before assessing outside financing needs, owners should carefully analyze the ability of current operating budgets to finance portions of an energy efficiency retrofit, including consideration of any reserves.

Construction/Equipment Loans: Whether secured by the property (construction loan) or equipment, excellent credit is usually required for these shorter term, project-based loans with relatively high interest.

Scope of BAU Upgrades

Upgrade work that would be required regardless of the retrofit. Estimates are in the 'BAU Costs' column in Figure 41.

Phase 1 Windows/Roof
Full roof replacement. Standard window replacement (Passive House window units and Passive House level installation are more expensive.)

Phase 2 Ventilation
Maintenance and repair costs of the existing system.

Phase 3 Exterior Recladding
Significant ongoing maintenance costs of façade repair, including additional local law 11 compliance costs.

Phase 4 VRF System
Replacement costs of the boiler and the maintenance costs of the steam heating system.

Phase 5 DHW Boiler
Heat exchanger replacement.

PACE Loans: Property Assessed Clean Energy (PACE) loans are financed through a buildings property tax assessment and typically cover work related to energy efficiency and renewable energy projects. Longer term than standard equipment loans, providers typically require the energy costs savings exceed the debt service on a monthly basis. Although anticipated in the near future, PACE loans are not currently available in New York City.

Affordable Housing Loan Programs: For rent regulated properties, the New York City Department of Housing Preservation and Development (NYC HPD) offers subsidized loans and grant programs to finance energy efficiency projects. NYC HPD also manages the J-51 tax benefit program, which provides tax abatements and exemptions to offset building capital investments in rent regulated properties. Some NYC HPD programs are also available to unregulated properties that enter into a regulatory agreement.

Mortgage Refinance: Proceeds from mortgage refinancing are a likely means of securing funds to perform the type of deep, holistic building transformations described in this study. Some lenders offer interest rate reductions for projects pursuing energy efficiency, or size supportable loans based on planned energy savings. Pairing a mortgage refinance with a construction loan is also a common financing approach for capital improvements.

It is important to make appropriate comparisons when discussing projects of this scope, especially when they are not commonplace in our market. The total cost of the optimal retrofit described in the study is estimated to be $10,135,000, or roughly $82 per square foot, or $62,000 per unit (Figure 41). The temptation in many circles will be to compare these figures to far less costly equipment upgrades. But the project envisioned in this study is not just an efficiency upgrade, it is a radical transformation of the asset, improving the performance and character of virtually every aspect of the property.

It would be ideal to point to the costs of similar projects, but the lack of comparable transformations of existing buildings is one of the reasons this study was undertaken. The other primary means of providing tenants with 21st century performance is to build new. New construction costs in New York City for high-rise apartment buildings currently average $302 per square foot[13]. The retrofit described in this report provides similar comfort and energy performance at less than one-third the cost.

Ultimately, the appropriate benchmark for a deep, holistic retrofit of the type described here might be asset value. The costs of the optimal retrofit are roughly 12% of the current market value of the property. New apartment buildings in the vicinity have an average sale cost that is roughly twice that of the subject building. It is clear that the retrofit described here—featuring a completely new exterior skin, vastly improved interior conditions, and highly responsive, efficient systems—would deliver an increase in market value several times greater than the costs.

A substantial percentage of our existing building stock must undergo deep, holistic retrofits if we are going to meet our climate action goals and avoid the most calamitous impacts of global climate change. The problem of climate change can seem overwhelming in scale and complexity, but the responses required can be broken into a series of small actions. What must each city do? Each building? What are the steps that building should take? Implementing the answers to these questions is the surest path to a sustainable future and the subject of this report.

There are, of course, many different pathways to producing highly efficient buildings. We've selected the Passive House pathway to inform this report because of its focus on comfortable, healthy spaces and its strong track record of delivering significant heating and cooling energy savings. The costs are substantial, but the benefits are extensive and result in a radically transformed building of significantly higher value that will allow our community to meet its climate action goals. Inaction is not an option.

New York City and State are both currently working on programs that incentivize deep retrofits of buildings and demonstrate clear national leadership on this issue. Chief among these are the High Performance Track of the NYC Retrofit Accelerator and NYSERDA's RetrofitNY program (see page 12). Many of the recommendations within this report align with the mission of these programs. Moving forward, we will need to incentivize the more effective delivery of retrofitted systems, whether this means creating a strong market demand for modular recladding systems or ensuring that efficient equipment such as the high performance packaged heating and cooling units discussed earlier in this report are available here. We will also need to identify mechanisms that connect the broader societal benefits of deep retrofits with the costs to individual building owners. This might involve property tax relief briefly discussed above, or PACE programs, or some mixture of these and other initiatives.

Path Forward

Based on the various findings and lessons within these pages, we recommend the following path forward to build on the work of this report, and further explore both the feasibility of deep retrofits and ways to scale their implementation.

Deep Retrofit Studies: Building on this foundational feasibility study, we recommend quickly applying this analytical framework to multiple other building typologies to determine the commonality of the findings and to provide additional guidance for owners. These studies could provide less contextual narrative and process description, but no less technical information on the strategies required to meet our climate action goals. Additional challenges that might be explored in these studies include lot-line buildings, mixed-use buildings, and commercial properties.

Modular Systems Research: The costs estimated here assume current methods of production and construction, processes that have been resistant to change while other sectors have advanced productivity significantly. Additional research, perhaps in concert with the RetrofitNY program, is required to determine the feasibility of creating modular retrofit systems that might encapsulate buildings of this type in a new envelope and perhaps include heating, cooling and ventilation systems.

Finance and Policy Research: There currently is a limited market for the type of extensive and holistic retrofit of an occupied building described here. Both policy-makers and real estate stakeholders should develop a firm grasp on the financial and policy instruments that might directly incentivize such a market.

High Performance Systems Research: This report identifies a specific product, available in the EU and the UK, that would significantly reduce the cost and complexity of the deep retrofit. Further study should identify systems (such as air-to-water domestic hot water heat pumps) or products that are either available elsewhere or are on the cusp of commercialization, that could significantly improve the feasibility and dramatically reduce the cost of these radical transformations of existing buildings.

Education and Training: Extensive education and technical training is required to enable high performance retrofits to move forward at scale. These activities should be directed not just towards architects, engineers and related consultants, but at building owners and managers, the finance sector, and virtually every category of professional that influences decisions about buildings and the way they use energy.

It is clear from our analysis that it is feasible to transform an occupied building of this type to meet the demands of our coming century, while providing a living environment of far higher quality than most of us currently enjoy. Our task is to ensure a sustainable, equitable future for our communities.

This study finds that buildings can definitely play a leading role in ensuring such a future. Now we to need to determine the most effective means of grasping this opportunity.

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end notes

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