FEASIBILITY STUDY TO IMPLEMENT THE

PASSIVHAUS STANDARD

ON

TALL RESIDENTIAL BUILDINGS

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

INTRODUCTION

The Passivhaus Standard was developed in Germany in the early 1990's. It is based on the concept of using simple, direct and primarily architectural solutions to create ultra-low energy buildings. Strategies include optimized orientation and shading, passive solar gain, excellent thermal performance of the building enclosure, minimized thermal bridging, exceptional airtightness, and mechanical ventilation with energy recovery. In order to achieve certification, the Standard sets very low energy consumption limits for heating, cooling and total building primary energy demand. Buildings constructed to the Passivhaus Standard also benefit from improved acoustic performance, thermal comfort, and indoor air quality.

The Intergovernmental Panel on Climate Change has identified Passivhaus as among the few whole-building strategies that are capable of reducing building energy use sufficiently to help limit global warming.

To date, there are approximately 60,000 buildings globally built to the Passivhaus Standard[1]. The Standard is applicable to residential, commercial, industrial and institutional buildings, and has been proven to be feasible in Europe and internationally. Municipalities in Germany, Belgium and Spain have mandated Passivhaus construction in various ways. In New York State, there are several single family homes, small to mid-sized multifamily residential buildings, and a tall academic residential project that are Passivhaus certified or vying for certification.

NYSERDA has generously supported Passivhaus efforts including the first certified Passivhaus in New York State, the Hudson Passive Project and a training series through the Association for Energy Affordability and Passive House Academy. These efforts were aimed at small scale construction. The purpose of this study is to enhance these efforts with a focus on mixed-use high-rise residential buildings in New York. Buildings of this scale and typology constitute a large segment of the construction industry in New York City and have a high potential for energy savings through Passivhaus.

OBJECTIVES

The purpose of this case study is to present a feasible model for designing high-rise mixed-use buildings to achieve the Passivhaus standard. The study is based on a particular building design, however, common approaches are identified that can be used to apply Passivhaus to a broad range of high-rise residential building designs. The study addresses an industry-wide lack of familiarity with Passivhaus and dispels misperceptions about its applicability.

Specifically, this case study investigates the feasibility of adapting the design of a sustainable high-rise mixed-use building in the 2016 New York City market to Passivhaus requirements. The base-case building is a 593,000 ft^2, 26-story multifamily high-rise building in Queens, New York. This building has three floors of retail space totalling 118,000 ft^2. The reference building is targeting LEED v.3 Silver Certification and 35% energy cost savings from ASHRAE 90.1-2007, with the inclusion of a co-generation system. For the purposes of simplification and to provide a more representative comparison, the base case building design in the study does not include the co-generation system and targets 20% energy cost savings. Construction is expected to start in 2017.

The study analyzes the base case building through Passivhaus methodologies and investigates measures required to meet the Passivhaus standard. The study examines the impacts of achieving the standard from architectural, enclosure detailing, mechanical, structural, constructability, resiliency, zoning and code perspectives. In addition, the study reports how a proposed Passivhaus design impacts costs and marketability.

METHODOLOGY

The study was carried out according to the following methodology:

1. **Analysis of the base case building relative to Passivhaus requirements**
- Passivhaus Planning Package (PHPP) energy model of the base case design.
- Analysis of the base case for potential energy reductions using Passivhaus strategies with respect to siting, massing, enclosure design, and mechanical systems.

2. **Establishment of strategies and target energy balance for the Passivhaus redesign**
- Passivhaus Planning Package (PHPP) energy model for the target Passivhaus design, investigating various scenarios to achieve Passivhaus energy balance.
- Development of architectural and mechanical concepts to meet the target Passivhaus energy balance.

3. **Design of Passivhaus version of the building**
- Redesign and documentation of architectural components of the base case building to achieve Passivhaus, including enclosure details and interior layouts.
- Redesign and documentation of mechanical components of the base case building to achieve Passivhaus, including heating, cooling, ventilation and electrical.

1 Passipedia.org. retrieved from: http://passipedia.org/examples

- Confirmation of the new design's performance using the Passivhaus Planning Package (PHPP) energy modeling tool.

4. Evaluation of the Passivhaus Design

- Architecture and Engineering analysis: Analysis of the successful aspects of the Passivhaus design that can be emulated, and challenges that require further study. Elements addressed include Building Code, Multiple Dwelling Law, NYC Housing and Preservation department standards for subsidized units, accessibility, and zoning floor area. Aesthetic implications, resiliency and security aspects of the design were also reviewed.
- Construction analysis: Identification of the general differences in construction means and methods required for the Passivhaus high-rise design as compared to the base case building.
- Market analysis: Evaluation of the Passivhaus design relative to common market concerns.
- Financial analysis: Comparison of construction and operating costs and savings of the proposed Passivhaus high-rise to the base case building, addressing both first cost and life-cycle net present value (NPV).

It should be noted that since the onset of this study, LEED v3 (referencing ASHRAE 90.1-2007) has been replaced with LEED v4 (ASHRAE 90.1-2010.) The 2016 NYC Energy Code has also been updated to reference ASHRAE 90.1-2013 as compared to the 2014 NYC Energy Code (ASHRAE 90.1-2010) used for the base case in this study.

PASSIVHAUS DESIGN APPROACH

For purposes of comparison, the Passivhaus redesign of the base case building aimed to change as little of the original aesthetic intent as possible. PHPP analysis showed that almost no aesthetic changes were necessary, including no reduction of the amount of glazing. While this approach enabled a clear comparison, it is imperative that new buildings pursuing Passivhaus or other low-energy targets consider aesthetic and energy use issues in parallel from the beginning.

A concerted effort was made to use products and construction means and methods familiar to the current New York construction industry. Main architectural improvements included upgrades to insulation levels, windows, thermal break details and air barrier installation strategies. These changes allowed mechanical systems to be substantially reduced or eliminated. Remaining mechanical systems were optimized to operate at higher efficiency levels than the base case systems.

FINDINGS

The findings of this study suggest that it is viable to design large high-rise residential buildings in New York City to meet the Passivhaus Standard. Technical challenges can be overcome with minimal aesthetic changes and a glazing ratio of up to potentially 40%. The multi-family project type and scale are favorable to meet Passivhaus requirements due to controllable internal heat gains and low enclosure to volume ratios. Some code and regulatory requirements conflict with Passivhaus strategies and these must be aligned to enable implementation.

The financial analysis demonstrated that the Passivhaus design represents an increased capital cost of 2.4%, a 40 year NPV of $5.2 million, and a payback of 24 years as compared to the base case building.

Key Findings

- **47%** reduction in primary energy from base case building
- **85%** reduction in heating demand
- **2.4%** initial cost increase
- **$5.2M** 40 year NPV
- **24** year payback
- **No** major aesthetic changes
- **Reduced** mechanical equipment size
- **Improved** resiliency, acoustic performance and thermal comfort
- **Typical** high-rise construction methods

FEASIBILITY STUDY TO IMPLEMENT THE PASSIVHAUS STANDARD ON TALL RESIDENTIAL BUILDINGS

PREAMBLE

The "Fifth Assessment Report"[2] by the Intergovernmental Panel on Climate Change (IPCC) indicates that total anthropogenic Greenhouse Gas (GHG) emissions have risen more rapidly between 2000 and 2010 than in the previous three decades. GHG emissions were at the highest levels in human history during that period, growing at an average rate of 2.2% per year as compared to an average of 1.3% per year between 1970 and 2000. Climate change is projected to accelerate unless global efforts are taken to dramatically reduce GHG emissions. The New York City Panel on Climate Change (NPCC) projects an increase of average annual temperatures in New York City by 2° to 3°F by the 2020s and 4°F to 6.5°F by the 2050s. Sea levels are projected to rise from 4 to 10 inches by the 2020s and 11 to 30 inches by the 2050s[3]. According to the IPCC report, the building sector is responsible for 19% of global GHG emissions and 32% of total global energy use. In New York City, nearly 75% of GHG emissions come from buildings[4].

The impacts of human-induced climate change are no longer anecdotal or solely impacting distant places. New York State has been severely distressed by climate change as witnessed by Hurricane Sandy, increased heat waves and flooding. Climate change has now reached a tipping point that requires more than mitigation. Adaptation is now necessary for human survival and well-being.

The building sector has a substantial role to play in both mitigation of, and adaptation to climate change through energy efficiency measures and resiliency. Common green building rating systems such as LEED have shifted the design and construction industry towards general sustainability. These systems have quantified energy reduction targets to minimize environmental impact. However, the targets are typically not deep enough to mitigate climate change. LEED and other systems also do not address how buildings can resiliently adapt to new weather conditions or events.

As a response to these issues, there has been increased interest in New York in the ultra-low energy **Passivhaus Standard**. Passivhaus is a globally recognized standard for the design of very low energy buildings. The IPCC identified Passivhaus as one of the few approaches to lowering building energy use enough to help mitigate climate change. This study explores the feasibility of Passivhaus for tall residential buildings in New York as a more sustainable and resilient model.

2 IPCC, 2014: Climate Change 2014: Synthesis Report, p. 45. retrieved from: https://www.ipcc.ch/report/ar5/syr/

3 City of New York. 2015. One City Built To Last, pgs. 5 & 7. retrieved from: http://www.nyc.gov/html/builttolast/pages/home/home.shtml

4 City of New York. 2015. One City Built To Last, pgs. 5 & 7 retrieved from: http://www.nyc.gov/html/builttolast/pages/home/home.shtml

SECTION 1

PROJECT OVERVIEW

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1.1. STATEMENT OF PROBLEM

The study investigates the feasibility of adapting the design of a new 26-story multifamily high-rise building in Queens, New York to meet the requirements of the Passivhaus standard. The basic Passivhaus 'Classic' certification is considered in this study[5]. The reference building is 593,000 ft^2, with a rental apartment tower and a three story retail base. The building is targeting LEED Silver Certification and is slated to start construction in 2017. The building was selected so that the study can serve as a resource for similar future development in New York City and elsewhere. While every building has unique contexts and conditions, the intent of the study is to address common approaches to apply Passivhaus broadly to high-rise residential buildings.

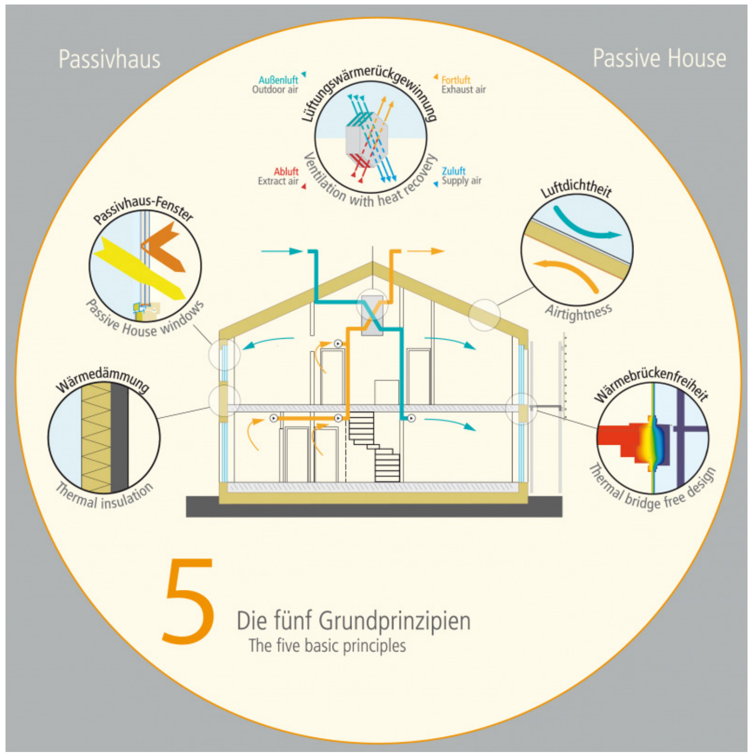


Figure 1.1:
The five basic principles of Passivhaus (graphic credit: Passive House Institute).

Overview of Passivhaus
The Passivhaus standard was developed in Germany in the early 1990's. It is based on the concept of using simple, direct, and primarily architectural solutions to create ultra-low energy buildings. Strategies include optimized orientation and shading, passive solar gain, elevated thermal enclosure performance, minimized thermal bridging, high levels of air tightness, and mechanical ventilation with energy recovery. Despite its name, the standard is applicable to residential, commercial, industrial and institutional buildings. The standard is proven to be feasible in Europe, and is in use worldwide.

A building constructed to the Passivhaus standard must meet strict energy efficiency criteria for its enclosure performance, space heating, space cooling, and primary energy demand. Because the building is essentially airtight, a continuous supply of filtered fresh air is supplied to living and working spaces, and stale air is continuously exhausted from spaces with high-efficiency heat exchange to minimize energy loss. The Passivhaus standard is applicable to both new construction and renovations. For the renovation of existing buildings, the performance criteria are slightly more lenient, but the approach can still result in a roughly 90 percent reduction in average heating and cooling energy usage and up to a 75 percent reduction in primary energy usage[6].

Passivhaus buildings are also beneficial due to their high indoor air quality, thermal comfort, and acoustics. They are extremely resilient due to the high performance of the exterior enclosure, and can remain comfortable for long periods following a power outage. There have been concerns

5 Passive House Institute. "Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard". October, 11, 2015. Revtrieved from http://passiv.de/downloads/03_building_criteria_en.pdf

6 Peper, Sören; Feist, Wolfgang. "Klimaneutrale Passivhaussiedlung Hannover-Kronsberg Analyse im dritten Betriebsjahr; 1. Auflage, Proklima, Hannover 2002.

Passivhaus Standard Criteria

Rating System	Heating Demand (kBtu/(ft²yr))	Cooling Demand (kBtu/(ft²yr))	Airtightness Requirement (ACH @50Pa)	Primary Energy (kBtu/(ft²yr))	Renewable Primary Energy Demand (kBtu/(ft²yr))	Renewable Energy Generation (kBtu/(ft²yr))	Thermal Comfort (Radiant Temperature Asymmetry)
Passive House Classic	4.75	5.39*	0.6**	38	19	-	<7.56F with interior temperature of 68F and exterior temperature of 7F
Passive House Plus				-	14	19	
Passive House Premium				-	9.5	38	

* Includes dehumidification

** 0.036 CFM/ft² used for enclosure analysis

Table 1.1:
Passivhaus Standard Criteria (Passive House Institute)

expressed about the potential for problems in highly insulated, airtight buildings similar to Sick Building Syndrome issues which occurred in some buildings in the 1960's and 1970's. However, the Passivhaus mechanical ventilation requirement to maintain a regular flow of fresh air, coupled with the proper use of vapor retarders protects against interior condensation and mold growth. Further details on the Passivhaus Standard can be found in "Active for more comfort: Passive House" prepared by the International Passive House Association[7].

The Intergovernmental Panel on Climate Change has identified Passivhaus as among the few whole-building strategies that are capable of reducing building energy use sufficiently to help limit global warming[8]. The standard's high performance enclosure criteria and ultra-low energy use intensity targets make it a highly favorable methodology to address both climate change mitigation and resiliency. To date, there are approximately 60,000[9] buildings globally that have been built to meet the Passivhaus Standard. Municipalities in Germany, Belgium and Spain have mandated Passivhaus construction through legislation.

Passivhaus Buildings in New York

There are several single family homes and small to mid-rise multifamily residential projects in New York City and State that are Passivhaus certified or vying for certification[10]. Cornell University is currently constructing the largest of these projects, The House at Cornell Tech. This is the most comparable local project to this study, but it varies from a typical apartment building typology because it is an academic residential building with a very high proportion of small apartments. When complete, this will be the tallest building in the world to target Passivhaus to date.

New York City Mayor Bill de Blasio's OneNYC report[11] references Passivhaus as a potential strategy to achieve the report's goals of reducing the GHG emissions from City buildings by 35%, and from other buildings 30% by 2025. The report indicates that residential buildings are responsible for 34% of the City's total GHG emissions and that multi-family residential building present the greatest typological opportunity for energy savings due to their relative size and distribution of energy use.

Mayor de Blasio's plan to create and preserve 200,000 units of affordable housing will further increase the impact of residential buildings on GHG emissions.

7 International Passive House Association. "Active for more comfort: Passive House". Darmstadt, 2014. Retrieved from http://www.passivehouse-international.org/upload/ipha-brochure/

8 Lucon O., D. Urge-Vorsatz, A. Zain Ahmed, H. Akbari, P. Bertoldi, L. F. Cabeza, N. Eyre, A. Gadgil, L. D. D. Harvey, Y. Jiang, E. Liphoto, S. Mirasgedis, S. Murakami, J. Parikh, C. Pyke, and M. V. Vilarino, 2014: Buildings. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p.676.

9 Passipedia.org. retrieved from: http://passipedia.org/examples

10 Nypassivehouse.org. retrieved from: http://nypassivehouse.org/category/projects/

11 City of New York. 2015. One City Built To Last, p. 10. retrieved from: http://www.nyc.gov/html/builttolast/pages/home/home.shtml

In addition, construction of residential units continues to rise. The New York City Department of Buildings (DOB) authorized the construction of 52,618 residential units in Fiscal Year 2015, a 156% increase from 2014, when permits were issued for 20,574 units. This marks the sixth consecutive year of increases in permitted residential construction[12]. This rapid pace of residential development will likely increase the share of NYC's GHG emissions produced by residential buildings. Therefore, the impact of Passivhaus on new residential buildings will be even more significant.

Further details on the status of the Passivhaus Standard in New York City can be found in "Passive NYC" prepared by the Building Energy Exchange[13].

1.2. PURPOSE OF THE FEASIBILITY STUDY

The purpose of this report is to present a feasible model for designing high-rise residential buildings to achieve the Passivhaus Standard. The report also addresses an industry-wide lack of familiarity with the standard and dispels misperceptions about its applicability to high-rise residential buildings. Many designers, specifiers, builders and developers are unaware of the specifics of the Passivhaus standard and perceive it to be economically unfeasible. This lack of familiarity means that the standard, which can save over 75% of heating and cooling energy[14] from typical new buildings, is typically not even considered.

The study examines the impacts of achieving the standard from architectural, enclosure detailing, mechanical design, constructability, resiliency, zoning and code among other perspectives. Costs impacts and marketability are also reviewed.

The study addresses multiple real and perceived barriers to implementing the standard at a large scale in New York, and how these barriers can be overcome. For example, while it is often understood that Passivhaus buildings are airtight, it may not be clear that windows are typically operable. There is a perception that mechanical system options are limited, while in reality Passivhaus projects can use many types of systems. The perception of high construction cost is a particular concern even though cost effective local Passivhaus projects have been completed. Some architects and developers are wary that Passivhaus may allow less glass and result in more boxy compact forms than the market demands. Fortunately, many well designed Passivhaus buildings exist and overcome these perceived limitations. Passivhaus exterior wall details and construction techniques are thought to be more complicated than typical details. Designers and contractors may be hesitant to incorporate new techniques. This study includes suggestions for achievable details and construction techniques to show how Passivhaus can be achieved in New York with current technology.

The intended audience for this study includes developers, long-term owners, not-for-profit organizations, private investors, government agencies, universities, construction managers, architects, mechanical engineers and other stakeholders.

Owners often pursue performance goals that exceed code minimums by selecting standards or systems such as LEED, Enterprise Green Communities, or Energy Star. The Passivhaus standard is now an attractive option.

Legislative requirements are becoming more stringent, and all stakeholders will face increasing demands to deliver buildings with significantly higher energy performance. Consequently, construction managers, architects and engineers will need to be well versed in high performance strategies such as Passivhaus to remain competitive as the market evolves.

1.3. RESEARCH PROCESS

This study has been developed according to the process outlined below:

Task 1. Analysis of the base case building relative to Passivhaus requirements

Establish Base case
The research team determined the base case for the feasibility study, and established that it would be a 26 story high-rise mixed-use residential tower in New York City. The base case building design targets exceeding the requirements of ASHRAE 90.1-2007 by 20% and targets a LEED Silver rating. The LEED energy model for the base case building is not yet validated by the United States Green Building Council (USGBC).

Passivhaus Planning Package (PHPP) Energy Model of the Base case Design
Passive House Academy (PHA) undertook an energy analysis of the base case design with Passivhaus mandated PHPP software. This analysis projected the amount of energy savings required to achieve Passivhaus.

12 New York Building Congress, 2015. Construction Outlook Update. retrieved from: https://www.buildingcongress.com/outlook/080315.html

13 Building Energy Exchange. "Passive NYC". Retrieved from http://be-exchange.org/resources/project/61

14 Peper, Sören; Feist, Wolfgang. "Klimaneutrale Passivhaussiedlung Hannover-Kronsberg Analyse im dritten Betriebsjahr; 1. Auflage, Proklima, Hannover 2002.

Analysis of Base case Building

The team analyzed the base case design for potential energy reductions using Passivhaus strategies. Strategies considered included siting, massing, surface area to volume ratio, orientation, solar exposure, shading, window to wall ratio, enclosure assemblies, and mechanical systems.

Task 2. Establishment of strategies and target energy balance for the Passivhaus redesign

PHPP Energy Model for Target Passivhaus Design
The team evaluated approaches to achieve Passivhaus with PHPP. Passivhaus Boundary options were reviewed and a boundary was defined. A target energy balance was created through three iterations of the PHPP energy model.

Architectural Design Strategies to Achieve the Passivhaus High-Rise
FXCollaborative and Simpson Gumpertz & Heger (SGH) reviewed the ability of typical high-rise enclosure systems to achieve Passivhaus requirements. This review included systems included in the base case building such as rain-screens, hand-set masonry cavity walls, curtain walls, and fenestration systems. Alternate strategies were also reviewed.

Mechanical Engineering Strategies to Achieve the Passivhaus High-Rise
FXCollaborative and Dagher reviewed the ability of mechanical systems to achieve Passivhaus performance. This review included energy recovery ventilators/heat recovery ventilators (ERV/HRV), heating systems, cooling systems, downsizing of systems, and the impact of passive gains per improved exterior envelope performance.

Task 3. Design of Passivhaus Version of the Building
The research team redesigned select components of the base case building to meet the Passivhaus Standard based on the results of Task 2. These changes were documented through drawings and narratives. PHA confirmed the performance of the redesign through PHPP modeling.

Architectural Design
FXCollaborative and SGH redesigned architectural aspects of the base case building as required to achieve Passivhaus. This redesign strived to provide an exterior enclosure that met Passivhaus requirements while maintaining the design intent of the original building. Interior changes were incorporated as required by redesigned enclosure and mechanical systems. Special technical challenges such as air-tightness at elevator shafts and entrance lobbies were also reviewed.

Mechanical Design
FXCollaborative and Dagher redesigned mechanical aspects of the base case building design to achieve Passivhaus performance. Mechanical heating and cooling loads were reduced through Passivhaus enclosure strategies, and then further reduced through the use of energy recovery ventilation units. Sizes of heating and cooling systems were reduced as much as possible. The team also investigated the resultant impact on air quality.

Confirmation of the Design's Performance
PHA updated the PHPP energy model per design revisions. Modeling results determined that the revised design met Passivhaus requirements.

Task 4. Evaluation of the Passivhaus Design
The research team evaluated the Passivhaus design from multiple perspectives as follows:

Architectural and Engineering Analyses
FXCollaborative, SGH and Dagher outlined successful aspects of the Passivhaus design, and described challenges that require further study. The team addressed a variety of issues including New York City Building Code, Multiple Dwelling Law, Department of HPD standards for subsidized units, Zoning Floor Area and accessibility. The team also reviewed other issues such as aesthetic implications, resiliency and security.

Construction Analysis
The research team identified general differences in construction means and methods. Differences included procurement, installation, sequencing, availability of labor, construction schedules, air-tightness testing, and other relevant construction related topics.

Market Analysis
The research team evaluated the Passivhaus design relative to common market concerns of owners and tenants.

Financial Analysis
Dharam Consulting compared construction and operating costs and savings of the proposed Passivhaus design to the base case building. First cost and life-cycle net present

value (NPV) analyses are included.

1.4. RESEARCH LIMITATIONS

This is a paper study and not a completed building. The following research limitations should be noted:

- The study is not intended to be a "how-to" construction guide for achieving Passivhaus. Each project has unique climate, site, programmatic and construction contexts which affect Passivhaus outcomes. All projects should be individually studied.
- Actual performance of a building constructed using the described methods and systems may differ from results in the PHPP model, which is based on assumptions regarding weather, occupancy patterns and resident behavior.
- While the base case building has similarities to other buildings currently being constructed in the New York market, there are also unique features not common to all residential buildings, such as three floors of retail program, and two-pipe fan coil units for the apartments.

SECTION 2

PASSIVHAUS ANALYSIS METHODOLOGY

The Passivhaus analysis methodology consists of five main steps that establish a framework to compare a high-rise residential building targeting LEED with its Passivhaus design. The first step was to establish a base case and define the Passivhaus boundary. The base case and the specified areas included in the analysis serve as a control for the comparison of the Passivhaus redesign. Secondly, a PHPP energy model of the base case building was completed to provide a detailed energy analysis and to identify areas for improvement in order to meet Passivhaus benchmarks. The next step was to run iterative PHPP models to achieve Passivhaus requirements. This step established target performance values for the Passivhaus redesign, such as target R-values for exterior walls. The final step was the Passivhaus redesign and verification. Base case enclosure and MEP systems were redesigned to meet the Passivhaus standard. A final PHPP iteration of the Passivhaus redesign was then used to verify that all Passivhaus requirements were met. These steps and corresponding results are further detailed in the following sections.

Figure 2.1:
Street level rendering of the base case building.

2.1. DESCRIPTION OF THE BASE CASE BUILDING AND PASSIVHAUS BOUNDARY

Description of the Base case Building
The base case building is a high-rise in a mixed-use retail, residential, and community facility development located in Queens, New York. It shares a zoning lot with a separate mid-rise building to the east, also part of the same development.

The building is 26 stories including 3 stories of retail use at the building base and 450 rental apartments with residential amenity spaces on the 4th Floor and 25th Floor. The apartment mix will include both inclusionary units and moderate income units. The development is currently targeting 20% energy cost savings and LEED Silver certification but is awaiting submission to USGBC for certification.

Passivhaus Boundary
The building typology of a residential tower above a retail podium is common in New York City, so the research team included both in the Passivhaus boundary. The Passivhaus boundary thus includes all areas of fully enclosed, conditioned space used for retail, residential, and other purposes. Below grade parking is excluded from the Passivhaus boundary since it is not fully enclosed, conditioned space. Some below grade areas are included in the Passivhaus boundary such as rooms used for mechanical space, elevator pits, staircases, bicycle storage, a superintendent workshop, communication storage, and retail storage. The mechanical penthouse is also included in the Passivhaus boundary. To the east, the Passivhaus boundary is drawn at a lot-line wall adjacent to a neighboring mid-rise building.

Base case Building Enclosure
The exterior wall system for the residential portion of the base case building is a cement panel rain screen assembly. Windows are aluminum framed, double glazed insulated units (IGUs) with operable in-swinging casement windows. The retail podium portion of the building has a mix of rain screen and brick cavity wall assemblies with storefront and curtain wall fenestration. The building has a window-to-wall ratio of approximately 36% including the 3 story retail base.

The compactness ratio of the building was found to be very favorable at 0.07 ft^2/ft^3. By comparison, a favorable compactness ratio to achieve Passivhaus is considered to be 0.2 ft^2/ft^3. Lower compactness ratios signify less surface area relative to building volume, and less opportunity for heat to transfer through the enclosure.

Base case Building MEP Systems
The central plant of the base case building provides space heating, space cooling and domestic hot water. The actual original building design consists of a combined heat and power (CHP) system that operates in conjunction with hot water condensing boilers and absorption chillers. To provide a more representative comparison, the CHP has been removed and the building central plant is modified to consist of natural gas boilers and electric chillers. There are three 350 ton water-cooled electric chillers and eight 2550 MBH (3000 MBH input rating) hot water condensing boilers along with associated pumps and accessories. The chillers and boilers are connected to a dual temperature water loop that circulates chilled or hot water depending on the season. The boilers are also responsible for providing domestic hot water for the building throughout the year.

For residential units, vertically stacked fan coil units provide heating and cooling. These units are served with hot and cold water from the central plant. Ventilation is provided through ducted openings in the exterior wall to the fan coil units. Central roof fans exhaust the toilets and kitchens. Residential corridors utilize dedicated gas-fired packaged air-cooled rooftop units with energy recovery ventilation. Energy recovery is achieved through toilet exhaust from apartments. Amenity areas are conditioned by horizontal and/or vertical fan coil units, provided with chilled and hot water from the central plant.

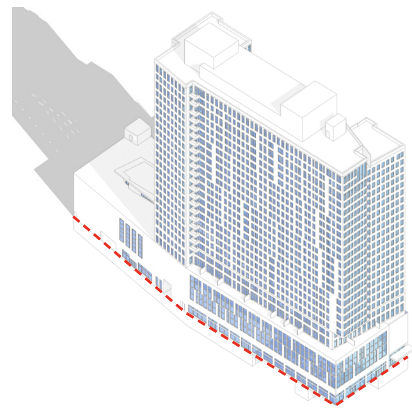
Base case Building Lighting and Appliances
Given that the retail areas are core and shell spaces, the research team assumed that tenant requirements would be provided that set thresholds for lighting power density per Table 2.7, and equipment power densities of 1.35 W/ft^2.

The base case building utilizes LED lighting fixtures for all interior lighting in the residential tower. Typical units have three downlights at the kitchen, a downlight at the foyer, vanity, and shower. Living rooms and bedrooms rely on plug load receptacle lighting. Well performing Energy Star refrigerators, dishwashers and common area clothes washers are specified. Ranges and ovens are gas fueled.

2.2. BASE CASE PHPP ANALYSIS

The Passive House Planning Package (PHPP) software is an Excel based calculation program developed by the Passive House Institute. The PHPP is both an energy model and a design tool. It is used to establish target design values, and is also used to verify that the completed design will perform to the Passivhaus Standard. The PHPP model utilizes user-defined inputs to calculate the annual energy demand of the building. The main results calculated by the PHPP are the annual heating demand, maximum heating load, annual cooling demand, maximum cooling load, summer thermal comfort with passive cooling and annual primary energy demand. Calculations are very detailed and thoroughly account for many factors affecting the overall energy balance. User inputs for building geometry, surrounding context, and location provide information for the PHPP to process the effects of solar gains and shading. The effects of thermal bridging at various junctions in the building envelope such as window-to-wall connections, specific construction details, penetrations, assembly fixing clips, and steel angles are also included in the PHPP model. Ventilation in the PHPP can simulate the use of natural, induced, window ventilation, mechanical ventilation, and combinations of each. Domestic hot water is modelled to account for the effects of heat transfer through piping runs. The PHPP model also simulates auxiliary energy use for pumps, fans and controls, electrical energy for lighting, appliances, personal electronics and relevant inefficiencies related to electrical heating, cooling and hot water systems.

Unlike EQuest or EnergyPlus, which are hourly simulation tools used for energy code compliance, PHPP uses a monthly energy calculation in terms of user interface. However, behind the scenes at the Passive House Institute in program development, it is built with an hourly simulator and the accuracy using the monthly method is calibrated and verified to within an acceptable tolerance of the hourly methodology.



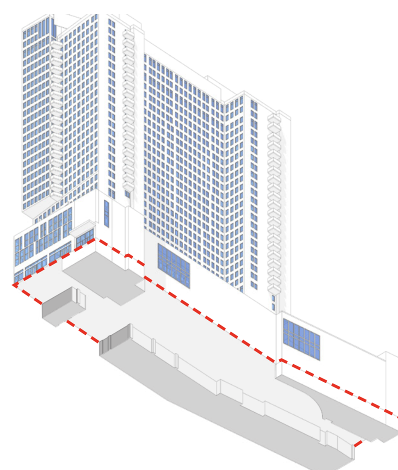


Figure 2.2:
DesignPH base case geometry and extents of the Passivhaus Boundary including below grade spaces.

2.2.1. Inputs & Assumptions

Information gathered from the base case building 100% Design Development drawings and specifications were input into PHPP. Inputs and assumptions are summarized in the following sections.

Representative New York City Context

The study used a modified site context to approximate the effect of overshadowing from planned adjacent buildings on the energy use of the study building. Existing buildings around the site primarily consist of low rise one to five story buildings. However, the area was recently up-zoned to allow for larger development. The study developed massing assumptions for future development on the surrounding sites.

Three sites already have buildings designed with construction planned to begin around the same time as the base case building. These buildings were massed to reflect information that could be gathered about their most current design.

Context massing was developed based on what is permitted by the new zoning districts including maximum floor-to-area ratios and inclusionary housing bonuses. Most adjacent sites are suited to residential development, but one site is reserved for a large office building.

Shadow studies showed that the base case building with the adjusted up-zoned context received some overshadowing from adjacent buildings during winter mornings and a slight degree of shading in the afternoon. During summer, the southern facade is fully exposed, while the northern facades receives some solar gain in the late afternoon. The result of the modified context in PHPP analysis was a slightly lower primary energy demand due to additional shading.

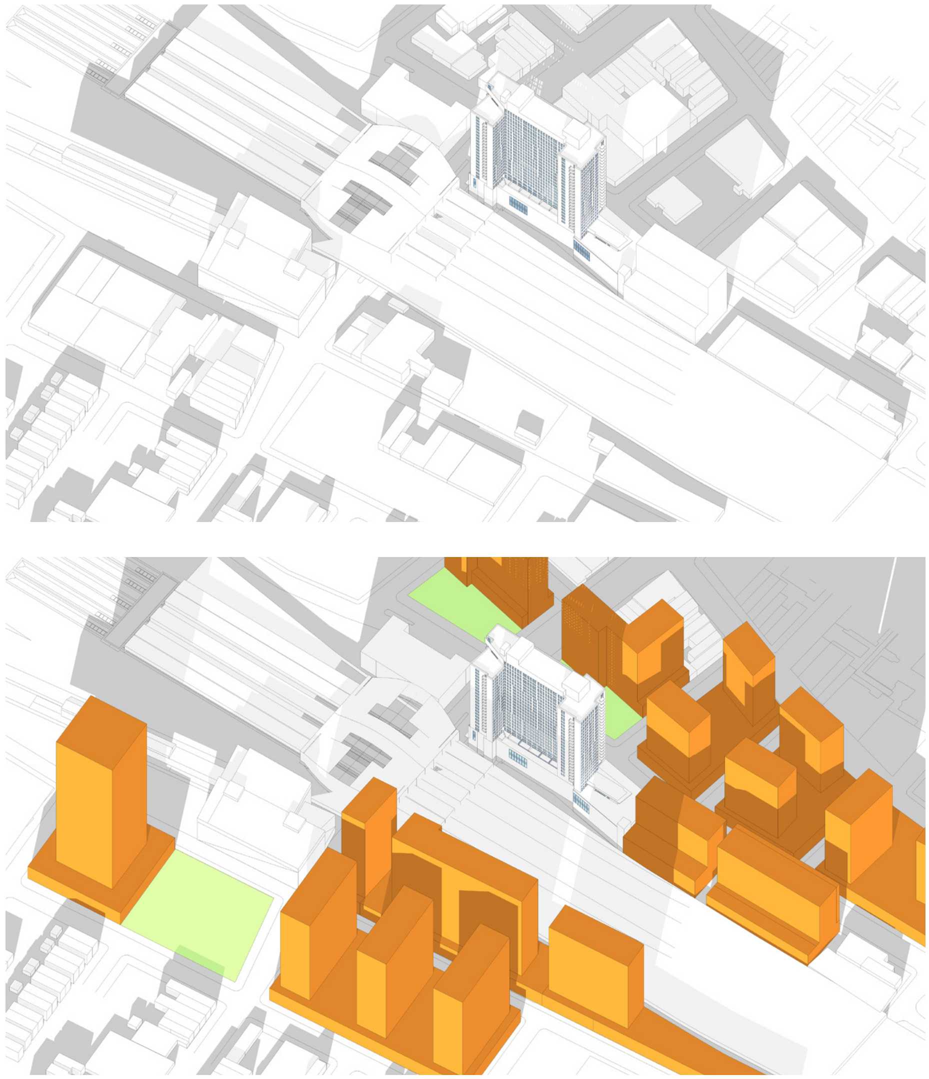


Figure 2.3:
Existing context (top) and representative New York City context (bottom).

Passivhaus Boundary and Three-Dimensional Geometry
The three-dimensional geometry of the building was modeled using DesignPH, a plugin for Trimble SketchUp. DesignPH enables 3D geometry built in SketchUp to be exported as data and imported in PHPP. Exported data included geometry such as window frame widths, shading and solar gain on all surfaces throughout the year. The geometry was modeled to a degree of detail to register the effects of shading from large and small elements such as massing and balconies. Windows were accurately modeled inset from the exterior wall to register shadows cast from the wall depth.

R-Values
R-values of various base case building assemblies were input in the PHPP with adjustments based on the thermal conductivity of details and assembly components. These included adjustments due to rainscreen steel clips and rails, brick ties, brick shelf angles. Two-dimensional models of these details were created to estimate the effect of these components on effective R-values. Exterior Doors were assumed to be code minimum. The overall effective R-values of the enclosure assemblies are outlined in Table 2.1.

Thermal Bridging
Thermal bridges occur when highly conductive materials such as steel or concrete penetrates through the insulation layer of an enclosure. A detail is considered "thermally broken" when highly conductive materials are separated to reduce heat flow. Codes typically do not mandate specific thermal bridge limits. As a result, thermal bridge effects are inconsistently factored into energy models if at all. Passivhaus however, mandates thermal bridge analysis and identifies target heat loss coefficient limits for linear (Psi Ψ) and point (Chi χ) details.

Base case building thermal bridge conditions were identified and quantified. Table 2.2 lists the estimated thermal bridge coefficient input into the base case PHPP.

Windows
For modeling purposes, base case building windows were simplified to four types: curtain wall, glass door, residential window, and storefront. Performance data such as U-value and SHGC was input for window frames and glazing. U-values for window frames were obtained from project documents and recalculated based on international norms per PHPP standards. All windows assume a common heat loss through spacers (Psi: 0.04 Btu/ft·°F·hr). Window inputs are outlined in Table 2.3.

Ventilation
Base case residential and retail ventilation is provided by outside air intakes at or near each residential and retail unit. Residential corridors are ventilated with ERV units that recover energy from residential toilet exhaust.

Air Infiltration
The base case building PHPP was modelled with an air leakage rate of 0.40 CFM/ft^2 leakage through the envelope (or 0.263 CFM/ft^2 @ 50Pa). This was based on ASHRAE 90.1-2010 requirements which reflect the 2014 New York City Energy Conservation Code.

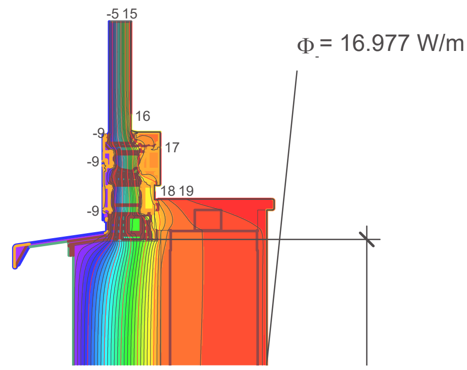


Figure 2.4:
Example thermal analysis of window

Heating and Hot Water Distribution
Heating and hot water distribution pipes generally have two impacts on energy consumption. First is the generation of internal heat gains which can increase cooling during summer. Secondly, the distribution can reduce system efficiency if the runs are very long. The PHPP took both of these factors into account and calculated gains and losses based on the temperature of the hot water, the length of the distribution runs, and the heat losses from storage tanks. All pipes runs were assumed to vary in size from 0.5 inch to 2.5 inch nominal diameter. All pipe lengths were estimated with a tolerance of 10%.

Lighting
Base case building lighting was included based on lighting layouts, fixture schedules, specifications and projected use patterns. Installed lighting in apartments and common areas was modeled as achieving a luminance of 20 foot candles (FC) and, with the LED fixture design, equated to a maximum lighting power density of 0.28 W/ft², below the maximum value of 0.51 W/ft² from ASHRAE 90.1-2013, the basis for the 2016 NYC Energy Conservation Code (NYCECC).

Installed lighting in retail spaces was modeled at a luminance of 60 FC (three times brighter than residential areas) equating to a maximum lighting power density of 0.83 W/ft². This is below the 1.26 W/ft² maximum lighting power density (LPD) allowed for retail spaces per ASHRAE 90.1-2013.

Auxiliary Electricity
Auxiliary energy use for hot water distribution pumps, fans and controls was included.

Assembly	R-Value (hr·ft²·°F/Btu)	Assumed Effective R-Value (hr·ft²·°F/Btu)
Roof	R 33.06	R 33.06
Ground floor slab over garage	R 18.50	R 18.50
Basement slab	R 0	R 0
Rain screen with steel stud backup (average)	R 21.85	R 12.02
Brick cavity with CMU backup	R 17.85	R 10.71
Lot line wall with CMU backup	R 15.90	R 15.90
Foundation wall	R 4.34	R 4.34

Table 2.1:
Effective R-Value Inputs for base case building assemblies.

Type	Psi Ψ Estimated (kBTU/hr·ft·°F)	Length of Occurrence (ft)
Balcony	0.556	29,257
Roof to Wall	0.15	1,030
Wall to Floor	0.15	842
Wall to Roof	0.15	1,335
Wall to Wall	0	3,851
Window Fitting	0.54	(Length determined by DesignPH)
	Chi Estimate	Quantity
Chi Column	1.2	23

Table 2.2:
Thermal Bridge Inputs for base case building PHPP

Window Type	U-Value Frame* (BTU/hr·ft²·°F)	U-Value Glass (BTU/hr·ft²·°F)	SHGC
Curtain Wall	1.0 (R 1.0)	0.24 (R 4.2)	0.62
Glass Door	2.0 (R 0.5)	0.29 (R 3.4)	0.38
Residential	0.42 (R 2.4)	0.29 (R 3.4)	0.38
Storefront	1.0 (R 1.0)	0.24 (R 4.2)	0.62

Table 2.3:
Window Inputs for base case building PHPP
*Estimated using a single profile and ISO standards.

Electrical Appliances & Receptacle Loads
All electrical appliance loads were based on well performing Energy Star products available in the US. For appliances where a maximum threshold was defined, the maximum value was used to conservatively predict consumer choice. Electrical consumptions were based on PHPP averages as defined by the International Passive House Institute.

Receptacle loads in apartments were modeled as 0.5 W/ft^2. Although a residential unit space is typically designed with a total electrical demand of 3 W/ft^2, the typical expectation from a utility provider such as ConEd is an average demand of approximately 1 W/ft^2, of which 0.51 W/ft^2 is expected to be utilized by the installed and receptacle lighting, leaving the difference of approximately 0.5 W/ft^2 to be used by receptacle equipment. Receptacle loads for retail spaces were modeled as 1.35 W/ft^2, based on LEED 2009 Core & Shell Appendix.

2.2.2. Calibration of the Base case LEED Energy Model with PHPP
Results from the base case PHPP model were compared with results from the LEED DOE-2 Energy Model, which had not yet been reviewed by USGBC for LEED compliance. PHPP inputs were refined and results double checked iteratively until the PHPP model was as consistent as possible with the LEED energy model. Because the modeling software and weather data used for the LEED model differs significantly from PHPP, it is not possible to accurately compare results between the LEED model and the PHPP model. A full analysis of LEED energy modeling and PHPP modeling methodologies was outside the scope of this study, but merits further investigation.

2.3. BASE CASE PHPP RESULTS

The PHPP results in Table 2.4 show the primary (source) energy consumption for one year with reference to one square foot of living or usable space within the building. The energy consumptions are broken out in terms of space heating demand, heating load, cooling demand (including dehumidification), cooling load, primary energy and airtightness. Space heating demand is the amount of energy per year required to heat the building to a minimum of 68°F. Heating load is the power requirement needed to heat the building to 68°F at the peak period during the winter. Cooling demand is the amount of energy per year required to cool the building to 77°F. Cooling load is the power requirement needed to cool the building to 77°F at the peak period during the summer. Primary energy is the sum total amount of energy that the building will use for heating, cooling, hot water, electrical appliances, lighting and auxiliary energy for fans controls and water pumps. This is multiplied by the International Average Primary (source energy) Energy Factors to determine the source energy generated to meet the building's energy demand[14].

Results show the base case building meets none of the requirements to achieve Passivhaus certification. The building is estimated to consume 70.80 kBtu/(ft²yr), over one and three-quarter times the source energy limit required by the Passivhaus standard (38 kBtu/(ft²yr)). In order for the building to meet the Passivhaus standard, heating demand would have to be reduced by 76%, heating load by 69%, cooling demand by 30%, cooling load by 25%, and primary energy by 46%. Overall, results

Base Case Building

	PHPP Result		PH Requirement	Fulfilled?
Heating Demand	19.72 kBtu/(ft²yr)	415% of	4.75 kBtu/(ft²yr)	No
Heating Load	10.29 Btu/(ft²hr)	325% of	3.17 Btu/(ft²hr)	No
Cooling Demand	7.73 kBtu/(ft²yr)	143% of	5.39 kBtu/(ft²yr)	No
Cooling Load	4.22 Btu/(ft²hr)	133% of	3.17 Btu/(ft²hr)	No
Primary Energy*	70.80 kBtu/(ft²yr)	186% of	38.0 kBtu/(ft²yr)	No
Airtightness**	0.263 cfm/ft²	731% of	0.036 cfm/ft²	No
Passivhaus?				**No**

*Primary energy includes heating, cooling, dehumidification, DHW, auxiliary electricity, lighting, and electrical appliances. All PHPP Results reflect source energy consumption.

**Pressurization test result n_{50}

Table 2.4:
Base Case Building PHPP Results

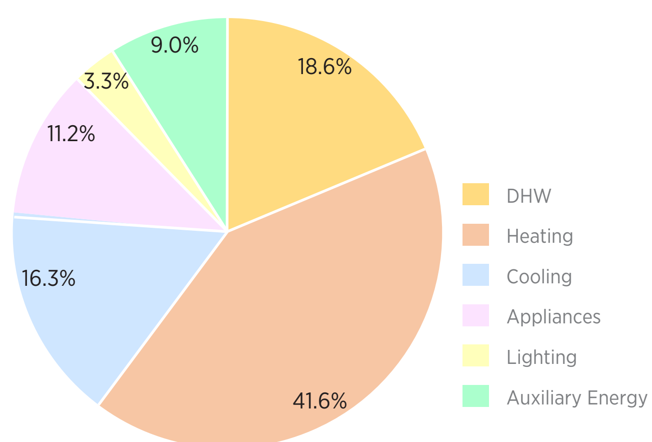


Figure 2.5:
Base case Building PHPP Results - Energy Use Breakdown

from the PHPP estimate that the base case building will consume 19,372,123 kBtu/yr of site energy. The energy use breakdown of the base case PHPP is shown in Figure 2.5. Most significant areas for improvement exist in space heating and domestic hot water.

2.4. PASSIVHAUS ENERGY BALANCE ITERATIONS

The base case PHPP model was modified in iterations to establish target Passivhaus energy balances. Inputs were modified in six categories: airtightness, insulation, windows, thermal bridging, ventilation, and the mechanical system. These modifications provided target values for the Passivhaus redesign.

As per Passivhaus requirements, iterations changed the cooling set point from 75°F to 77°F, the heating set point from 70°F to 68°F, and set airtightness at 0.036 cfm/ft^2 @ 50 Pa. Multiple values were iterated for insulation. The effect of additional insulation over values shown was found to be small and would have diminishing returns.

During the iterative process, the research team also investigated the possibility of using readily available double glazing components. However, PHPP iterations which incorporated double glazing did not meet Passivhaus requirements for space cooling and comfort.

Different mechanical strategies were explored. Iteration 1 proposed a decentralized system of an air-to-air heat pump manufactured by Nilan that has an integrated energy recovery system. These high efficiency units provided ventilation, space cooling, space heating and domestic hot water in each residential unit. Unfortunately, the unit's cooling capacity was too low to provide adequate thermal comfort during peak cooling season in New York City.

Iteration 2 proposed a semi-centralized HVAC system consisting of multiple rooftop ERV units serving the residential tower, along with a combined heat and power system. The rooftop units were located in mechanical rooms and only provided heated or cooled air. The rooftop units did not incorporate any fans, instead, individual supply and exhaust fans with variable speed motors were used in every apartment to allow occupants to control heating and cooling as needed. Air flow through the rooftop units during summer was designed to pass through an energy recovery system with return air from the residential units. Outdoor air would be cooled but remain humid. Next, air flow would pass through an evaporator coil for dehumidification. Lastly, the dehumidified air would be reheated to ideal supply temperature. During winter, air flow would be reversed, with hot water coils served by the CHP system providing supplemental heating. The CHP system also provided domestic hot water. Although this system was promising for a humid climate such as in New York by greatly reducing the energy consumption for reheating dehumidified air, it was ultimately determined that it is incapable of providing adequate cooling to keep conditioned spaces below the threshold for thermal comfort.

Two initial iterations are described in Table 2.7.

2.5. PASSIVHAUS ENERGY BALANCE

A third iteration was used to set a target energy balance. The energy balance was refined as the Passivhaus design progressed.

Section 3 describes the Passivhaus redesign in greater detail. The architectural and MEP redesign sought to minimize any aesthetic impacts and utilize typical construction practices in New York City high-rises to the extent possible. The architectural design improved enclosure assemblies and details using systems already in use in the base case building. Likewise, the MEP design opted to use and improve a HVAC system very similar to the one already in place in the base case. Inputs for the Passivhaus design are shown in Table 2.7.

14 Energy Star, 2013. Energy Star Portfolio Manager Technical Reference: Source Energy.

Passivhaus Design

	PHPP Result		PH Requirement	Fulfilled?
Heating Demand	2.86 kBtu/(ft²yr)	60% of	4.75 kBtu/(ft²yr)	Yes
Heating Load	2.34 Btu/(ft²hr)	74% of	3.17 Btu/(ft²hr)	Yes
Cooling Demand	4.65 kBtu/(ft²yr)	87% of	5.39 kBtu/(ft²yr)	Yes
Cooling Load	2.67 Btu/(ft²hr)	84% of	3.17 Btu/(ft²hr)	Yes
Primary Energy*	37.7 kBtu/(ft²yr)	99% of	38.0 kBtu/(ft²yr)	Yes
Airtightness**	0.036 cfm/ft²	-	0.036 cfm/ft²	Yes
Passivhaus?				**Yes**

*Primary energy includes heating, cooling, dehumidification, DHW, auxiliary electricity, lighting, and electrical appliances. All PHPP Results reflect source energy consumption.

**Pressurization test result n_{50}

Table 2.5:
Passivhaus Design PHPP Results

Passivhaus Design versus Base case Building

	Passivhaus Design	Base case Building	Percent Savings
Heating Demand	2.86 kBtu/(ft²yr)	19.72 kBtu/(ft²yr)	**85%**
Heating Load	2.34 Btu/(ft²hr)	10.29 Btu/(ft²hr)	**77%**
Cooling Demand	4.65 kBtu/(ft²yr)	7.73 kBtu/(ft²yr)	**40%**
Cooling Load	2.67 Btu/(ft²hr)	4.22 Btu/(ft²hr)	**37%**
Primary Energy*	37.7 kBtu/(ft²yr)	70.8 kBtu/(ft²yr)	**47%**
Airtightness**	0.036 cfm/ft²	0.263 cfm/ft²	**86%**

*Primary energy includes heating, cooling, dehumidification, DHW, auxiliary electricity, lighting, and electrical appliances. All PHPP Results reflect source energy consumption.

**Pressurization test result n_{50}

Table 2.6:
Comparison of Passivhaus Design and Base Case PHPP Results

				Base Case	Iteration 1	Iteration 2	Passivhaus Design
Architectural	Airtightness*	Pressurization Test @ 50 Pa		0.263 cfm/ft2	0.036 cfm/ft2	0.036 cfm/ft2	0.036 cfm/ft2
	Insulation (Effective R-Value)	Roof		R 33.06	R 42.10	R 42.11	R 41.40
		Ground Floor Slab		R 18.50	R 18.50	R 18.51	R 18.90
		Basement Slab		R 0	R 16.50	R 16.51	R 16.52
		Rainscreen Wall (average)		R 12.02	R 26.00	R 26.00	R 26.00
		Brick Cavity Wall		R 10.71	R 26.10	R 26.10	R 26.10
		Lot Line Wall		R 15.90	R 17.30	R 17.31	R 17.32
		Foundation Wall		R 4.34	R 16.50	R 16.51	R 16.52
		Basement Walls		R 0	R 13.10	R 13.11	R 13.12
	Windows	U-Value Frame	Residential	0.42 (R 2.4)	0.14 (R 7)	0.14 (R 7)	0.14 (R 7)
			Curtain Wall	1.00 (R 1)	0.14 (R 7)	0.14 (R 7)	0.14 (R 7)
		U-Value Glass	Residential	0.29 (R 3.4)	0.14 (R 7)	0.14 (R 7)	0.175 (R 5.7)
			Curtain Wall	0.24 (R 4.2)	0.13 (R 7.5)	0.13 (R 7.5)	0.175 (R 5.7)
		SHGC	Residential	0.38	0.25	0.25	0.38
			Curtain Wall	0.62	0.5	0.5	0.62
	Thermal Bridging	Ψ	Typical	0.15	< 0.006	< 0.006	< 0.006
		Ψ	Foundation	0.15	0.02	0.02	0.02
		χ	Columns	1.2	1	1.0	1.0
		Ψ	Balconies	0.556	0.03	0.03	0.03
		Ψ	Windows & Doors	0.15	0.023	0.023	0.023
		χ	Typical	1.2	< 0.018	< 0.018	< 0.018
Mechanical	Ventilation	System Type		Energy Recovery Ventilator (ERV) for Corridors; Outside air provided directly to mechanical units without energy recovery for all other spaces	Minimum 1 ERV(integrated into Heat Pump) for every apartment (Decentralized System); Multiple ERVs for all other spaces (Semi Centralized System)	Multiple ERVs for all spaces (Semi Centralized System)	Multiple ERVs for all spaces (Semi Centralized System)
		System Efficiency		Approximately 75% for Corridors; Not Applicable for all other spaces	80%	80%	85%
	Mechancial System	System Description		Water-cooled Electric Chillers and Hot Water Boilers serving Two Pipe Fan Coil Units	Heat Pump, Heating Cooling and Hot Water Combined System in one unit per apartment; Seperated Heat Pump Cassettes Inline or Combined with PHI certified ERV's	Gas Powered CHP Cogen System feeding Hot Water system and Heating Coils with electrical generation for lighting and heat pump support. Heat pump heating and Hot water support with integration into ventialtion ductwork in a unique two part HRV/ERV system	Water-cooled Electric Chillers with magnetic bearing compressors Natural gas condensing Hot Water Boilers serving Two Pipe Fan Coil Units
		Central Plant Equipment		Electric Chillers, Hot Water Boilers, and Cooling Towers	None	circa 2.50	Electric Chillers, Hot Water Boilers, and Cooling Towers
		Cooling Efficiency		4.70 COP for Electric Chiller	circa 2.00	circa 3.00	Peak condition: 0.61 kW/ton (COP 5.76); NPLV 0.352 kW/ton for Electric Chiller
		Heating Efficiency		85% Thermal Efficiency for Boilers	circa 1.80	circa 2.00	94.5% Thermal Efficiency for Boilers
		Domestic Hot Water System Description		Indirect heat exchangers and storage tanks served by Boilers	Heat Pump, Heating Cooling and Hot Water Combined System in one unit per apartment; Seperated Heat Pump Cassettes Inline or Combined with PHI certified ERV's	Indirect heat exchangers and storage tanks served by Combined Heat and Power Units, also supported by Heat Pump	Natural gas condensing Water Heaters
		Domestic Hot Water System Efficiency		Same as Heating Efficiency	circa 5.00	Circa 80 % with Cogen and 150% for Heat Pump Support	95.5% Thermal Efficiency
	Lighting	Lighting in Apartments & Common Areas		20 FC @ 0.28 W/ft2 Avg.	0.14 W/ft2 Avg.	0.14 W/ft2 Avg.	20 FC @ 0.28 W/ft2 Avg.
		Lighting in Retail Spaces		60 FC @ 0.83 W/ft2 Avg.	0.25 W/ft2 Avg.	0.25 W/ft2 Avg.	60 FC @ 0.83 W/ft2 Avg.
	Receptacle	Residential Recptacle Loads		0.50 W/ft2 Avg.	0.50 W/ft2 Avg.	0.50 W/ft2 Avg.	0.50 W/ft2 Avg.
		Retail Recptacle Loads		1.35 W/ft2 Avg.	1.35 W/ft2 Avg.	1.35 W/ft2 Avg.	1.35 W/ft2 Avg.

Table 2.7:
Comparison of PHPP inputs for base case, Iteration 1, Iteration 2, and Iteration 3 (based on the final Passivhaus design).

SECTION 3

PASSIVHAUS DESIGN

The Passivhaus design resulted in very few aesthetic changes to the building. No large scale changes were required. Some minimal changes were necessary to aspects of windows and doors including visible frame widths and the position of frames in walls.

This minimal aesthetic impact was accomplished with improvements to enclosure systems that were already used in the base case building. Changes were kept within common design and construction practices as much as possible. Some uncommon details were required, but all were kept as simple as possible. A concerted effort was made to ensure that all products used were available in the New York market.

All design details are provided for illustrative purposes only and are not intended for use in construction documents.

3.1. ENCLOSURE DESIGN

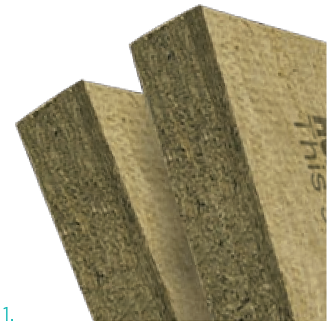
Enclosure assemblies used in the base case building were upgraded to Passivhaus performance targets. Brief descriptions of each assembly follow. Additional descriptions are provided in this section accompanied by Figures, R-value calculations, and other information.

Cladding materials are unchanged from the base case. However, attachments for cladding materials were changed to lower conductivity or thermally broken types.

Amounts of insulation were increased in each enclosure assembly to meet R-values as defined in the PHPP energy balance. Effective R-values were used to account for thermal bridge losses through assemblies. Insulation was moved external to the air and vapor barrier as much as possible to minimize concerns of condensation within assemblies. According to common recommendations for New York City climate Zone 4A, at least 2/3 of the insulation in all assemblies is placed external to the air and vapor barrier.

Three types of insulation are used in the Passivhaus assemblies: semi-rigid mineral wool, rigid plastic extruded polystyrene foam (XPS), and rigid plastic expanded polystyrene foam (EPS). Mineral wool is used in favor of foam insulation where possible to avoid complicated detailing to meet fire safety requirements[14]. Mineral wool is also preferable over foam insulation due to its smaller environmental footprint. Foam insulation is used in areas where fire concerns are safely addressed or where mineral wool cannot be used. These areas include below grade and roof applications where insulation is exposed to water and where the insulation must have compressive strength to support pavers, backfill, or a slab. XPS insulation is used in the roof and below grade applications. EPS insulation is integral to an insulated CMU block product.

Air barrier and vapor retarding (AVB) products were kept within the same general families of compatible products as in the base case building design. Membrane or liquid applied products were selected for each assembly based on required vapor permeability and the projected ability to meet air tightness requirements.



1.

2.

3.

4.

Figure 3.1:
Types of insulation used in Passivhaus Proposal - 1.Semi-rigid mineral wool insulation 2.Mineral wool insulation with vapor permeable facing 3.XPS rigid foam insulation 4.Insulated CMU with EPS foam insulation

14 NFPA 285 Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-load bearing Wall Assemblies Containing Combustible Components

Enclosure details were developed to compare solutions for the base case and Passivhaus design. The Passivhaus details include the improvements discussed in this section. Details can be found in Appendix B.

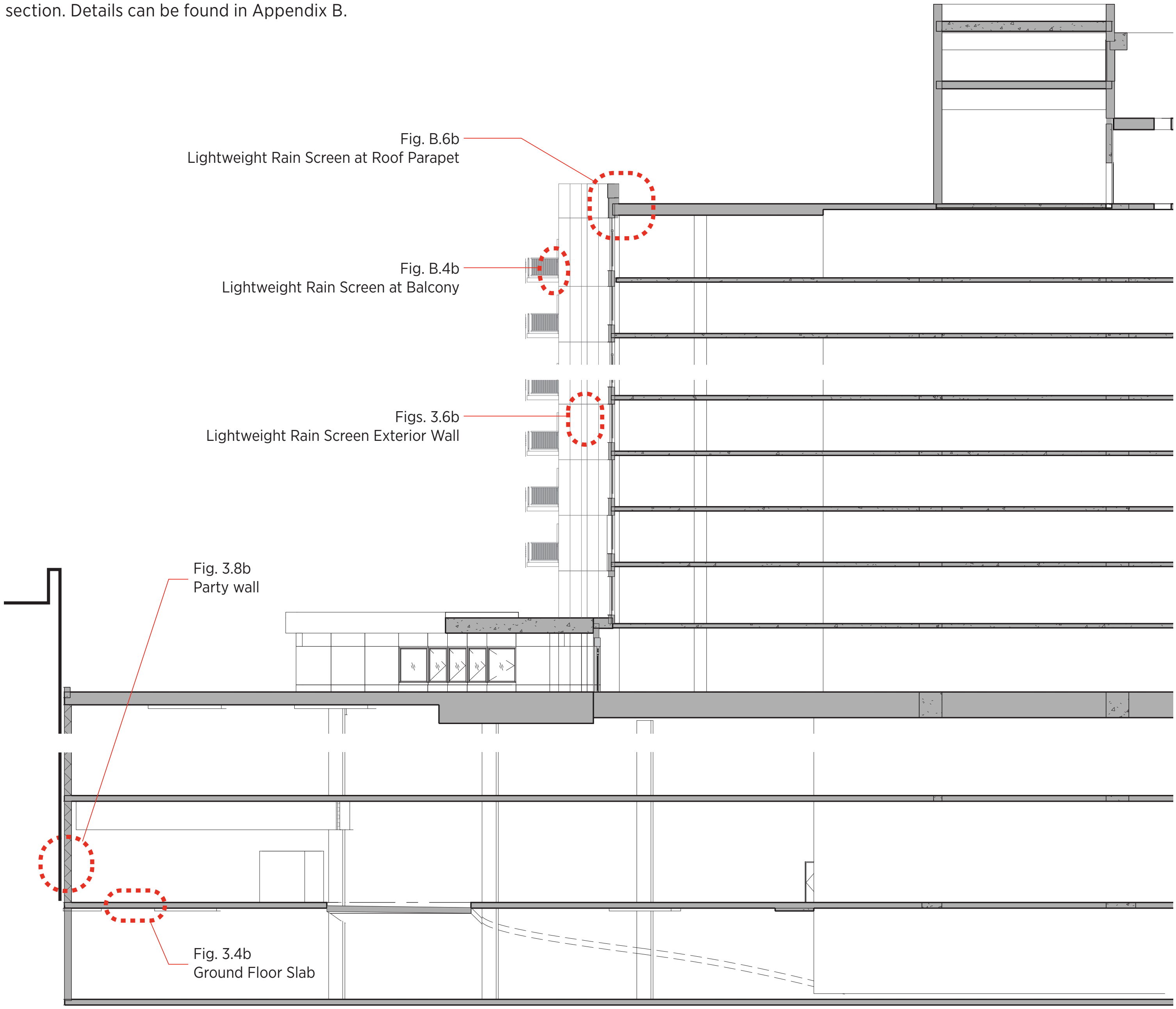


Figure 3.2:
Diagrammatic building section identifying key details.

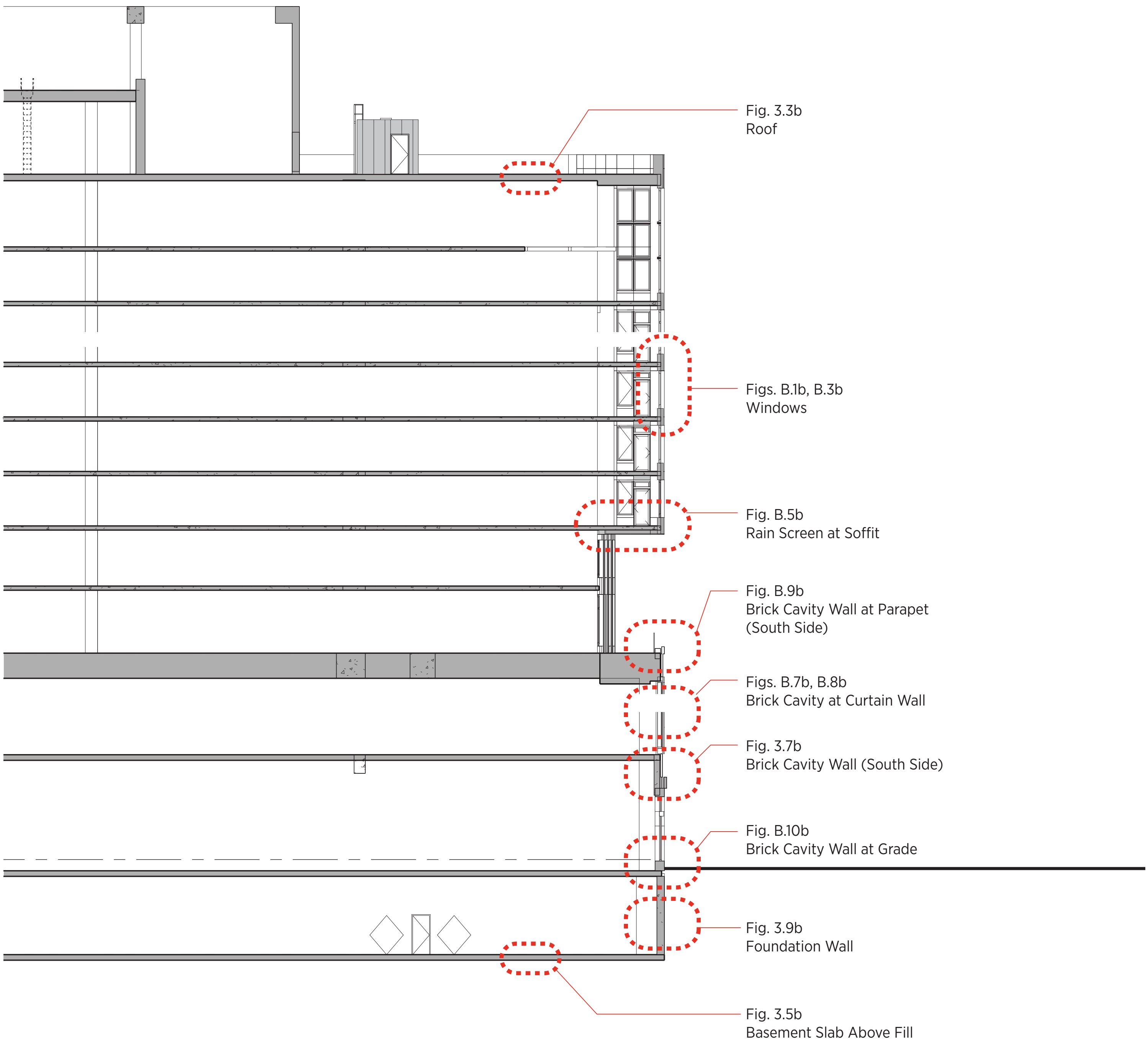


Fig. 3.3b
Roof
Figs. B.1b, B.3b
Windows
Fig. B.5b
Rain Screen at Soffit
Fig. B.9b
Brick Cavity Wall at Parapet
(South Side)
Figs. B.7b, B.8b
Brick Cavity at Curtain Wall
Fig. 3.7b
Brick Cavity Wall (South Side)
Fig. B.10b
Brick Cavity Wall at Grade
Fig. 3.9b
Foundation Wall
Fig. 3.5b
Basement Slab Above Fill

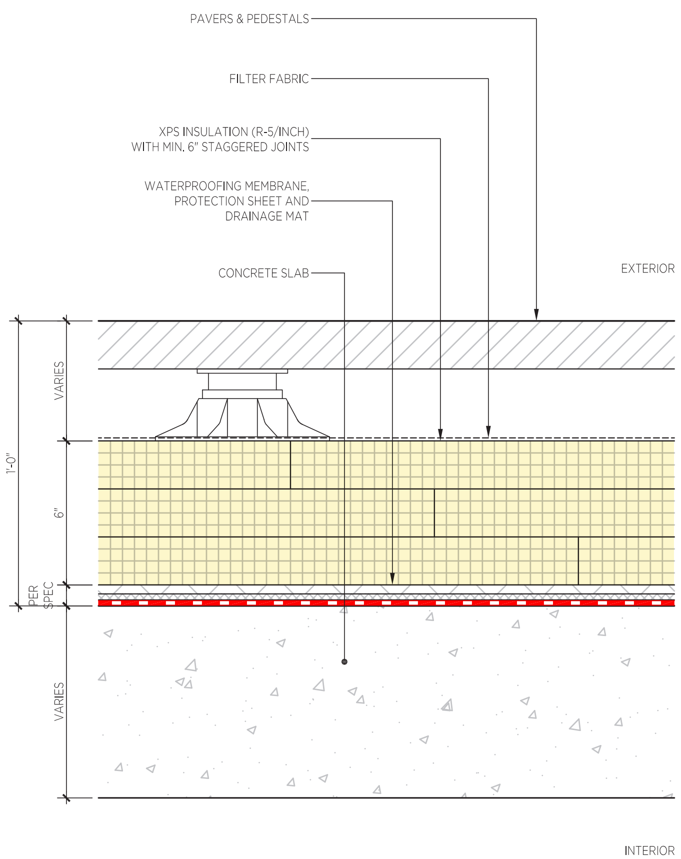


Figure 3.3a:
Base case—Roof

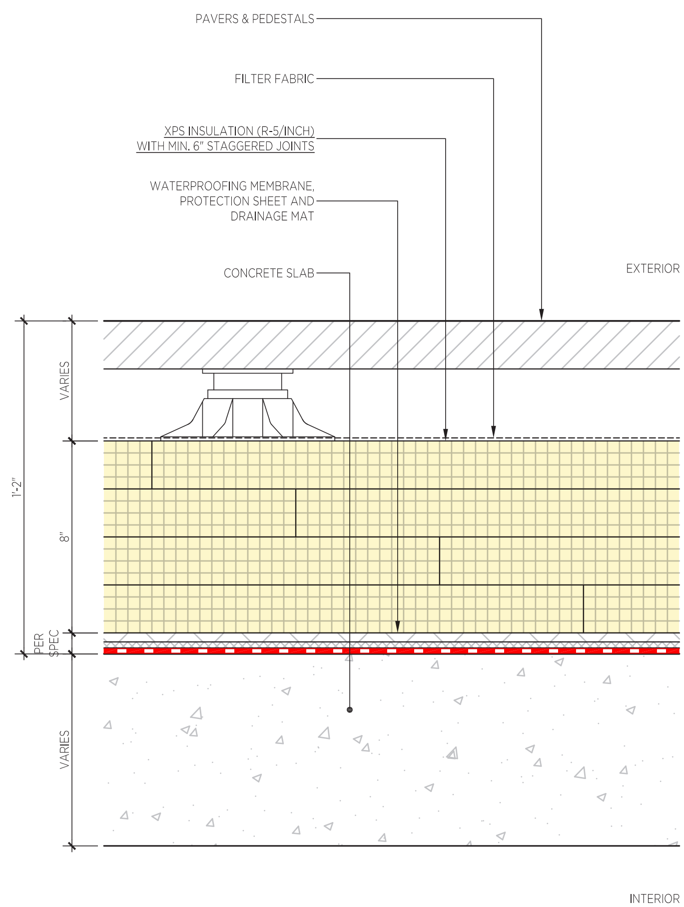


Figure 3.3b:
Passivhaus Proposal—Roof

Roof

The base case roof assembly is an inverted membrane type (IRMA). The assembly is composed of a waterproofing membrane on the concrete deck with 6" of XPS foam insulation and other materials above. The waterproofing membrane acts as an air and vapor barrier.

The same basic assembly was improved for Passivhaus performance by adding 2" of the same insulation for a total of 8" of XPS insulation.

Item	**Roof Assembly**	**Thickness (in)**	**R Value**	**U Value**
A	Outside Air Film	0	0.17	
B	Precast Concrete Pavers	2	0.19	
C	Pedestal - Air Gap	3.165	1	
D	Filter Fabric	0.08	0	
E	XPS Rigid Insulation	6	30	
F	Drainage Mat w/ Filter Brick	0.5	1.2	
G	Protection Sheet	0.005	0	
H	Hot Rubberized Asphalt Water Membrane	0.25	0	
I	Concrete Slab	varies	0.5	
	Total	**12**	**33.06**	**0.030**
	Assumed Effective Total		**33.06**	

Table 3.1a:

Base case—Roof assembly R-value

Assembly no.	Building assembly description	Interior insulation?
1	Roof	no

Surface Film Resistance [hr.ft².F/BTU] interior Rsi : 0.57

exterior Rse : 0.23

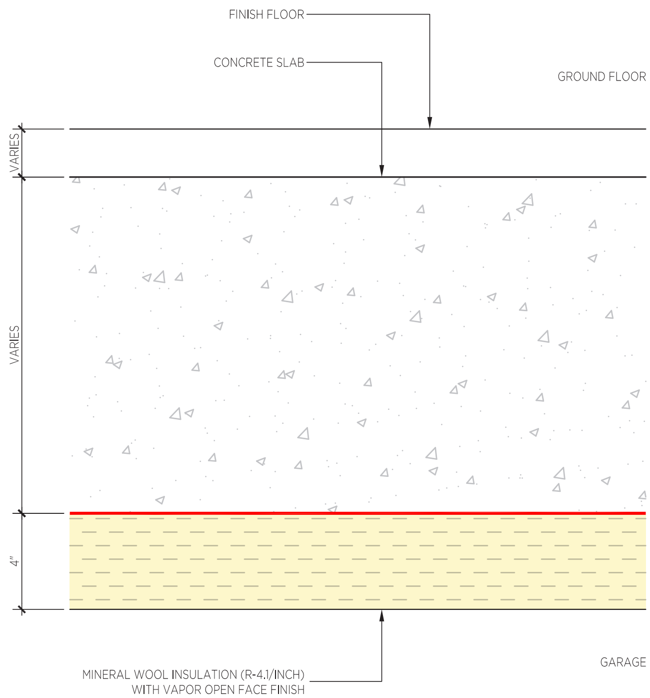
	Area section 1	R per inch	Area section 2 (optional)	R per inch	Area section 3 (optional)	R per inch	Thickness [in]
1.	XPS Foam	5.00					8.00
2.	Concrete	0.07					8.00
3.							
4.							
5.							
6.							
7.							
8.							
	Percentage of sec. 1	100%	Percentage of sec. 2		Percentage of sec. 3		Total 16.00 in

U-value supplement BTU/hr.ft^2.°F

R-Value: 41.4 hr.ft^2.°F/BTU

Table 3.1b:

Passivhaus Proposal—Roof assembly effective R-value (from PHPP)



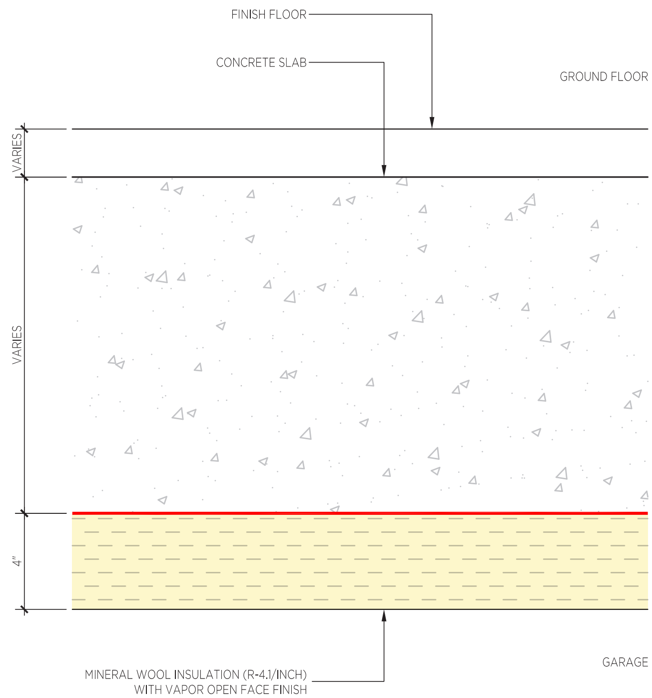


Figure 3.4a:
Base case—Ground floor slab above unconditioned space

Figure 3.4b:
Passivhaus Proposal—Ground floor slab above unconditioned space

Ground floor slab above unconditioned space

The base case ground floor slab over unconditioned space utilizes 4" of mineral wool insulation with a perforated face finish as a finished ceiling. The concrete slab acts as the air barrier.

The same assembly is used for the Passivhaus design.

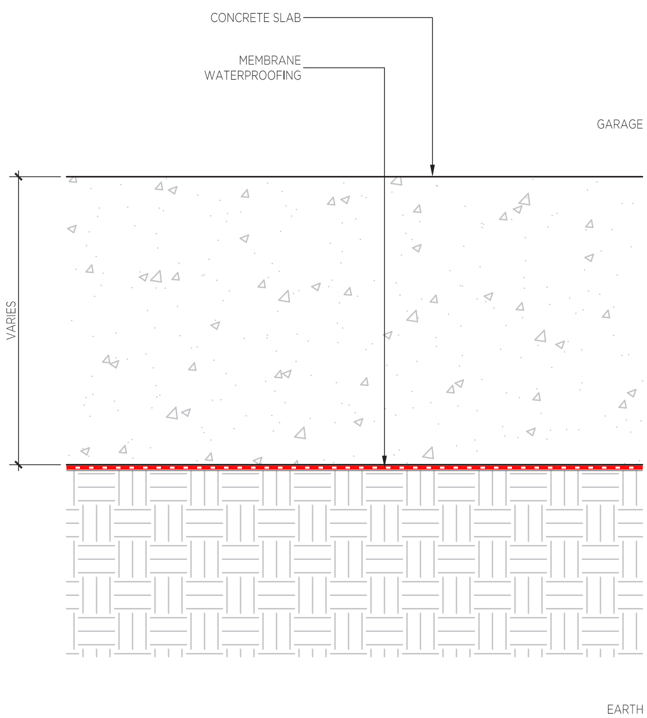
Assembly no.	Building assembly description	Interior insulation?
2	Ground Floor Slab	no

Surface Film Resistance [hr.ft².F/BTU] interior Rsi : 0.97
exterior Rse : 0.97

	Area section 1	R per inch	Area section 2 (optional)	R per inch	Area section 3 (optional)	R per inch	Thickness [in]
1.	Concrete	0.07					8.00
2.	Mineral Wool - Rockbd.	4.10					4.00
3.							
4.							
5.							
6.							
7.							
8.							
		Percentage of sec. 1		Percentage of sec. 2		Percentage of sec. 3	Total
		100%					12.00 in

U-value supplement BTU/hr.ft^2.°F **R-Value:** 18.9 hr.ft^2.°F/BTU

Table 3.2:
Passivhaus Proposal—Ground floor slab assembly effective R-value (from PHPP)



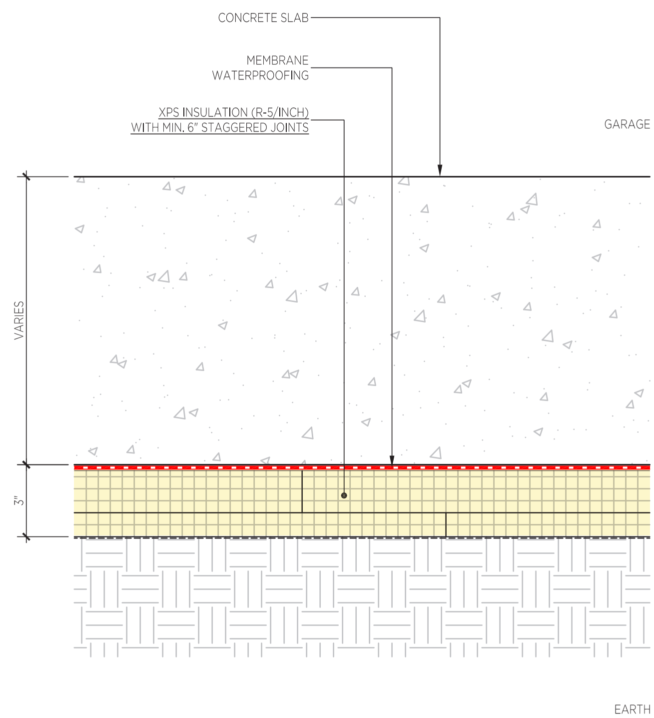


Figure 3.5a:
Base case—Basement slab above fill

Figure 3.5b:
Passivhaus Proposal—Basement slab above fill

Basement slab

The base case basement slab is not insulated. A vapor retarder is used under the slab.

The Passivhaus design adds 3” of XPS foam insulation under the slab at rooms in the Passivhaus boundary. Due to structural limitations, insulation was not added under pile caps. The same vapor retarder as the base case design is used.

Assembly no.	Building assembly description	Interior insulation?
3	Basement Slab	no

Surface Film Resistance [hr.ft².F/BTU]		
	interior Rsi :	0.97
	exterior Rse :	0.00

	Area section 1	R per inch	Area section 2 (optional)	R per inch	Area section 3 (optional)	R per inch	Thickness [in]
1.	Concrete	0.07					8.00
2.	XPS Foam	5.00					3.00
3.							
4.							
5.							
6.							
7.							
8.							
	Percentage of sec. 1		Percentage of sec. 2		Percentage of sec. 3		Total
	100%						11.00 in

U-value supplement		BTU/hr.ft^2.°F	**R-Value:**	16.5	hr.ft^2.°F/BTU

Table 3.3:

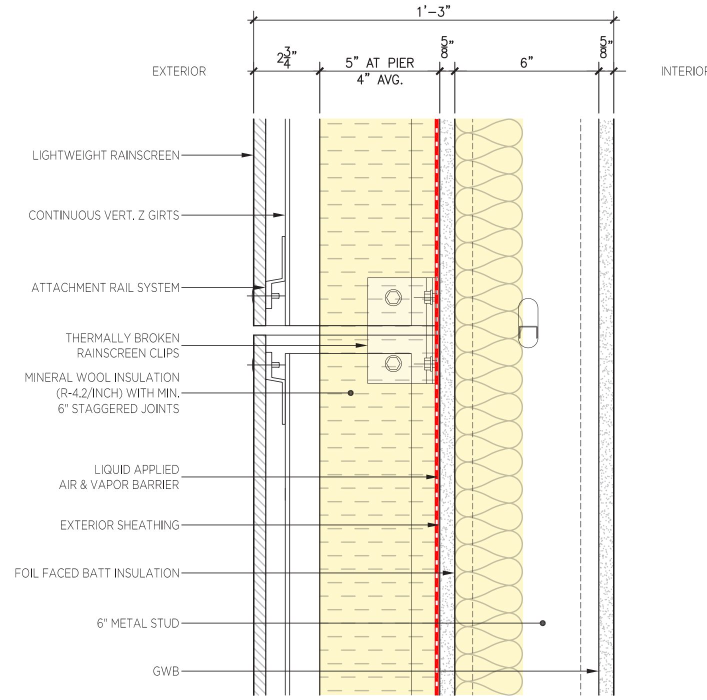
Passivhaus Proposal—Basement slab above fill effective assembly R-value (from PHPP)

Lightweight rain screen with steel stud backup

The base case utilizes a typical lightweight rainscreen cladding system supported by discontinuous metal clips attached to an interior metal stud backup wall. Continuous external mineral wool insulation is located in the rainscreen cavity. Additional mineral wool insulation is located between the metal studs. A liquid applied vapor permeable air barrier is specified.

The Passivhaus version of the assembly changes the clip type and location of insulation. Deeper fiberglass clips are used to allow all mineral wool insulation to be external and continuous in the rainscreen cavity. The fiberglass rainscreen clips result in a 20% reduction in effectiveness of the insulation[15]. No insulation is used between interior metal studs. The air and vapor barrier (AVB) is modified to a bituminous peel & stick air and vapor barrier membrane to improve quality control. A vapor barrier is safe to use in this application because all of the insulation is external to the AVB.

15 Payette Research. 2014. "Thermal Performance of Facades".



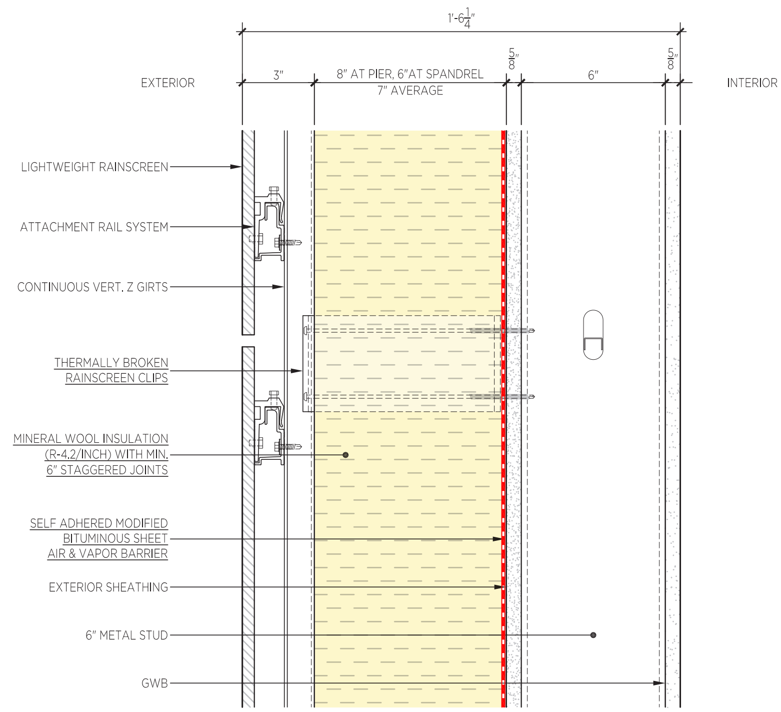


Figure 3.6a:
Base case—Lightweight rain screen steel stud backup (R-17.65)

Figure 3.6b:
Passivhaus Proposal—Lightweight rain screen steel stud backup (R-26.0)

Item	Wall Assembly	Thickness	R Value	U Value	Thickness	R Value	U Value
A	Outside Air Film	0	0.17		0	0.17	
B	Cement Panel	0.5	0.44		0.5	0.44	
C	Wall Cavity	2.244	1		2.244	1	
D	Roxul Cavity Rock DD	5	21		3	12.6	
E	Perm A Barrier VPS	0.006	-		0.006	-	
F	Densglas	0.625	1.2		0.625	1.2	
G	6" Stud	6	1		6	1	
H	Gypsum Board	0.625	0.56		0.625	0.56	
I	Inside Air Film	0	0.68		0	0.68	
	Total	**15**	**26.05**	**0.038**	**13**	**17.65**	**0.057**
	Assumed Effective Total		**14.33**			**9.72**	
	Average Effective Total = 12.02						

Table 3.4a:
Base case—Lightweight rain screen steel stud backup assembly R-value

Assembly no.	Building assembly description	Interior insulation?
4	Rainscreen (20% loss due to Cascadia Clip in U-value supplement)	no

Surface Film Resistance [hr.ft².F/BTU] interior Rsi : 0.74
exterior Rse : 0.23

	Area section 1	R per inch	Area section 2 (optional)	R per inch	Area section 3 (optional)	R per inch	Thickness [in]
1.	Mineral Wool	4.20					7.00
2.	Sheathing	0.58					0.63
3.	Air Space	0.64	Stl Stud 1.5@16"	0.00			6.00
4.	GWB	0.58					0.63
5.							
6.							
7.							
8.							
	Percentage of sec. 1	91%	Percentage of sec. 2	9.4%	Percentage of sec. 3		Total 14.25 in

U-value supplement 0.01 BTU/hr.ft^2.°F

R-Value: 26.0 hr.ft^2.°F/BTU

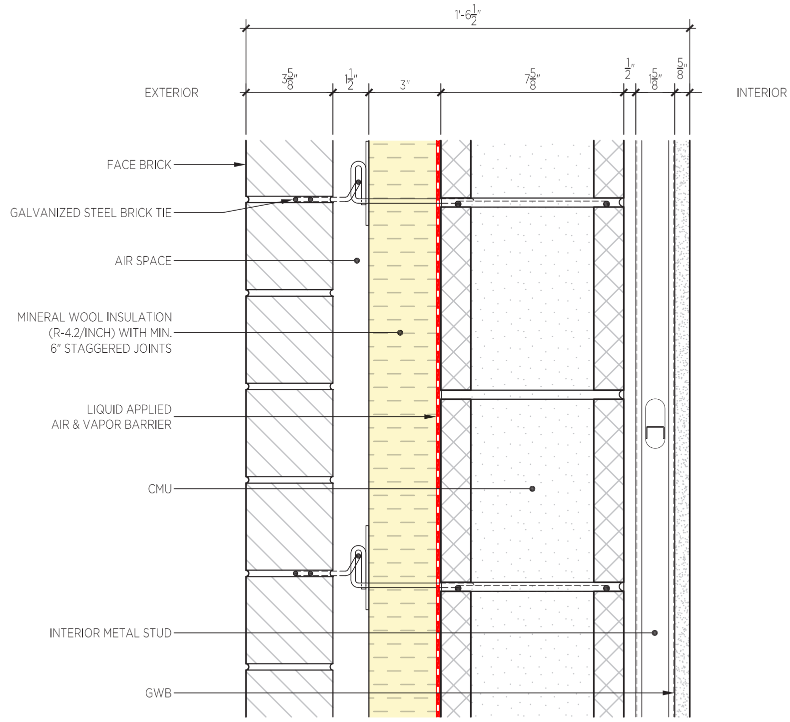
Table 3.4b:
Passivhaus Proposal—Lightweight rain screen steel stud backup assembly effective R-value (from PHPP)

Brick cavity with CMU backup

The base case utilizes a typical brick cavity system supported by a concrete masonry unit (CMU) backup wall. Typical brick supports are used including continuous steel shelf angles and galvanized steel wire brick ties. 3” of continuous mineral wool insulation is used inside the brick cavity. A typical liquid applied vapor permeable air barrier is used to facilitate application around brick ties.

The Passivhaus version of the assembly changes a few aspects of the detail. The cavity is increased from 4 1/2” to 6” to enable the use of stand-off galvanized steel shelf angles and additional insulation. Brick ties are changed to stainless steel to reduce thermal bridging. Insulation in the brick cavity is increased from 3” to 5”. The combination of stainless steel wire brick ties and galvanized steel stand-off shelf angles is assumed to result in an effective R-value reduction of 16-18% through the external insulation (12% for the steel stand-off shelf angle, and 4-6% for the stainless steel wire ties)[16]. An additional 2” of continuous internal mineral wool insulation is used. The use of exterior and interior insulation in these thicknesses should keep interior surfaces warm enough to prevent condensation, but a vapor permeable air barrier is used to enable drying to both sides of the wall if condensation occurs.

16 Payette Research. 2014. “Thermal Performance of Facades”.



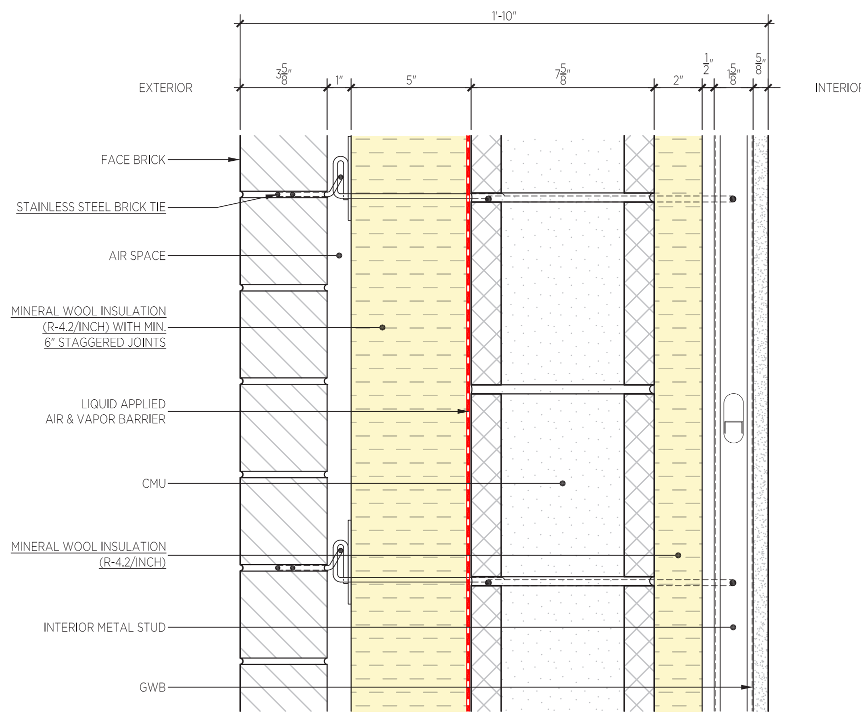


Figure 3.7a:
Base case - Brick cavity with CMU backup

Figure 3.7b:
Passivhaus Proposal - Brick cavity with CMU backup

Item	Wall Assembly	Thickness	R Value	U Value
A	Outside Air Film	0	0.17	
B	Face Brick	3.625	0.64	
C	Wall Cavity	1.5	1	
D	Roxul Cavity Rock DD	3	12.6	
E	Perm A Barrier VPS	0.006	-	
F	CMU (Solid Grouted w/115 lb/ft3 density)	7.625	1.2	
G	2.5" Stud	2.5	1	
H	Gypsum Board	0.625	0.56	
I	Inside Air Film	0	0.68	
	Total	**18.881**	**17.85**	**0.056**
	Assumed Effective Total		**10.71**	

Table 3.5a:

Base case—Brick cavity with CMU backup assembly R-value

Assembly no.	Building assembly description	Interior insulation?
5	Brick (18% loss for steel stand-off shelf and wire ties in U-value sup.)	yes

Surface Film Resistance [hr.ft².F/BTU] — interior Rsi : 0.74; exterior Rse : 0.23

	Area section 1	R per inch	Area section 2 (optional)	R per inch	Area section 3 (optional)	R per inch	Thickness [in]
1.	Brick	0.17					3.63
2.	Air Cavity	0.05					1.00
3.	Mineral Wool	4.20					5.00
4.	CMU	0.18					7.63
5.	Mineral Wool	4.20					2.00
6.	Air Space	0.64	Stl Stud 1.5@16"	0.00			1.63
7.	GWB	0.58					0.63
8.							
		Percentage of sec. 1		Percentage of sec. 2		Percentage of sec. 3	Total
		91%		9.4%			21.50 in

U-value supplement 0.01 BTU/hr.ft².°F

R-Value: 26.1 hr.ft².°F/BTU

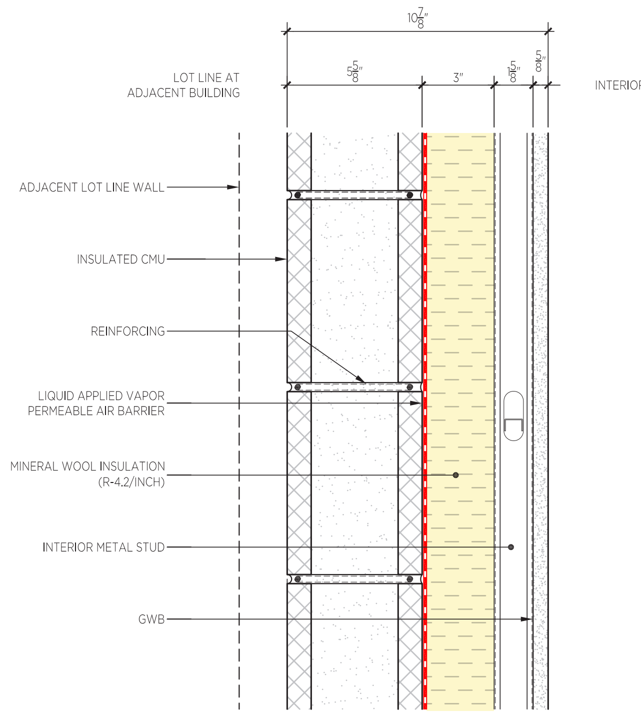
Table 3.5b:

Passivhaus Proposal—Brick cavity with CMU backup assembly effective R-value (from PHPP)

Lot line wall with CMU backup

The base case utilizes concrete masonry unit (CMU) walls with a liquid applied vapor permeable air barrier on the interior surface of the CMU. Continuous interior insulation is used.

The Passivhaus upgrade required an insulating CMU product with continuous EPS insulation sandwiched between internal and external concrete block faces. The same liquid applied vapor permeable air barrier is used. Less continuous internal insulation than the base case is needed.



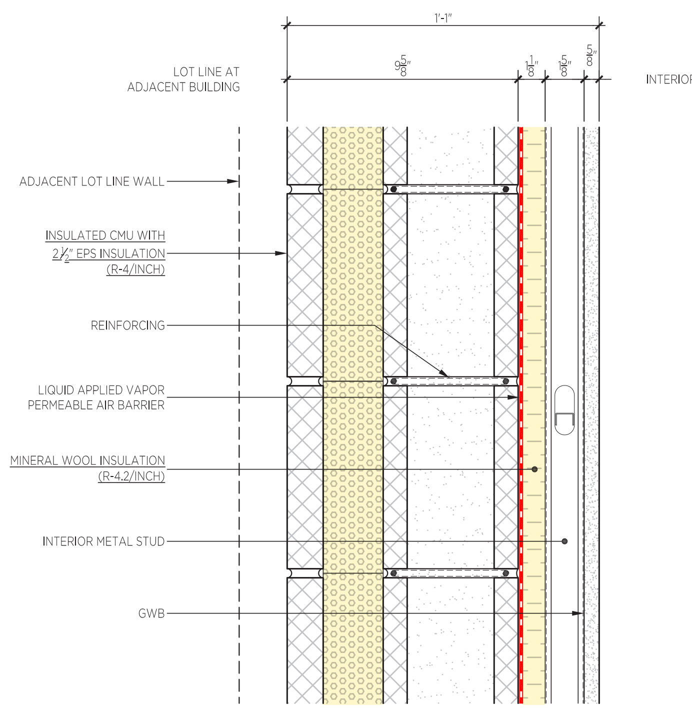


Figure 3.8a:
Base case - Lot line wall with CMU backup

Figure 3.8b:
Passivhaus Proposal - Lot line wall with CMU backup

Item	Wall Assembly	Thickness	R Value	U Value
A	Outside Air Film	0	0.17	
B	CMU (Solid Grouted w/115 lb/ft3 density)	5.625	0.89	
C	Mineral Wool	3	12.6	
D	1 5/8" Stud	1.625	1	
E	Gypsum Board	0.625	0.56	
F	Inside Air Film	0	0.68	
	Total	**10.875**	**15.90**	**0.063**
	Assumed Effective Total		**15.90**	

Table 3.6a:

Base case—Lot line wall with CMU backup assembly R-value

Assembly no.	Building assembly description	Interior insulation?
6	Insulated CMU Party Wall	yes

Surface Film Resistance [hr.ft².F/BTU] interior Rsi : 0.74 exterior Rse : 0.23

	Area section 1	R per inch	Area section 2 (optional)	R per inch	Area section 3 (optional)	R per inch	Thickness [in]
1.	Concrete Block Solid	0.23					1.50
2.	EPS Foam	4.00					2.50
3.	Concrete Block Hollow	0.13					7.00
4.	Mineral Wool	4.20					1.00
5.	Air Space	0.64	Stl Stud 1.5@16"	0.00			1.63
6.	GWB	0.58					0.63
7.							
8.							
	Percentage of sec. 1	91%	Percentage of sec. 2	9.4%	Percentage of sec. 3		Total 14.25 in

U-value supplement BTU/hr.ft^2.°F

R-Value: 17.3 hr.ft^2.°F/BTU

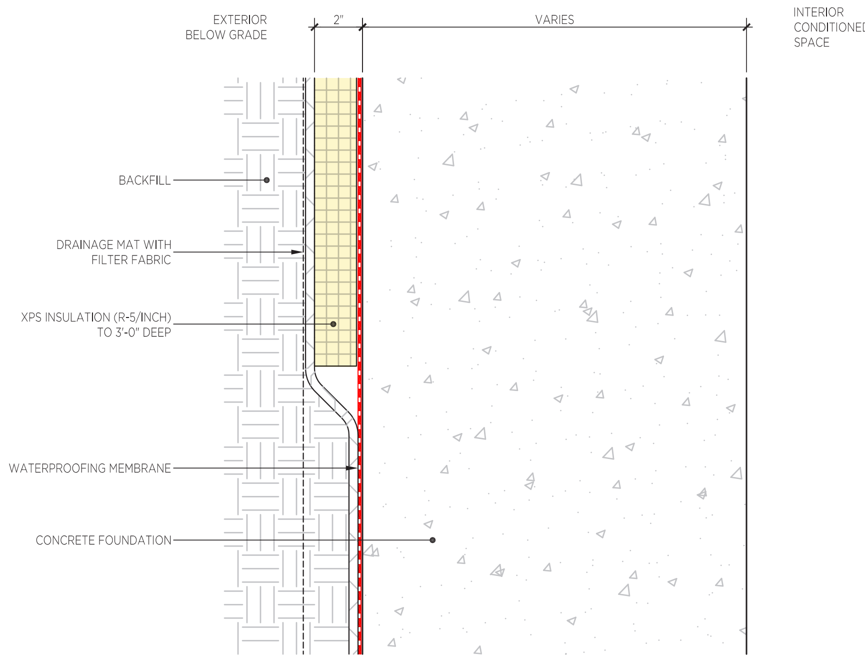
Table 3.6b:

Passivhaus Proposal—Lot line wall with CMU backup assembly effective R-value (from PHPP)

Foundation wall

The base case utilizes 2” of XPS insulation external of the foundation wall to a depth below the frost line at occupied spaces. A standard waterproofing membrane is used.

The Passivhaus detail required an additional 1” of XPS insulation for a total of 3” full depth at occupied spaces in the Passivhaus boundary. The same waterproofing membrane is used.



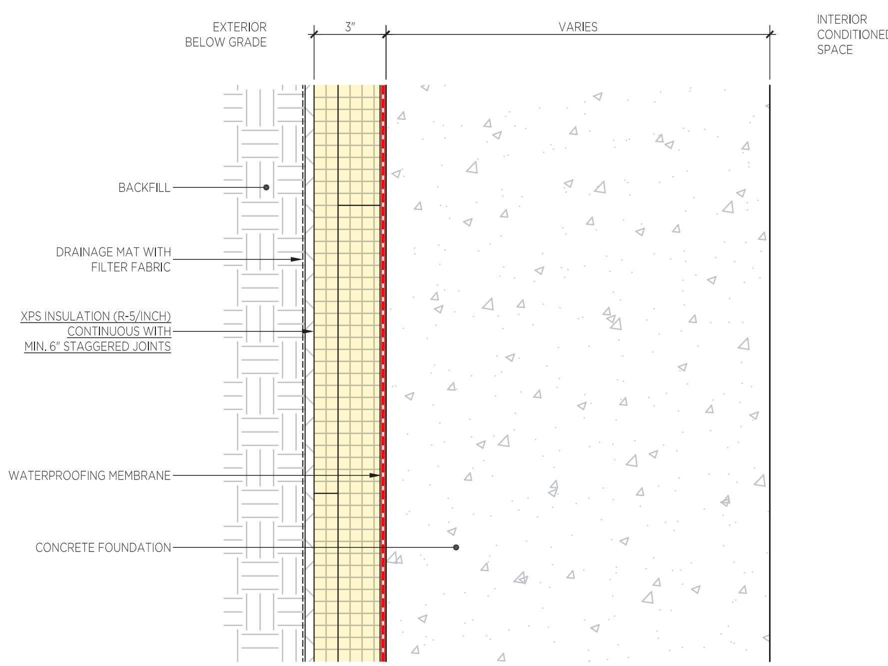


Figure 3.9a:
Base case - Foundation wall

Figure 3.9b:
Passivhaus Proposal - Foundation wall

Up to 3'-0" below ground

Item	Wall Assembly	Thickness	R Value	U Value
A	Soil	0	1.1	
B	XPS foam	2	10	
C	Concrete	8	0.56	
D	Inside Air Film	0	0.68	
	Total	**10**	**12.34**	**0.081**
	Assumed Effective Total		**12.34**	

Below 3'-0" below ground

Item	Wall Assembly	Thickness	R Value	U Value
A	Soil	0	1.1	
B	Concrete	8	0.56	
C	Inside Air Film	0	0.68	
	Total	**8**	**2.34**	**0.427**
	Assumed Effective Total		**2.34**	

Table 3.7a:

Base case—Foundation wall assembly R-value

Assembly no.	Building assembly description	Interior insulation?
7	Foundation Wall	no

Surface Film Resistance [hr.ft².F/BTU] interior Rsi : 0.74

exterior Rse : 0.23

	Area section 1	R per inch	Area section 2 (optional)	R per inch	Area section 3 (optional)	R per inch	Thickness [in]
1.	XPS Foam	5.00					3.00
2.	Concrete	0.07					8.00
3.							
4.							
5.							
6.							
7.							
8.							
	Percentage of sec. 1	100%	Percentage of sec. 2		Percentage of sec. 3		Total 11.00 in

U-value supplement BTU/hr.ft^2.°F

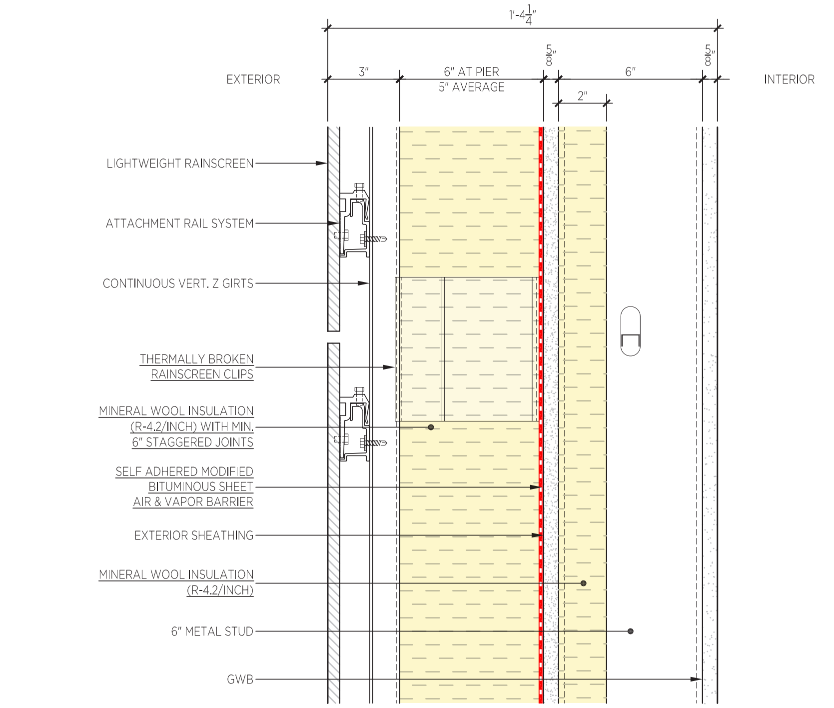
R-Value: 16.5 hr.ft^2.°F/BTU

Table 3.7b:

Passivhaus Proposal—Foundation wall assembly effective R-value (from PHPP)

Alternative Enclosure Assemblies
A rainscreen assembly similar to the base case with continuous outboard insulation and interior insulation between metal studs may be viable with advanced thermally broken clips. After revised details were developed, the design team became aware of such clips being available, with similar strength as the selected clips, but better thermal performance. The selected clip utilizes long screws that span from the exterior un-insulated edge of the fiberglass clip through to the metal stud. This thermal bridge causes an approximately 20% loss of insulation R-value. Thermal bridging through screws may result in cold metal stud surfaces that can cause condensation. Details were developed with full external insulation to allow drying and to avoid trapping potential condensation in between insulation layers. The advanced clips are also fiberglass but do not have through fasteners. These truly thermally broken clips are reported to result in a 3% to 7% loss of insulation R-value. Conduction through these clips is reported to be low enough that in the proposed alternate detail, metal stud surfaces would never get cold enough to cause condensation. This approach would allow the use of cavity insulation similar to that used in the base case. The thermally broken clips would minimize temperature differentials between the front and back of metal studs, thereby minimizing losses through studs between cavity insulation. This approach would likely reduce the assembly thickness by two inches and reduce gross area and/or increase usable area.

As demonstrated at The House at Cornell Tech residential building, unitized rainscreen wall systems are able to achieve Passivhaus levels of performance. These wall systems are similar to other rainscreen assemblies, but are pre made in the factory, and utilize



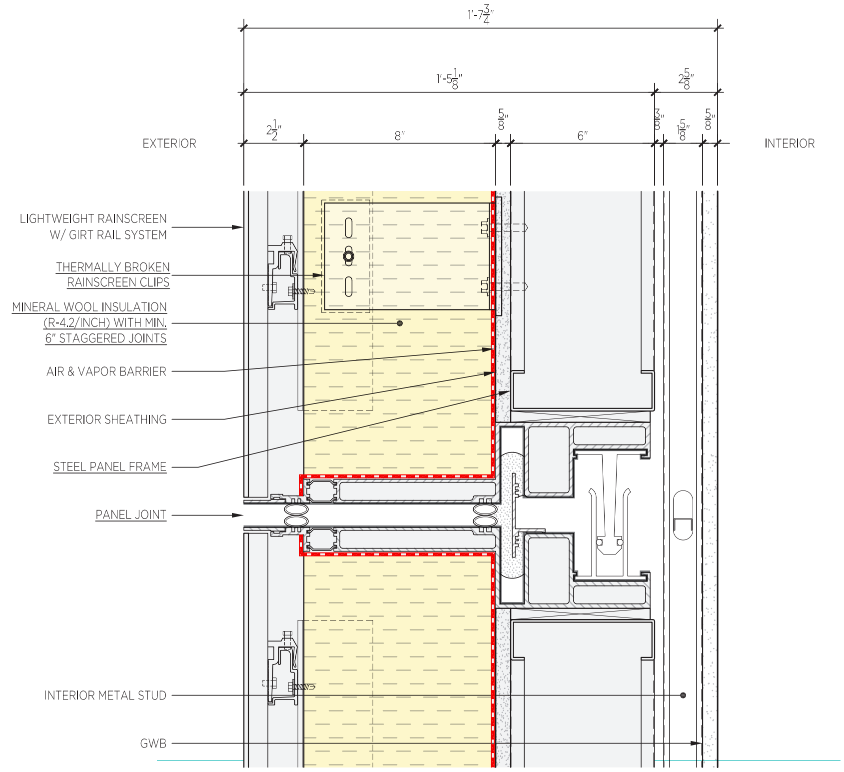
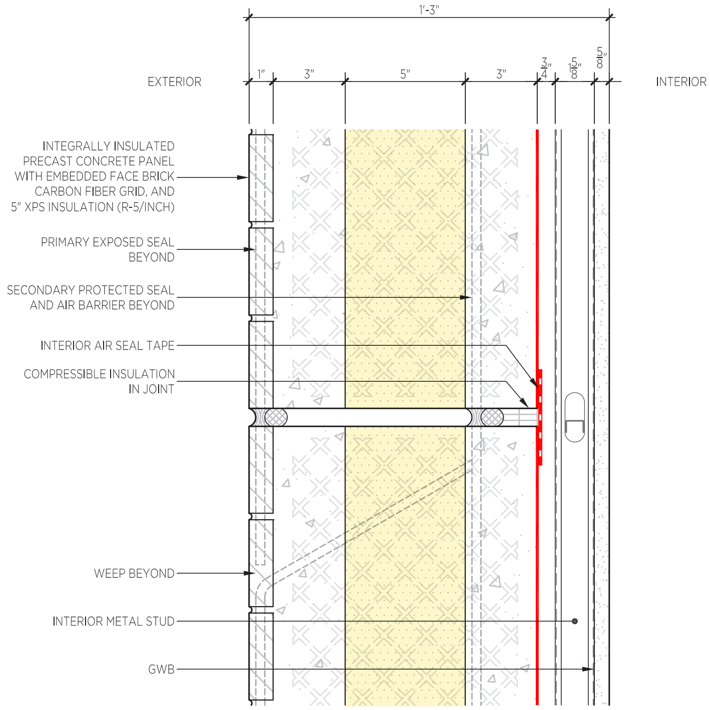


Figure 3.10a:
Alternate - Lightweight rain screen with steel stud and interior insulation

Figure 3.10b:
Alternate - Unitized rain screen panels



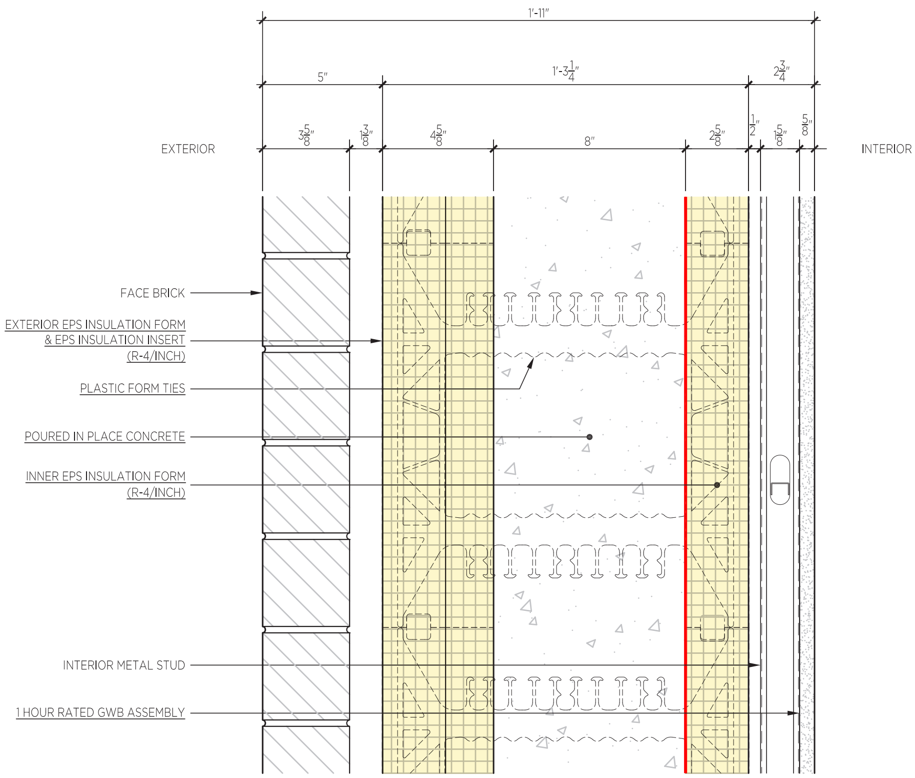


Figure 3.10c:
Alternate - Brick on precast insulated panel

Figure 3.10d:
Alternate - Brick on insulated form

perimeter frame and gasket systems. Technical challenges include thermal bridging and air tightness at the perimeter frame and anchors, and opening of joints during shipping. These systems are reported to be more expensive than the enclosure assemblies presented in this study and require less standard construction practices for the New York market.

Insulated precast concrete panels are a very promising enclosure system. These panels can be faced with brick or other materials and can be a direct replacement for the brick cavity wall described in the Passivhaus design. Insulated precast panels are composed of a face wythe of concrete, rigid insulation, and a back wythe of concrete held in place by thermally broken connectors. Connectors can be made of plastic, carbon fiber mesh or other materials and can be deep enough to allow for the R-values required by this study. Panels are attached to the building structure by anchors at the back wythe of concrete. Since the back wythe of concrete is thermally separated from the front wythe, there is virtually no thermal bridging at connections. These panels rely on two stage caulk joints for weather protection. Additional insulation in panel joints and air sealing tape at interior joints help panels meet Passivhaus thermal and air tightness performance requirements.

Insulating concrete form (ICF) structures are in use on low-rise Passivhaus buildings in the US, and on high-rise buildings in Canada. These products are composed of stackable blocks of inner and outer rigid insulation held together with plastic ties. This system acts as permanent formwork for the concrete structure, while also providing cladding support, insulation, air tightness, and vapor retarding properties. ICF walls can accept rainscreen, brick, or other cladding materials.

3.1.1. Enclosure Thermal Bridging

The base case building utilizes common construction techniques that include ubiquitous thermal bridges through the building envelope. Thermal bridges cause significant thermal loss, unintended energy use, and allow the potential for condensation & moisture related problems. Current energy modeling and enclosure design practices and codes do not require thorough accounting of thermal bridges.

Passivhaus requires that all thermal bridges be eliminated or otherwise accounted for in the PHPP energy model. This is done by setting target limits on heat loss through point or linear thermal bridges. Passivhaus maximums for thermal bridges are 0.0018 Btu/hr.ft2.F for point (Chi) and 0.006 Btu/(hr.ft.F) for linear (Psi) conditions. If a thermal bridge cannot be eliminated, it must be input into the PHPP energy model to account for its thermal loss. For example, the structure of the base case building did not allow the Passivhaus design to locate continuous insulation under pile caps and grade beams. These thermal bridges were unavoidable and input into the PHPP energy model. The Passivhaus Institute has approved this type of thermal bridge as an acceptable deviation for large buildings.

Improved details were developed for the Passivhaus design to reduce thermal bridging as described below. These details were verified by Passive House Academy with *FLIXO* heat flow models.

Due to the increased insulation, the Passivhaus design required 6” & 8” deep thermally broken rainscreen attachment clips whereas the base case used 4” & 6” deep aluminum clips. The Passivhaus design

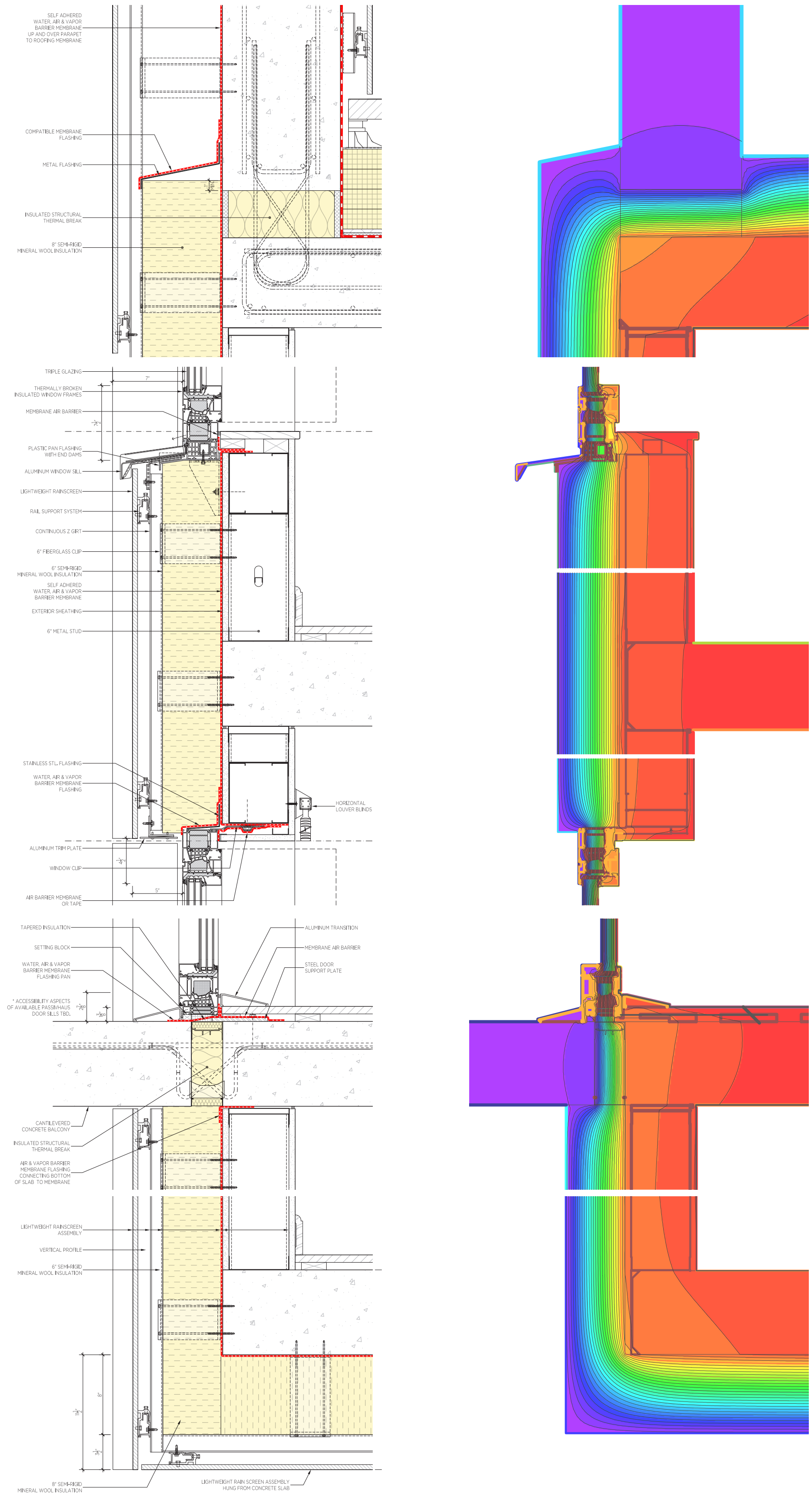


Figure 3.11:
Passivhaus Proposal—Assembled details of lightweight rain screen steel stud backup (left) and corresponding thermal bridge analyses of various junctions (right).

is based on a fiberglass clip with stainless steel through-anchors that minimize but do not eliminate thermal bridging. Product literature for a similar detail shows that the temperature of the screw at the metal stud would rarely, if ever, reach a low enough temperature to cause condensation. A number of other thermally broken clips are available in the US market, but only one is currently available in depths greater than 6”.

The proposed brick cavity attachments include stainless steel wire brick ties and galvanized steel stand-off shelf angles. While stainless steel ties are approximately 1/3 less conductive than the steel ties used in the base case, the proposed ties do create some thermal bridging through the insulation. A thermally broken brick tie is available, however, it is a screw-in anchor type that may rotate and cause air infiltration through the air barrier. Wire ties were selected instead of screw-through angle supports to minimize the cross sectional area of metal through the insulation, and because of the ease of installation of the wire ties and related air barrier.

Windows are located such that thermal breaks are correctly aligned within assembly insulation.

Window and storefront anchor clips are located inside of the insulation, and internal to frame thermal breaks.

Window intermittent dead load support angles are close to the face of insulation and have the potential to be considered thermal bridges. The nose of support angles could be coated with a thermal insulating coating such as recently developed aerogel types. Such coatings were not included in this study.

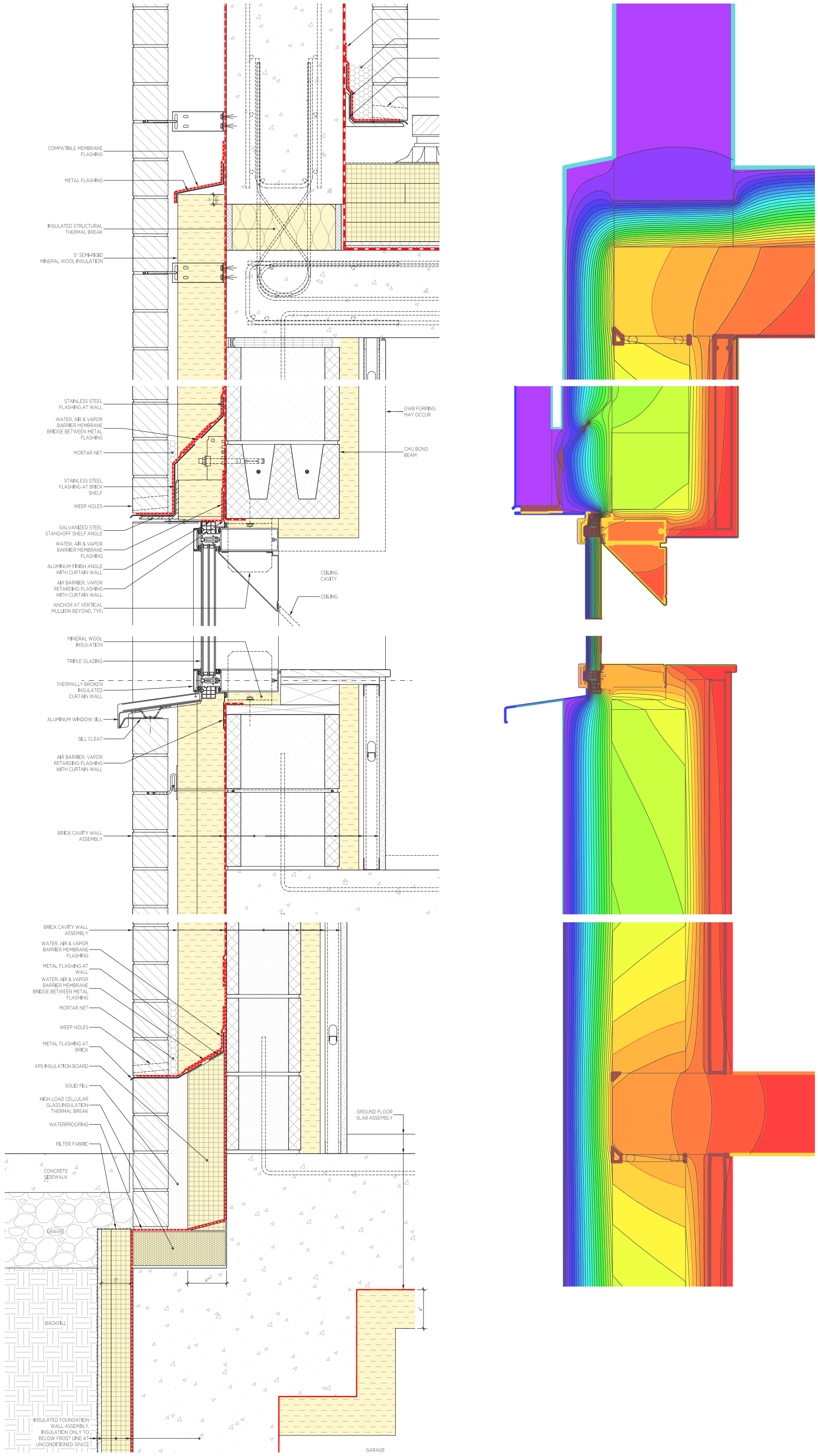


Figure 3.12:

Passivhaus Proposal—Assembled details of brick cavity on CMU (left) and corresponding thermal bridge analyses of various junctions (right).

Sills and trim are supported by thermally broken clips and frames.

Plastic sill pan materials are used in lieu of metal to minimize thermal bridging, although this is not common on high-rise construction. Plastic sill pans can be preformed to fit rough openings or site assembled with stock pieces and sealed.

Metal flashing is made discontinuous and bridged with reinforced sheet membrane materials.

Insulation attachment thermal bridging is minimized through the use of continuous thermally broken vertical zees and brick tie accessories to support the insulation and reduce the number of insulation pins. For example, in the Passivhaus design, a typical rainscreen pier requires five pins per floor and a spandrel requires two (figure 3.13).

Balconies and parapets utilize structural thermal break products to minimize thermal bridging. Alternate approaches to reducing parapet thermal bridging that were not used in the study include the use of autoclave aerated concrete block or cellular glass insulation products below CMU parapet walls.

Cellular glass insulation is used at the juncture of the exterior wall and the foundation at the ground floor to minimize thermal bridging.

Steel penetrations such as entry canopies and roof dunnage are modified to an insulated connection with stainless steel bolts.

Pipe penetrations such as roof drains and vents are modified to thermally broken, gasketed connections at the enclosure.

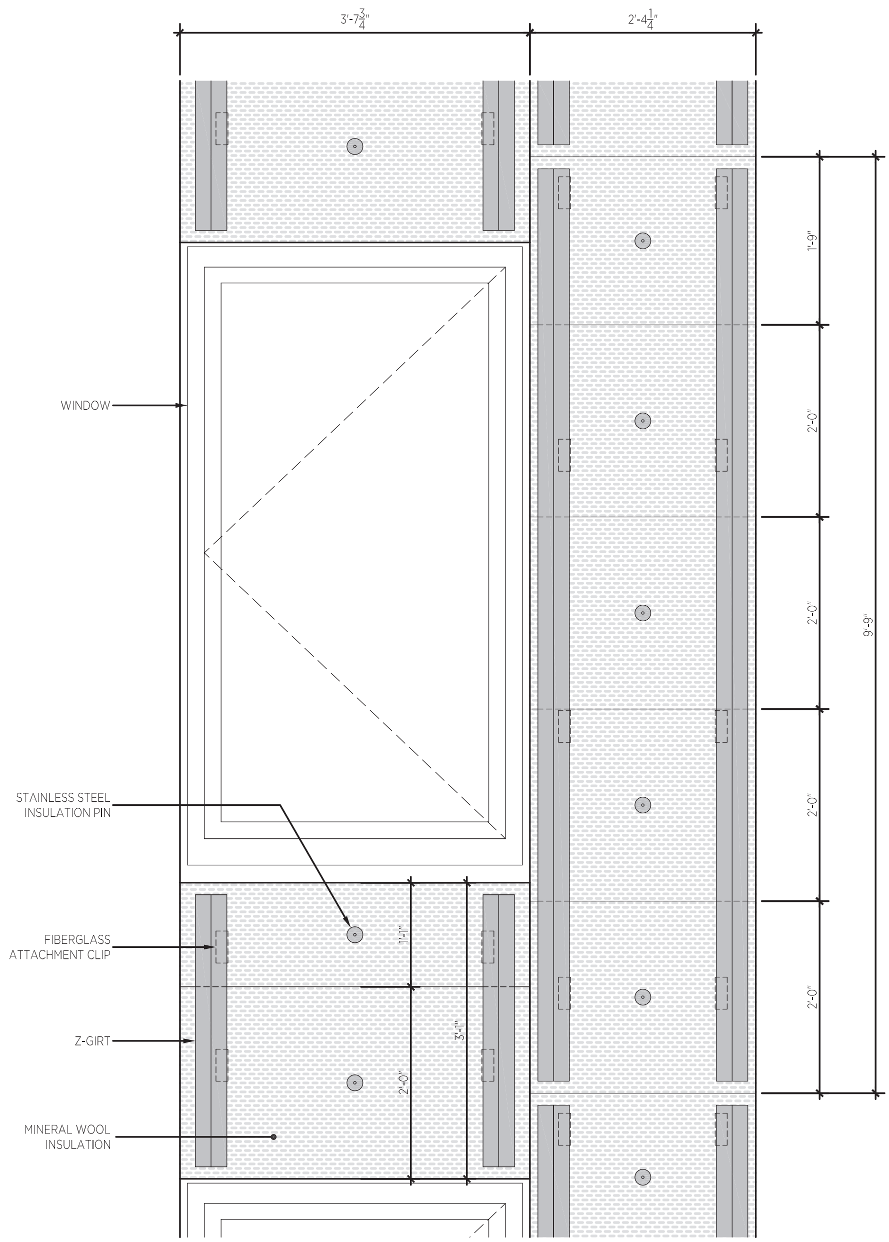


Figure 3.13:
Insulation fastening diagram.

3.1.2. Structural Considerations[17]

The base case concrete building structure offers thermal advantages over a steel structure. Concrete is less conductive than steel, reducing losses from thermal bridges. Concrete also provides significant interior thermal mass, which dampens the effect of external temperature swings and helps to maintain a consistent interior temperature.

Passivhaus enclosure detailing causes some additional structural engineering design effort and some variations on detailing. Structural thermal breaks, enclosure framing and brick cavity upgrades may be affected. Engineering for these items may be provided by the main structural engineer, or, for framing and brick cavities, by an enclosure consultant.

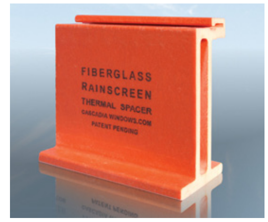
Structural thermal breaks at parapets, balconies, canopies, dunnage and similar conditions are feasible but are not common. An additional level of complexity is necessary in the design of these connections. Structural engineers generally want to avoid liability for these proprietary systems, and may require manufacturers to produce officially signed and sealed designs and calculations. As installations of these products increase, a track record of safety and viability will be established and their use will become commonplace.

Modifications to Base Case Design

The position of windows in the rainscreen assembly required upsizing of metal framing members. In the base case design, windows rest directly on the metal stud wall, with 18 gauge framing members. Windows in the Passivhaus design are pushed outside of the framing members, resulting in asymmetric loading on the stud wall. As a result, framing members were up-sized to 16 gauge. In addition, framing above and below the windows was upgraded from typical headers and sills to box beams.

Two brick cavity wall assembly upgrades require structural engineering. The cavity designated in the Passivhaus design is 6” deep. NYC building code requires supports & ties in cavities over 4 1/2” deep to be calculated. Stand-off shelf angles also may require additional calculations.

17 The recommendations in this section were developed with the assistance of Jarret Johnson of DeSimone Consulting Engineers.



Fiberglass Rainscreen Clips

Thermal Breaks for Steel and Concrete

Steel Standoff Shelf Supports

Cellular Glass Masonry Base Course

Figure 3.14:
Various items specified to minimize thermal bridging.

3.1.3. Windows and Glazing

Windows and glazing were carefully evaluated due to the large impact on energy use and the high cost of Passivhaus certified products. The base case has an overall window-to-wall ratio of 36% in keeping with the New York City Energy Code prescriptive threshold of 40%. While this ratio was thought to be favorable for Passivhaus, the base case building did not utilize common strategies to control solar heat gain, shading and thermal loss. Windows were evenly distributed on each side of the residential tower regardless of solar exposure. Retail windows were concentrated at northeastern and northwestern exposures where the opportunity for solar gain was minimal and the potential for thermal loss was high. No shading devices were used. The Passivhaus design was able to maintain the base case design despite these unfavorable window parameters. No changes of window-to-wall ratio, size or location were required. No additional passive solar measures such as shading devices or relocating windows based on solar orientation were required due to the compact nature of the building form and adjacent shading from the urban context.

The base case design uses windows frames, curtain wall, and glazing that are common in the New York City market. Frames are aluminum with minimal thermal breaks and no insulation. Insulating glass units are double glazed with high performance low-e coatings on the number two surface. Operable windows have common gasketing for airtightness.

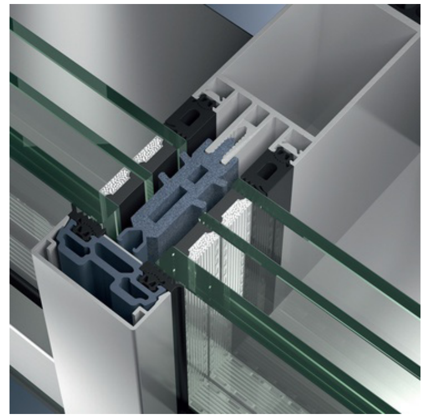
The Passivhaus design required substantially higher performance components. Window frames and curtain walls are upgraded to Passivhaus certified components with enhanced thermal breaks, increased insulation values and more robust gasketing.

Triple glazed insulating glass units were used to minimize thermal loss and to achieve Passivhaus interior thermal comfort criteria. High internal heat gains in the building required the insulating glass units to have a low-e coating to control solar gain. The same low-e coatings as the base case were used.

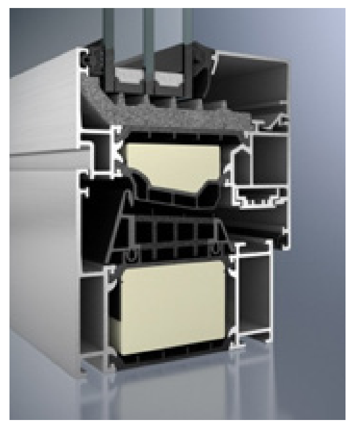
The study included the highest caliber Passivhaus certified window frame and curtain wall components to test their cost impact. However, less expensive but only slightly lower performing window frame components are available and can be used. A number of Passivhaus projects in New York City use window frames that have very high performance but are not Passivhaus certified.

Airtightness aspects of window and curtain wall installation details were reviewed. Base case building details rely on sealant as is common in typical New York City construction. The Passivhaus design utilized self-adhered membrane flashing instead of caulk to improve the consistency of workmanship at joints between fenestration and rough openings. Self-adhered membrane flashing also allowed the location of the typical tower window to be fully in the external insulation layer of the rainscreen wall assembly. The podium curtain wall product includes a gasketed flashing membrane that is part of the system, and allows ideal placement of the curtain wall within the wall insulation layer.

Vinyl and fiberglass windows were not considered in the study but may be applicable for other projects.



Schuco FWS 50+.SI Curtain Wall



Schuco AWS 90.SI+ Window

Figure 3.15:
Specified triple glazed windows for curtain wall and residential IGU.

3.1.4. Exterior Doors

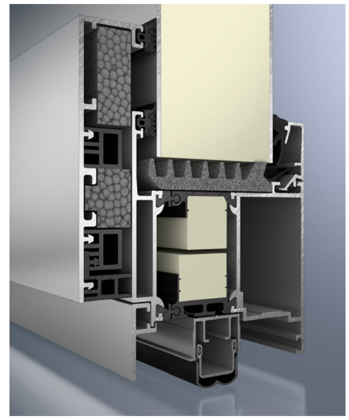
Three types of base case building exterior doors were addressed: all glass entry doors, opaque doors, and residential balcony doors. Passivhaus certified door components exist, however, they are not handicap accessible. Different solutions were found for each door type. Accessibility issues are discussed in Section 4.6.

The base case building utilizes all-glass doors at the main residential and commercial entrances to the building. These doors consist of un-insulated monolithic glass, non-thermally broken stiles & rails, and air permeable brush edging. Entrances typically have a flush or very minimal threshold for accessibility. The Passivhaus design replaces these doors with a high performance and accessible substitution. The selected door is triple glazed with thermally broken and insulated stiles & rails, but it is not Passivhaus certified.

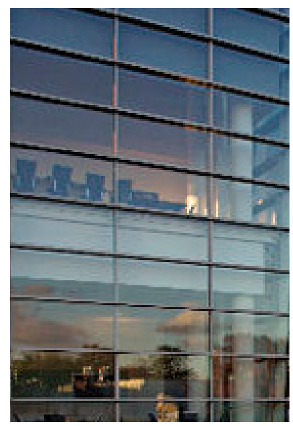
Base case service and egress doors are a typical opaque hollow metal type with code minimum air leakage and R-values. The door selected for the Passivhaus design is a thermally broken insulated opaque product that is not Passivhaus certified. Special sets of thresholds and gaskets designed for hurricane protection and/or safe areas are required to provide accessibility and adequate performance. The door selected for entrances in the Passivhaus design can also be used with an insulated opaque panel in place of glass.

The base case balcony door is similar to the typical residential window in that it has minimal thermal breaks, no frame insulation and double glazing. The proposed balcony door in the Passivhaus design is from the same Passivhaus certified system as the proposed residential window and has very good performance characteristics. This door was selected to limit interior temperature asymmetry within apartments to maintain comfort requirements. The proposed door does not meet handicap accessibility requirements on its own. However, a potential exception triggered by the use of an impervious concrete balcony may exempt these doors from handicap accessibility requirements in this special situation. This approach was selected to highlight the lack of availability of Passivhaus certified accessible doors, and does not intend to advocate for the use of accessibility exceptions.

The large size of the study building allows for the use of a small number of non-Passivhaus certified doors at entrances, service and egress doors, which can be offset in the overall Passivhaus energy balance.



Schuco ADS 112.IC Door



Tower Glass - PPG
Solarban 60 Clear

Figure 3.16:
Specified door frame and glazing.

3.1.5. Airtightness

Achieving Passivhaus certification requires the design to meet stringent airtightness standards. Performance must be verified through blower door testing of the entire building after construction. The typical Passivhaus airtightness requirement is a limit on air changes per hour of internal air volume at 50 Pa of pressure (n50: 0.6 ACH @ 50Pa). Large buildings with low surface area to volume ratios result in more overall infiltration than small buildings with high surface area to volume ratios. To address this disparity, the Passivhaus Institut recommends that large buildings (net internal air volume > 141,150 cubic foot), also meet an air permeability index (q50). This index is a limit on air flow through a given area of building envelope ($\leq$ 0.036 CFM/ft^2 @ 50Pa). In the case study building, the air permeability index is more stringent and is used in the Passivhaus design strategy.

The 2014 New York City Energy Conservation Code (NYCECC) also prescribes a maximum allowable air permeability index. The required standard of 0.4 CFM/ft^2 at a pressure differential of 0.3 inches water gauge (75Pa) can be converted to 0.263 CFM/ft^2 @ 50Pa for direct comparison with the Passivhaus requirements. The NYCECC value was used in the base case building model. The Passivhaus requirement is more than seven times as tight as the NYCECC requirement in terms of leakage per ft^2 of building enclosure.

Sufficient interior airtightness between residential units is necessary to ensure appropriate ERV balancing between zones. This is accounted for in base case building measures to meet the LEED prerequisite for Environmental Tobacco Smoke control. This

Rain screen	Brick Cavity
1. AVB installed over primer and sheathing, slab edges and other substrates.	1. Brick ties are mortared into the CMU backup wall.
2. Windows installed, support angles, sill pan, clips, frames & glass.	2. CMU joints struck flush to ease the liquid applied AVB application.
3. Membrane flashing installed between AVB and windows.	3. Liquid applied AVB applied to face of CMU wall.
4. Rain screen clips installed.	4. Membrane transitions applied at the slab edge and other special conditions.
5. Penetrations are sealed.	5. Storefront installed, anchors, vertical mullions, horizontal mullions, glass.
6. Metal and membrane flashing installed.	6. Gasketed storefront flashing sealed to AVB.
7. Insulation and pins installed.	7. Brick shelf installed.
8. Z girt installed.	8. Metal and membrane flashing installed
9. Rain screen cladding installed.	9. Insulation and pins installed
10. Sills and trim installed.	10. Brick installed.
	11. Sills and trim installed.

Table 3.8:
Enclosure assembly sequences to allow for airtightness assurance and testing.

prerequisite requires blower door testing and air leakage rates of less than 1.25 in^2/100 ft^2 of interior enclosure area.

The steps taken to ensure meeting the above airtightness requirements in the New York construction context are as follows:

Details

Many Passivhaus projects use air barrier systems that are uncommon and poorly understood in the New York market. These products often result in the use of separate air barriers and vapor retarders (AVB). We chose instead to use combined AVB materials and techniques that are common to the local market. A list of example products is included in Appendix A. Enclosure details were developed to enable simple installation and clear sequencing. These details allow for blower door testing and remedial work at appropriate times.

The proposed details avoid the use of sealant joints as part of the continuous air barrier due to the tendency for sealant to fail over time. The details avoid uncommon air and vapor barrier tape products. Instead, typical sheet membrane products and their compatible system components are used.

Interior airtightness detailing for doors, partitions, junctions and interior penetrations is accounted for in the base case building to meet LEED requirements. Base case interior air-sealing details were developed referencing Steven Winter Associate's Air Sealing Guide for Multifamily Masonry Construction[18].

Miscellaneous Areas

A number of typical building components leak air, creating stack effect related infiltration and exfiltration within buildings, imbalance in the ventilation system and energy loss. Full implementation of Passivhaus air tightness measures can minimize these effects. The following were considered in the study:

Stack effect pressures are caused by differing interior and exterior air densities resulting mainly from interior & exterior temperature differentials and building height. These pressures act on enclosures and cause infiltration and exfiltration. It is common for these pressures to be in excess of the Passivhaus standard blower door test pressure of 50Pa. The effect of these pressures at building lobbies, operable windows and other enclosure openings must be considered. If unchecked, infiltration stack effect pressures can disrupt ventilation flows throughout buildings.

The Passivhaus design utilizes constant airflow regulating (CAR) dampers to restrict the amount of undesired air flow. This minimizes stack effect ventilation issues while allowing operable windows.

Building entrance doors must be as air tight as possible to minimize stack effect issues. Residential and commercial lobbies have high occupant and tenant traffic that cause doors to be opened many times per day. Open doors are a main point of stack effect infiltration from the exterior to elevator shafts and stairwells, and through the buildings. Vestibules are used to minimize air entry, however, vestibules are a partial measure even if well sealed as interior and exterior doors may be open at the same time. Revolving doors are often not considered appropriate for residential buildings. To isolate entry door related losses, the Passivhaus design isolates entry lobbies in separate ventilation zones with dedicated energy recovery ventilators.

Elevator shaft vents in large buildings were, but are no longer a ventilation challenge for Passivhaus. New York City Building Code used to require these vents to have 1/3 of the vent area permanently open. These openings caused large leaky gaps in envelopes. NYCECC 2011 and 2014 now require these vents to have motorized dampers tied to the fire alarm system to enable vents to be closed in normal operation and open in emergencies. Insulated motorized dampers with gasketed air seals are available to minimize losses. R-values of insulating dampers and thermal bridging performance of their frames fall below Passivhaus rule-of-thumb minimums, but the dampers can be used to achieve overall Passivhaus targets in large projects. Elevator shafts may also be designed without smoke vents by utilizing pressurization. This type of system provides fresh air to corridors and other spaces through the elevator shaft. This study did not pursue pressurization, but the strategy merits further investigation.

The Passivhaus design does not include elevator shafts and egress stairwells in ERV ventilation zones. Elevator doors and egress stair doors are not air-tight. It is thought that leakage between ventilation zones through these vertical pathways is minimized by balanced ventilation and reduced stack effect infiltration from high levels of enclosure and interior airtightness.

Trash chutes are large holes in the building envelope that cause air leakage. Chutes must be open at the top for ventilation, and open at the bottom to allow trash to

18 Steven Winter Associates, Inc. Undated. "Air Sealing Guide, Multifamily Masonry Construction".

fall. This study considers the trash room inside the Passivhaus boundary, but this choice has pros and cons. When inside the boundary, some ventilation air is lost up the chute, causing inefficiency and imbalance. This can be minimized with the use of well sealed trash room doors. Stack effects that drive chute ventilation are variable, and may slow or reverse in summer conditions. Additional study is required to clarify if fans or other devices to control losses through trash chutes are viable and allowed by code. If the trash room is considered outside the Passivhaus boundary, the entire chute shaft should be considered as an exterior wall that must be air-tight and insulated. Chute intake doors at residential floors are made to fit tightly to minimize odor propagation, but they are not air tight due to fire code restrictions that prohibit the use of gaskets. As a result ventilation losses occur whether the trash room and chute are considered interior or exterior.

Dryer vents represent potential sources of air leakage. This Passivhaus design did not change the base case building conventional dryer approach of dryers being ducted directly to the exterior with no air dampers. This conventional approach avoids problems such as fire caused by excessive lint build-up, but creates constant air leakage and imbalance in the ventilation system. The base case building has a centralized laundry facility on the amenity floor with dryer vents localized to one room, limiting imbalance and loss to one ERV. These losses were considered allowable in meeting overall Passivhaus targets. Another approach is to use condensing dryers that re-circulate air instead of venting air. This approach eliminates air leakage, but causes additional internal heat gain. Dryer venting air losses are magnified in Passivhaus buildings that have dryers in individual apartments.

Gas meter room vents cannot be sealed. Leakage through these vents may result in a large proportional loss in small buildings. However, the scale of the study building's large volume is able to offset losses through the gas meter vent.

The use of traps at roof drains may help reduce potential air or thermal losses associated with drain risers.

Specifications, Quality Assurance & Testing[19]

Quality assurance standards above and beyond typical construction are required to meet the Passivhaus airtightness requirement. Specifications should include detailed sequencing installation drawings, and detailed quality assurance criteria. Roles and responsibilities of each team member should be explicit so that there is no confusion about how airtightness goals are to be achieved. The architect, airtightness consultant, general contractor, exterior wall subcontractors, manufacturers, and others all have important roles in creating a successful airtight enclosure.

Specifications should call for the air barrier subcontractor to be accredited by the Air Barrier Association of America (ABAA), and call for implementation of the ABAA Quality Assurance Program[20] during construction. ABAA procedures may be challenging to implement due to a limited number of accredited subcontractors. At minimum, ABAA Quality Assurance requirements and checklists should be outlined in the project specifications. Checklists are required to be completed on a daily basis, and are reviewed by an ABAA accredited auditor. In addition, ABAA requirements mandate a minimum of three air barrier pull tests per 1000 ft^2 of enclosure.

The air barrier subcontractor should be required to provide submittals for all air barrier products, and shop drawings detailing air barrier systems and interfaces with adjacent materials.

A dedicated air barrier construction kick-off meeting with all related parties is highly recommended. The kick-off meeting includes a page turn to review all details, clarify any questions, and raise any concerns about installation sequencing.

Specifications should also require the general contractor to designate an individual from their team to be responsible for the overall airtightness of the project. This person should be responsible for ensuring ongoing inspections of the air barrier.

Product	Air (CFM / ft^2 @ 75 Pa)
Sheet membrane (similar to Henry Blueskin SA)	0.0001
Liquid applied membrane (similar to Henry Air-bloc 31MR)	0.0001

Table 3.9:
Air and Vapor Barrier performance.

19 The recommendations in this section were developed with the guidance of airtightness experts Terry Brennan of Camroden Associates and Colin Genge of Retrotec Energy Innovations.

20 ABAA (Air Barrier Association of America) Quality Assurance Program. https://www.airbarrier.org/qap/index_e.php

A third-party airtightness consultant should be engaged to help develop design details, and assist with on-site air barrier review. The consultant should provide site visits during construction for inspection and testing.

Increased presence of the architect is necessary to provide additional scrutiny during installation of the air barrier and construction of the enclosure. Full time site presence is recommended during this period. The owner should allocate a contingency for potential unforeseen conditions that may require additional design during construction. Additionally, education and training of builders and the use of mock-ups prior to construction provides greater assurance that the building will perform at its intended levels.

The project team, with assistance from the airtightness consultant, should develop an airtightness testing plan to be coordinated with the construction schedule. We recommend the following testing procedures for a project of this scale:

- Although the Passivhaus standard requires blower door testing at 50Pa, for tall buildings tests should ideally be done at 75Pa to more closely simulate wind, stack effect pressures and blower door testing bias pressures between the bottom and top of the building.
- Tests and third party inspections should be done when enclosure subcontractors are present and should be treated as an educational process. After attending a few inspections or tests, subcontractors and installers learn common failures and means and methods of construction to achieve the requirements.
- Interior airtightness testing: In order to achieve LEED certification, the base case building is required to undergo blower door testing of residential units for compliance with the LEED prerequisite for Environmental Tobacco Smoke Control. The tests must be carried out in accordance with ANSI/ASTM-E779-03, Standard Test Method for Determining Air Leakage Rate By Fan Pressurization[21]. A sampling of units must be tested per the progressive sampling methodology defined in Chapter 4 of the Residential Manual for Compliance with California's 2001 Energy Efficiency Standards. This testing regime is thought to result in adequate interior airtightness for Passivhaus balancing requirements.
- First enclosure test: requires isolating and testing a corner of the first floor when the air barrier is installed. This test can be done without windows if necessary by temporarily sealing window openings. The airtightness target of this first test should be 10-20% more stringent than the final target. The first floor often does not pass due to inadequate sealing of junctions at the ground floor slab or lot line wall. Early testing allows the construction team to take early corrective measures.
- Second enclosure test: requires testing a section when windows are installed. This can be the same section as the first test or another. This test should take place concurrently with window-sealing inspections . Additional enclosure areas to be tested at this time include a typical roof/wall connection, terrace connection, areas with canopies or overhangs, mechanical penetrations, soffits, and storefronts. Smoke or infrared tests are sufficient at this stage, blower doors are not required. It is important that inspection of these junctions take place prior to general blower door tests to ensure proper installation of air barrier.
- Third enclosure test(s): Involves isolating and testing four to five entire floors of the building with windows installed. The first floor and top floor are critical due to roof and slab junctions, which are typically the weakest areas. We also recommend testing floors that have atypical enclosure conditions such as the third and fourth floors with terrace, soffit and other unique junctions.
- Final enclosure test: One whole building blower door test should be sufficient if specifications, education, mocks-ups, quality assurance and previous tests were undertaken. A relatively small number of fans would be required for a project of this scale - we estimate four to six fans. Prior to carrying out the blower door test, the building should be prepared per the ABAA Standard Method for Building Enclosure Airtightness Compliance Testing. This method includes closing all exterior doors and windows, opening interior doors and elevator doors, opening or closing HVAC intakes as determined by Passivhaus requirements and establishing base case pressures.

21 ANSI/ASTM-E779-03 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization.

3.2. MEP DESIGN

Three MEP systems were considered in the study as described below.

Iteration 1: Air source heat pumps with integrated energy recovery
The first HVAC system considered an air-to-air heat pump that also has an integrated energy recovery system. This kind of system is commonly referred to as a "Magic Box" because it can provide ventilation, heating and cooling. Preliminary analysis showed promising results, however, it was determined that the system did not have enough cooling capacity to provide adequate thermal comfort levels at peak cooling periods in the humid New York City summer climate. These units were originally designed for colder climates, and are not currently equipped to address hot and humid climates on their own.

Iteration 2: Semi-centralized ventilation with supply air heating and cooling
The second HVAC system considered semi-centralized packaged energy recovery and heat recovery systems that were intended to provide heated and air conditioned air directly to the spaces. This system seemed promising by greatly reducing the energy consumption for reheating dehumidified air. However, the system was ultimately determined incapable of providing adequate cooling to keep conditioned spaces inside summertime thermal comfort thresholds.

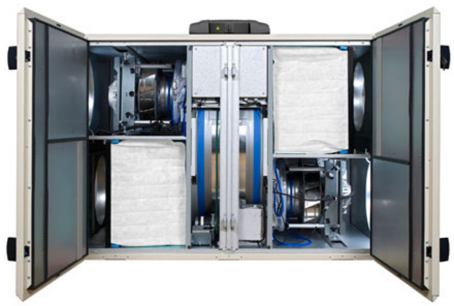
Passivhaus Design: Semi-centralized ventilation with optimized common systems
This approach was selected as the Passivhaus design. At first glance, the HVAC systems in the base case building design and Iteration 3 look nearly identical with the same components such as vertical fan coil units, water cooled chillers and condensing boilers. However, greatly reduced heating and cooling loads enable the HVAC equipment to operate at optimum efficiency and to be specified at reduced sizes.

3.2.1. Basic Mechanical System

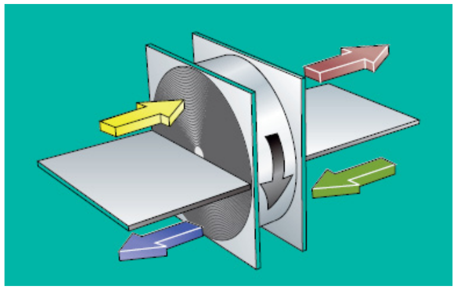
Ventilation
In the base case building design, energy recovery units are only specified to serve corridors. Fan coil units in apartments receive outside air directly through the exterior wall, with no energy recovery system. The Passivhaus design addresses this inefficiency by using Passivhaus certified energy recovery units with a minimum efficiency of 85%. These units serve not only the corridors, but also all apartments and amenity spaces. While this change adds supply air risers to serve residential units, it eliminates envelope inefficiencies caused by supply air openings in the enclosure.

Cooling
The cooling system in the base case design consists of electric water-cooled chillers. The total size of the chillers, which serve the residential and amenity spaces, is 1050 tons. The Passivhaus design also consists of chillers, but use high efficiency magnetic bearing compressors with Variable Frequency Drives (VFD). These have a coefficient of performance (COP) of 5.76 compared to the base case system's 4.70. The chillers are reduced in sizing to a total capacity of 400 tons.

Heating
With reduced envelope heating and cooling loads, fan coil units in the apartments are capable of providing adequate heating even with low hot water temperatures of 105F supply and 95F return. These



View inside a commercial scale energy recovery ventilator (ERV)



ERV rotary heat exchange

ERV Filter

Figure 3.18:
Various MEP components

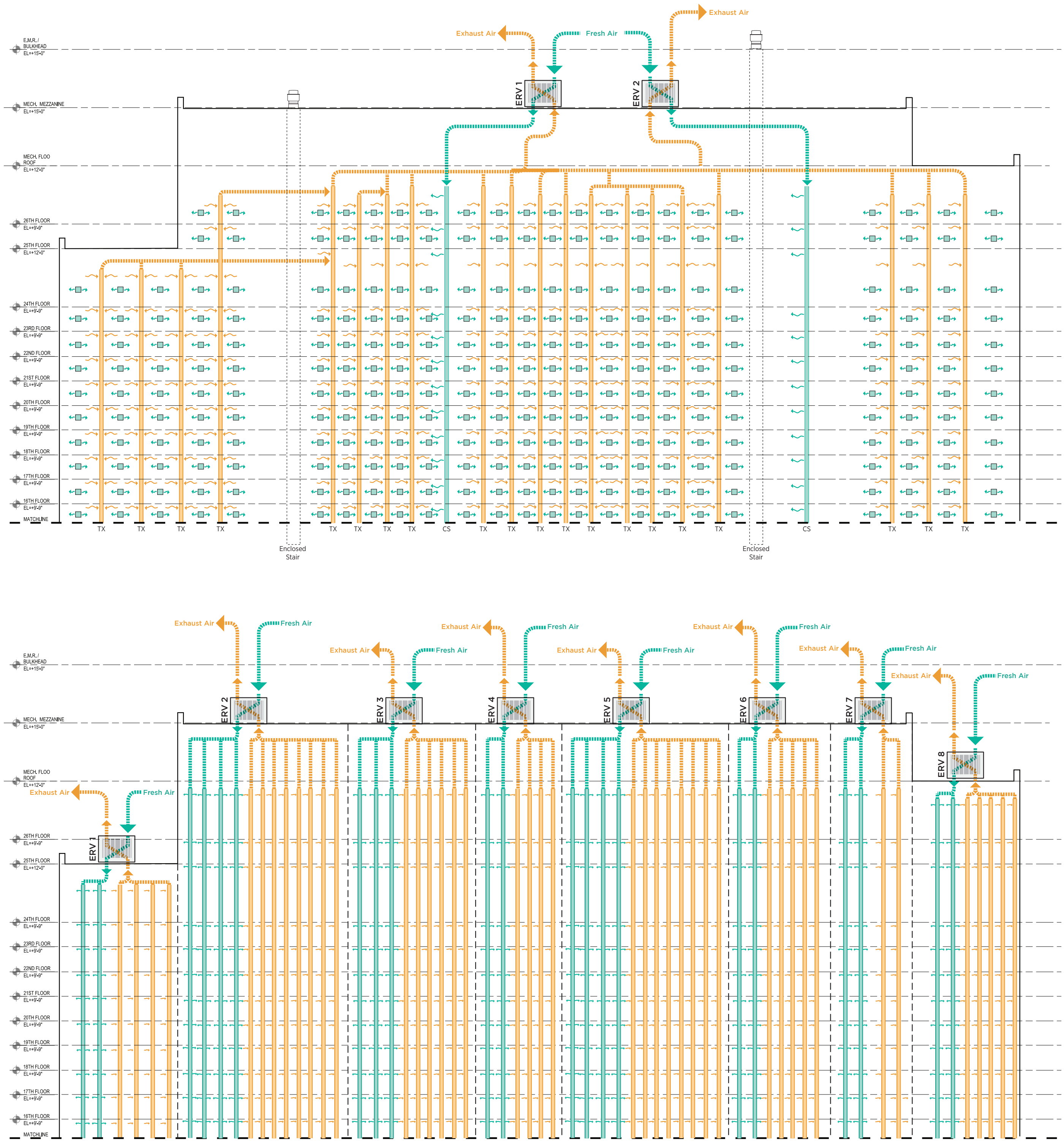
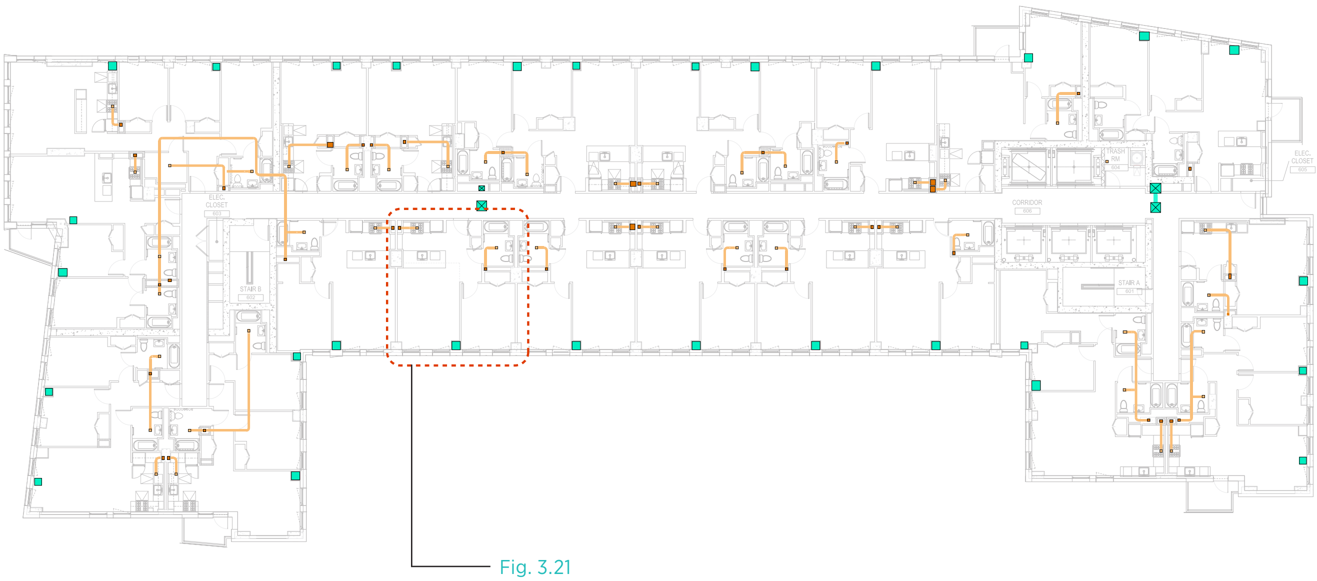


Figure 3.19:

Ventilation diagrams comparing base case building (top) and Passivhaus Design (bottom). The base case building uses 2 ERVs for corridor ventilation (supply air for apartments enters through the facade). The Passivhaus design uses 8 ERVs precondition all fresh air coming into residential units, corridors. Additional ERVs (not shown) include 1 for amenity spaces, 1 for lobby, 1 for cellar storage, 2 for mechanical rooms in cellar, and 1 for the bike room.



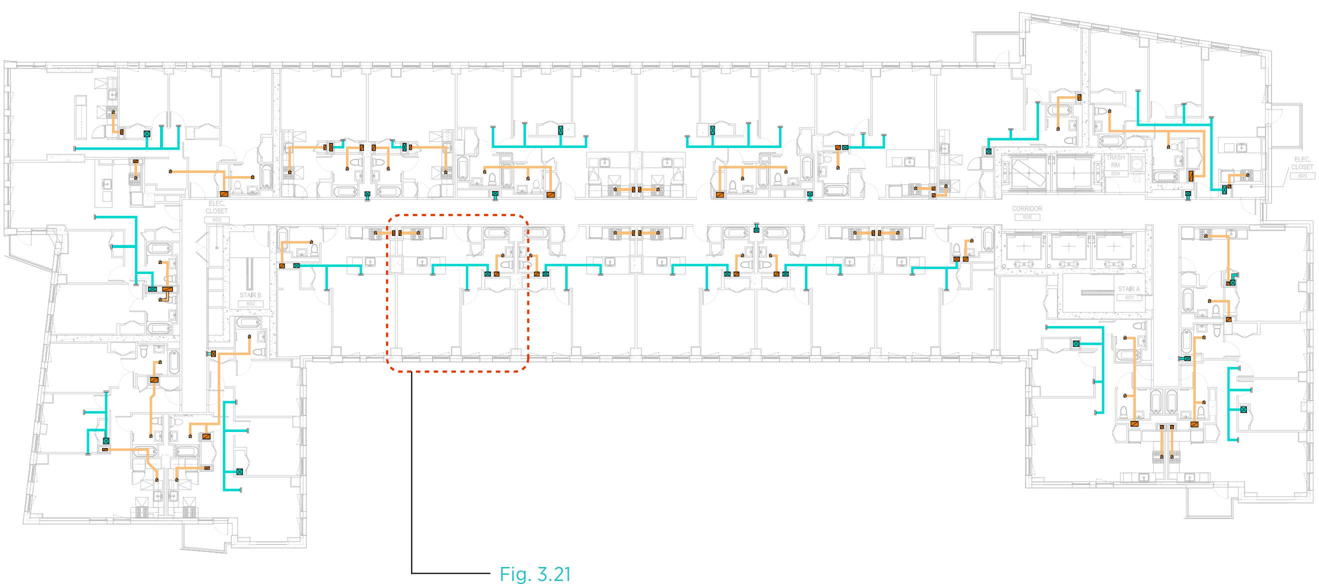
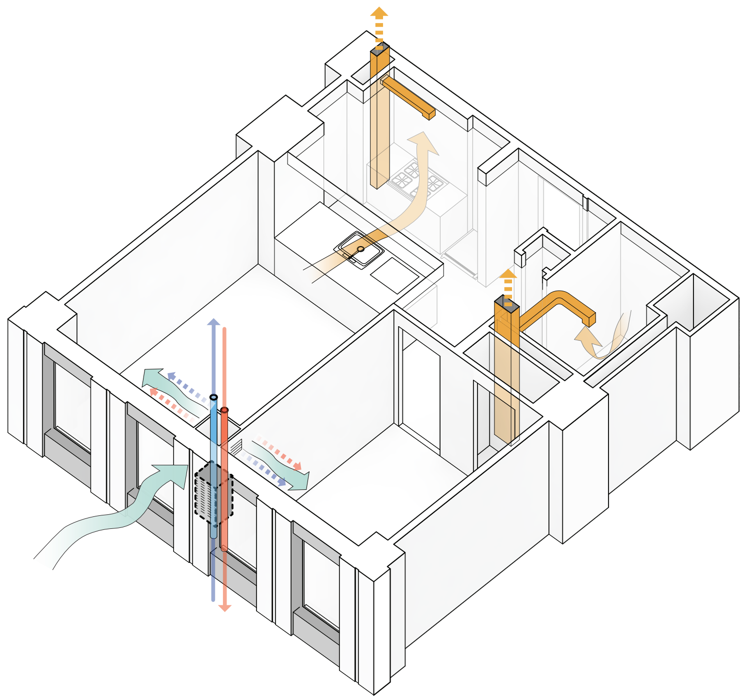


Figure 3.20:
Comparison of HVAC plan at typical residential floor - Base case Building (top) Passivhaus Proposal (below)



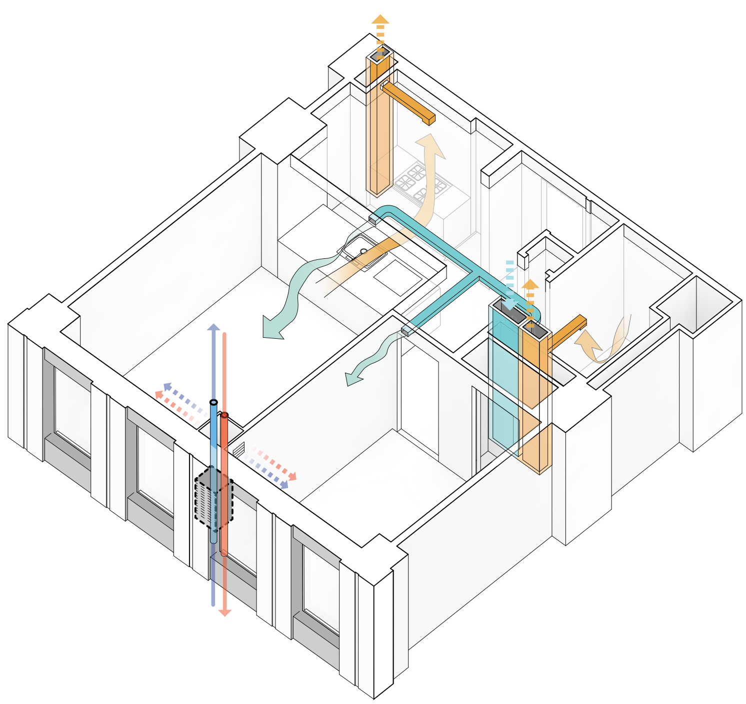


Figure 3.21:
Comparison of heating, cooling and ventilation in typical residential unit - Base case Building (top) Passivhaus Proposal (below)

low temperatures enable the condensing boilers to operate at an optimum efficiency of 94.5%, compared to the boilers in the base case design that operate at 85%. Total capacity of boilers is 3780 MBH (4000 MBH input rating), which are used exclusively for space heating

Domestic Hot Water
In the base case building, domestic hot water is provided by indirect water heaters that receive hot water from the boilers. However, as described in the preceding section, the heating load in the Passivhaus design is so low, that it can be fulfilled by hot water supplied at 105F, which allows the condensing boilers to operate at optimal efficiency. This low supply temperature is not sufficient for indirect water heaters. Instead, two separate 1432.5 MBH (1500 MBH input rating) natural gas condensing water heaters are provided in the Passivhaus design.

3.2.2. Ventilation System

Residential & Corridor
The Passivhaus design includes eight roof mounted energy recovery units that form a semi centralized system to provide ventilation to all residential units and corridors. The units have a very high energy recovery rate of 85% or greater and are Passivhaus certified. Each bathroom is ventilated at 25 CFM, each kitchen at 10 CFM and each living space receives at least 0.35 air changes of outside air per hour.

Each energy recovery unit is equipped with one combination hot water / chilled water coil installed on the main supply duct coming from the unit. Under peak conditions, the leaving supply air temperature from the unit is 79F during cooling season and 60F during heating season. The hot water / chilled water coil at every energy recovery unit will ensure that outside air provided to the rooms is supplied at room neutral temperatures of 77F during the cooling season and 68F during the heating season.

Amenity and Basement Mechanical Rooms: Dedicated Passivhaus certified energy recovery units are designed to ventilate the amenity and basement mechanical spaces per New York City mechanical code requirements.

Retail

Spaces for installation of future energy recovery units are provided. Tenants must be required to provide similar ventilation units as those for residential spaces. Retail spaces are to be ventilated per New York City mechanical code requirements.

Air Quality

All ERVs are designed to be equipped with MERV 13 filters to provide filtered outside air to all occupied spaces in the building. MERV 13 filters have an efficiency range of 80-85%, and exceed the outdoor air treatment requirements of ASHRAE 62.1 (Ventilation for Acceptable Indoor Air Quality), even for Fine Particulate Matter (PM2.5). The level of filtration is generally considered to be high for residential applications.

100% outside air is used for ventilation. Each apartment is ventilated at a minimum rate of 0.35 ACH. A typical 1 bedroom apartment is ventilated at 35 CFM, an increase of 5 CFM in comparison with the base case. Apartment exhaust is located at kitchens and bathrooms to remove contaminants immediately.

Gas fired appliances in the base case design have been replaced with electric appliances in the Passivhaus design, further improving air quality.

3.2.3. Heating and Cooling Systems

In the course of exploring options for HVAC systems to enable us to reach Passive House targets, the building design was taken into consideration and an effort was made to select an HVAC system that would result in minimal changes to the building envelope and layout. Hence, the HVAC system, at its core, remained as a two-pipe fan coil unit system, similar to the base-case building. The ventilation system was also designed as a centralized system to re-use the shafts for toilet and kitchen exhaust in the base-case building. If the building was designed from scratch, then alternative heating and cooling systems that would have been even more energy efficient, or cost-effective, or both, such as Variable Refrigerant Flow (VRF) could have been considered. Similarly, an alternative ventilation system, such as a decentralized system consisting of individual ERVs for every apartment, could have been considered.

Central Plant

The Passivhaus design central plant consists of two water-cooled chillers, each rated at 200 tons and two hot water condensing boilers, each rated at 2000 MBH. The chillers are served by a 400 ton cooling tower. There is an additional cooling tower, rated at 400 tons to exclusively serve the retail spaces, with the capability for winter operation.

The chillers & boilers are connected to a dual temperature water loop with a switch-over system that will circulate chilled water during cooling season and hot water during heating season. Chilled water is supplied at 43F and returned at 55F, while hot water is supplied at 105F and returned at 95F. There are two dedicated condenser water pumps

Design Conditions

Season / Condition	Summer	Winter
Indoor	77F, 50% RH	68F
Outdoor	92F dry bulb, 74F wet bulb	13F dry bulb, 10.6F wet bulb

Table 3.10:
Design temperature table.

Apartment / Corridor ERV Schedule

Service	Quantity	Supply/Return Airflow Rate (CFM)	Efficiency
Apartments	3	2800	86.0%
Apartments	1	3000	85.5%
Apartments	2	3300	86.5%
Apartments	1	3600	86.5%
Corridor	1	3800	86.3%

Table 3.11:
ERV Schedule

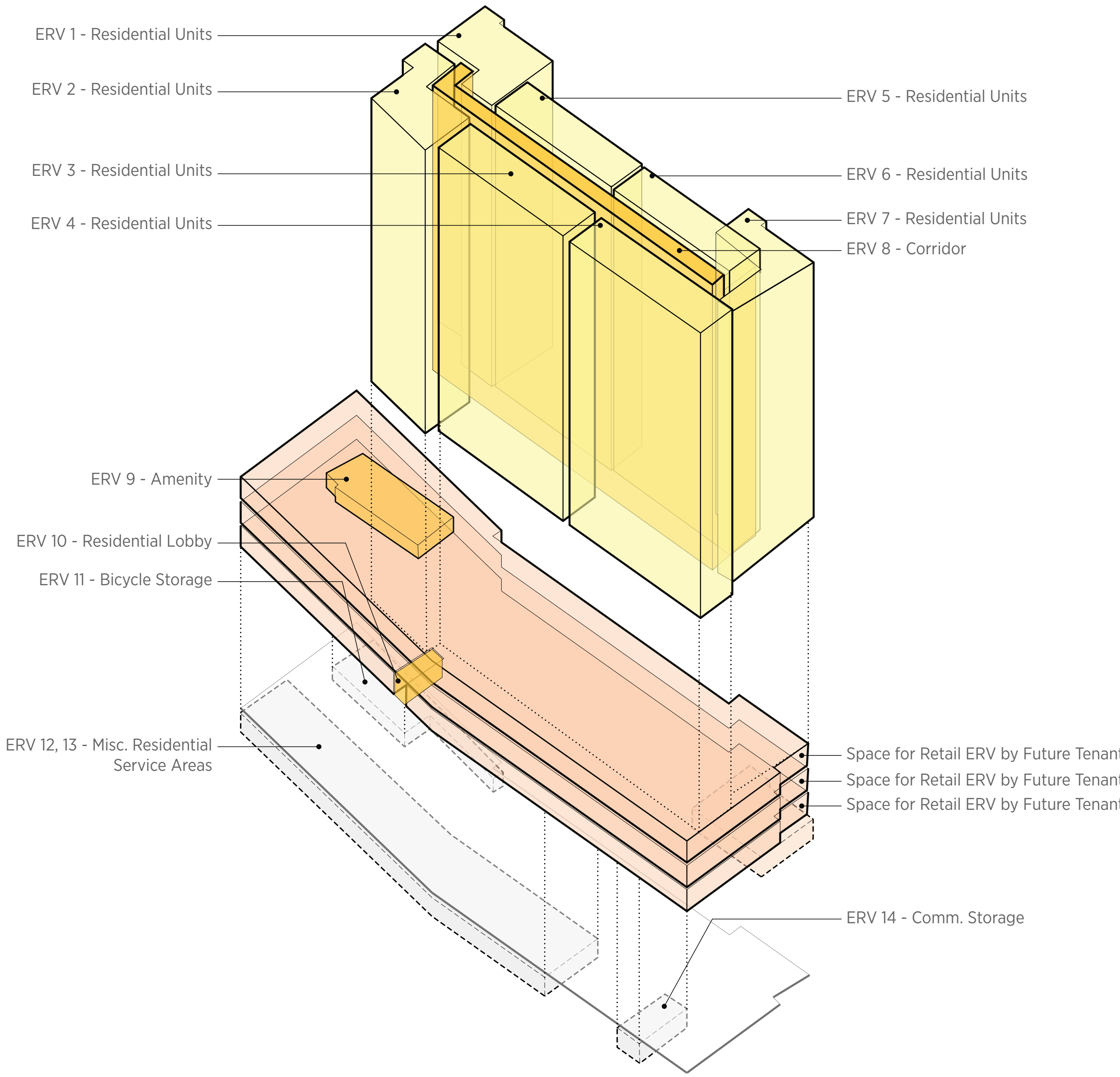


Figure 3.22:
Ventilation Zone Diagram

Figure 3.23a:
Base case Building - Composite roof plan (top) and Mechanical Mezzanine (below)

for the residential cooling tower and two dual temperature water system pumps. Additionally, each chiller and each boiler has dedicated circulation pumps.

The retail cooling tower has two dedicated primary condenser water pumps and two secondary condenser water pumps to circulate condenser water to the retail spaces. There are two hot water pumps to circulate hot water to the retail spaces.

With solar heat gain through windows, internal heat gains from occupants and equipment, and the low heat loss through the envelope, there is a possibility for some spaces to require cooling during winter season, while most other spaces require heating. For instance, at a particular time, spaces with south-facing windows may need cooling due to solar heat gain, while the remainder of the building requires heating. For this study, an analysis has not been performed to determine if this scenario is applicable, and if so, for what periods of the heating season. Assuming that such situations do occur, it presents a complication for the fan coil system loop, since it is a 2-pipe system and can only circulate hot water or chilled water at any given time. It can be resolved by zoning or subdividing the dual temperature water loop for fan coil units based on orientation, providing controls that ensure that every space receives heating or cooling as required by circulating hot water or chilled water. A hot water reset schedule based on outdoor air temperature will ensure that the appropriate level of heating is provided to all spaces during shoulder season as required. For situations when there is high occupancy in one or a few residential units due to gatherings or events, the operable windows can always be opened as required to obtain the necessary cooling or heating and ventilation.

Pipe insulation thickness is assumed to be double the nominal diameter of each pipe, using foil faced insulation with an 'R per Inch' of 4 hr.ft^2.F/Btu.in.

Residential
Heating & cooling in all residential units is provided by ductless, vertical fan coil units located at the perimeter of the building that will connect to the dual temperature water loop.

Corridor
The corridors will not have supplemental heating and cooling, since the ventilation

Figure 3.23b:
Passivhaus Proposal - Composite roof plan (top) and Mechanical Mezzanine (below). Note: Two ERVs are not shown - one ERV serving the lobby is located in the package room, and one serving the commercial storage space is located in the ceiling of that room.

system is capable of providing tempered outside air.

Amenity
All amenity spaces including lobbies are served by two-pipe, horizontal fan coil units that connect to the dual temperature water loop.

Retail
Capped connections of condenser water and hot water are provided to retail spaces to service future HVAC units to be installed by retail tenants.

Mechanical Spaces
Hot water unit heaters will protect the boiler room from freezing conditions, maintaining temperature of 55F in the space. ERVs with hot water duct heating coils will supply tempered outside air during the heating season (68F) to mechanical & storage spaces in the cellar. The mechanical spaces are not cooled.

3.2.4. Domestic Hot Water System

Domestic hot water is provided by four direct fired, condensing, storage type water heaters, each with input capacity of 750 MBH.

The building is served by two booster pumps, each rated at 50 HP.

3.2.5. Lighting

Lighting in residential units typically consists of installed fixtures in the kitchen, hallway and bathroom areas, and receptacle outlets for plug-in lighting in the living/dining rooms and bedrooms. This was modeled as achieving a luminance of 20 foot candles (FC) equating to a maximum lighting power density of 0.28 W/ft^2. Installed lighting in retail spaces was modeled at a luminance of 60 FC equating to a maximum lighting power density of 0.83 W/ft^2. The lighting values used for both residential and retail spaces have been kept the same between base case design and Passivhaus design for this study.

3.2.6 Receptacle Loads

Similar to lighting, receptacle loads are also the same between base case design and Passivhaus design. Residential spaces are assigned 0.5 W/ft^2, while retail spaces have 1.35 W/ft^2.

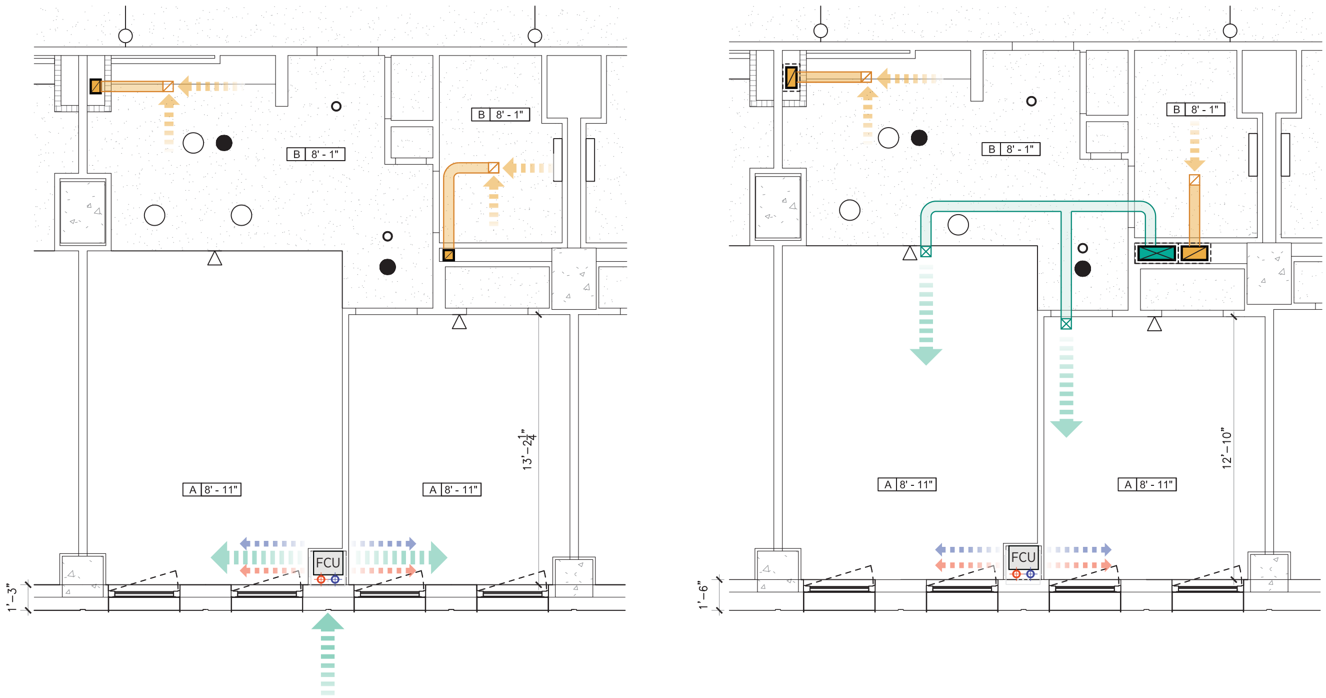


Figure 3.24:
Reflected ceiling plan of typical residential unit in Base case Building (left) and Passivhaus Proposal (right) indicating modifications due to increased exterior wall thickness and larger HVAC shaft.

3.3. IMPACT OF PASSIVHAUS MODIFICATIONS ON BUILDING AREA AND HEIGHT

3.3.1. Enclosure Changes

The Passivhaus design required thicker exterior walls for improved thermal performance. In comparison with the base case building, the exterior walls of the residential tower (floors 4-26) were 3" thicker, and exterior walls of the retail base (floors 1-3) were 1 1/2" thicker. The additional wall depth required minor modifications to floor plans. Base case building interior layouts and usable floor areas were largely preserved. In the residential tower, the additional wall thickness was added by expanding walls either to the exterior when zoning permitted or interior where interior spaces could accommodate the additional wall thickness. See Figure 3.25 for a diagram of plan changes on a typical residential floor. In the retail base, all base case building exterior walls were initially designed to the extents of the zoning envelope. Thus, all exterior walls on these floors had to expand inward in the Passivhaus design.

3.3.2. MEP System Changes - Ventilation supply and return

Vertical shafts in the architectural plan had to expand to accommodate the Passivhaus mechanical design. Ventilation for apartments in the base case design relied on supply air openings in the façade at the fan coil units, with vertical exhaust ducts in the shaft spaces. In the Passivhaus design, both supply and exhaust air is provided through risers to the roof. Through-façade openings are eliminated. Approximately 5 ft^2 of area per unit was taken by new shaft space. Additionally, 2" of insulation was applied to vertical exhaust ducts where the base case design had no insulation on exhaust ducts.

3.3.3. Building Height

The proposed Passivhaus roof assembly includes an additional 2" of insulation over the base case building roof assembly. The roof assembly occurs at four floors: the 4th floor, 5th floor, 25th floor and roof. The additional 2" of insulation over four floors could have increased the height of the building by a maximum of 8", however the base case provided increased floor-to-floor heights at those floors to accommodate roof drains and other atypical conditions in an enlarged ceiling cavity. Therefore, it is assumed that the additional 2" of insulation can be accommodated by dropping the slab 2" into the oversized ceiling cavity.

3.3.4. Areas and Zoning Deductions

Over the entire building, gross area increased by 3,863ft^2 (0.69%), net (usable) area decreased by 1,493 ft^2 (-0.30%), and zoning floor area decreased by 900ft^2 (-0.18%). See Table 3.12.

New York City Zone Green deductions were also calculated for the added insulation. This results in an additional bonus of 2,640ft^2 of zoning floor area. Zone Green deductions are further elaborated in Section 4.5.

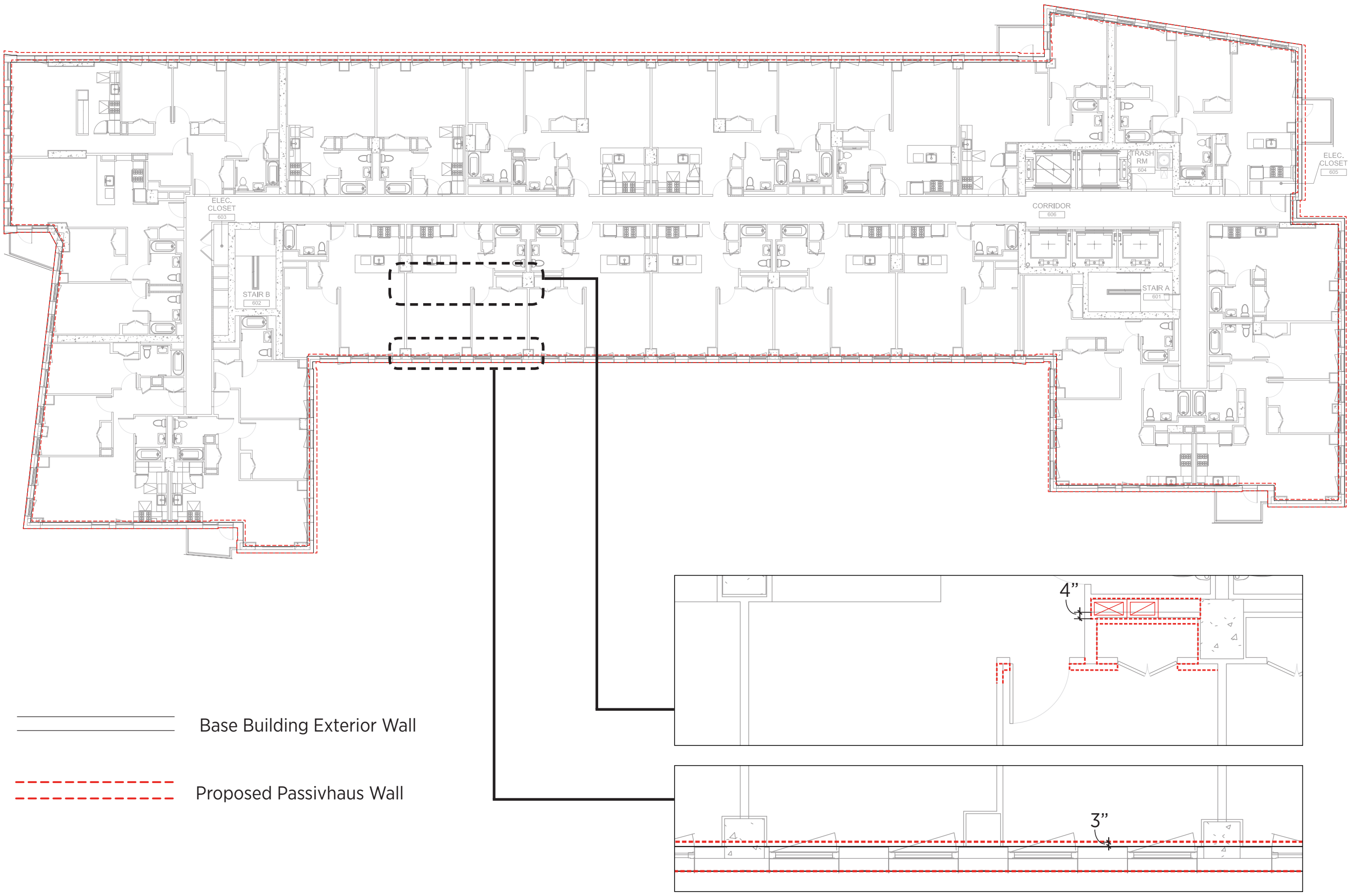


Figure 3.25:
Typical floor plan change diagram.

Building Areas	Gross Floor Area	Usable Floor Area	Zoning Floor Area	Zone Green Deduction	Net Zoning Floor Area
Base Case Building	556,752 ft^2	515,656 ft^2	494,046 ft^2	11,723 ft^2	482,323 ft^2
Passivhaus Design	560,615 ft^2	514,163 ft^2	493,146 ft^2	13,463 ft^2	479,683 ft^2
Difference (PH-BB)	3,863 ft^2	-1,493 ft^2	-900 ft^2	1,740 ft^2	-2,640 ft^2

*Areas calculated for zoning do not include cellar spaces

Table 3.12:
Floor area comparison between Base case Building and Passivhaus Proposal.

SECTION 4

EVALUATION OF THE PASSIVHAUS DESIGN

4.1. PERFORMANCE

From the summary of results in Table 4.1, it can be seen that the proposed building design is fully compliant with Passivhaus certification requirements. In order to achieve this, the building enclosure performance was improved significantly over the base case. Mechanical design was simplified from the base case due to greatly reduced heating load and demand in winter and reduced cooling load and demand in summer.

Given the mixed New York climate and the compact nature of the base case building, a balanced design strategy was needed to simultaneously manage both the winter and summer comfort experience. For this specific building, cooling demand is slightly more dominant than heating demand which is unusual for New York City residential buildings. This is due to the overall energy demand for heating being substantially reduced as a result of the higher performance of the envelope. Passive internal and solar heat gains are proportionally more significant due to the apartment density and un-optimized window distribution in the building. As a result, the annual sensible and latent cooling demand energy consumption exceeds the annual heating demand despite the shorter cooling and dehumidifiction season. Both heating and cooling demand values are comfortably below the Passivhaus thresholds, 60% and 86% of the respective limits. The total primary energy demand was ultimately the driving force of the design, ending up at 99% of the limit.

In comparison with the base case design, the Passivhaus design reduced primary energy by 47%. Heating demand improved by 85%

Passivhaus Design

	PHPP Result		PH Requirement	Fulfilled?
Heating Demand	2.86 kBtu/(ft^2yr)	60% of	4.75 kBtu/(ft^2yr)	Yes
Heating Load	2.34 Btu/(ft^2hr)	74% of	3.17 Btu/(ft^2hr)	Yes
Cooling Demand	4.65 kBtu/(ft^2yr)	87% of	5.39 kBtu/(ft^2yr)	Yes
Cooling Load	2.67 Btu/(ft^2hr)	84% of	3.17 Btu/(ft^2hr)	Yes
Primary Energy*	37.7 kBtu/(ft^2yr)	99% of	38.0 kBtu/(ft^2yr)	Yes
Airtightness**	0.036 cfm/ft^2	-	0.036 cfm/ft^2	Yes
Passivhaus?				**Yes**

*Primary energy includes heating, cooling, dehumidification, DHW, auxiliary electricity, lighting, and electrical appliances.

**Pressurization test result n_{50}

Table 4.1:
Passivhaus Design PHPP Results

with a 77% improvement on heating load. Cooling demand improved by 40% with a 37% improvement on cooling load. (Figure 4.1)

It should be noted that there are a number of conservative assumptions built into the PHPP model, including overestimates on thermal bridge loss factors, for both point and linear bridging, and underestimates on insulation R-values. Some safety factors have also been incorporated into the mechanical design to account for inevitable unforeseen challenges and alterations that arise during the construction process. This is a best practice procedure in Passivhaus design.

4.2. ARCHITECTURAL ANALYSIS

This study demonstrates that the base case building can be re-designed to meet the Passivhaus standards with very few aesthetic changes. Aesthetic changes include the following, which are virtually imperceptible and retain the overall design intent of the original building:

- Increased exterior wall thickness to enable additional insulation;
- Slightly repositioned windows within wall assemblies to align window thermal breaks with insulation;
- Nominally wider window frame thicknesses per Passivhaus certified products;
- Framed entry doors in lieu of all glass entry doors to achieve sufficient thermal and airtightness performance.

The Passivhaus design utilized the base case building window to wall ratio of 36%. This result dispels a misperception that

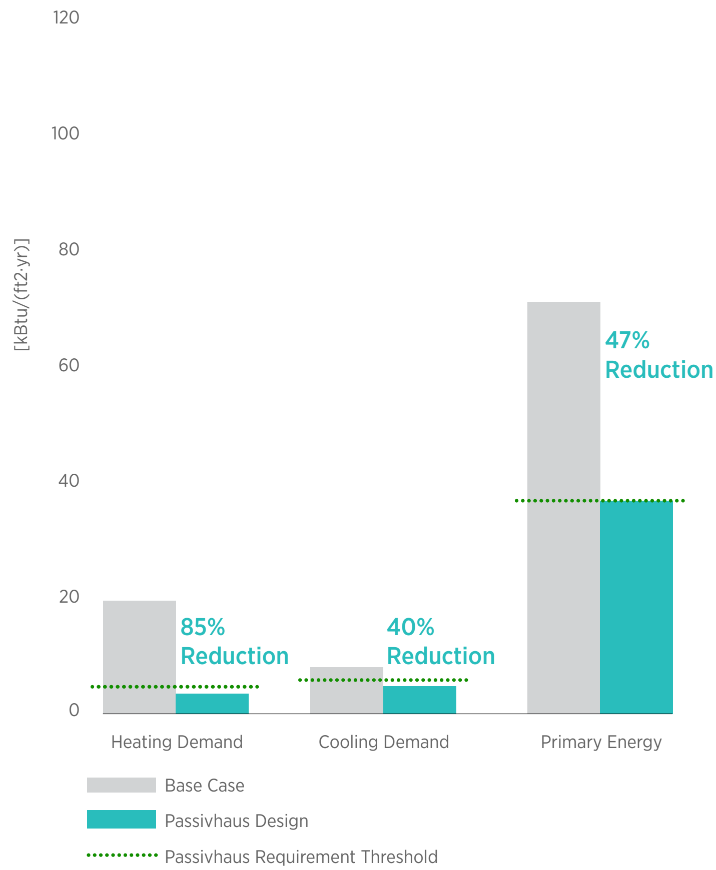


Figure 4.1:
PHPP results comparing base case building and Passivhaus Design.

Passivhaus buildings lack sufficient glazing for views or daylight. Further, this study suggests that optimal building orientation, window exposure, and the addition of shading devices may allow Passivhaus buildings at the scale of the base case building to achieve even better performance with the same glazing ratio, or have higher glazing ratios.

Architectural changes in the Passivhaus design mostly occur at the level of details and specifications. Better thermal comfort and acoustics are achieved through improved air tightness, reduced thermal bridging, additional insulation, and triple-glazed insulated windows.

4.3. MEP ANALYSIS

Reduced building heating and cooling loads allow the Passivhaus MEP design to utilize smaller equipment sizes and thereby lower equipment costs. These reduced loads also allowed central equipment such as boilers to be right-sized to operate at optimum efficiency. The study did not resize the mechanical penthouse to match reduced equipment sizes, but there is potential to reduce the mechanical penthouse size. Reduced mechanical penthouse area may save construction costs and allow for additional rooftop amenity space.

Improved fresh air delivery is a successful aspect of the Passivhaus design. The base case building ventilation system utilized fresh air intakes through the façade at every apartment at single filter fan coil units. This approach distributed supply air all around the building, exposing apartments to variable air quality. Maintenance of the base case building system is difficult due to the amount of fans and filters and their distribution. The Passivhaus ventilation system is simplified through the use of ducted, double-filtered 100% fresh air from centralized rooftop equipment to every area of the building. This approach allows consistent air quality, better filtration and simplified maintenance of a small number of centralized fans and filters. Aerosealing of duct air risers and use of CAR dampers ensure all apartments on every floor each receive the correct amount of ventilation air needed.

Since heating, cooling and ventilation is provided by a centralized system, the owner is responsible for their operating costs. Each tenant is responsible for electrical power consumption related to lighting, appliances, receptacle equipment and fan motors in the fan coil units in their apartment. The owner can choose to allocate the costs of heating and cooling to the tenants by either charging tenants (based on size of apartment and number of fan coil units) or using BTU meters in the heating & cooling distribution piping. Apartment ventilation rates are constant, so costs related to ventilation can be allocated as a proportion of the amount of ventilation air provided to the apartment.

4.4. RESILIENCY AND SECURITY

Resiliency

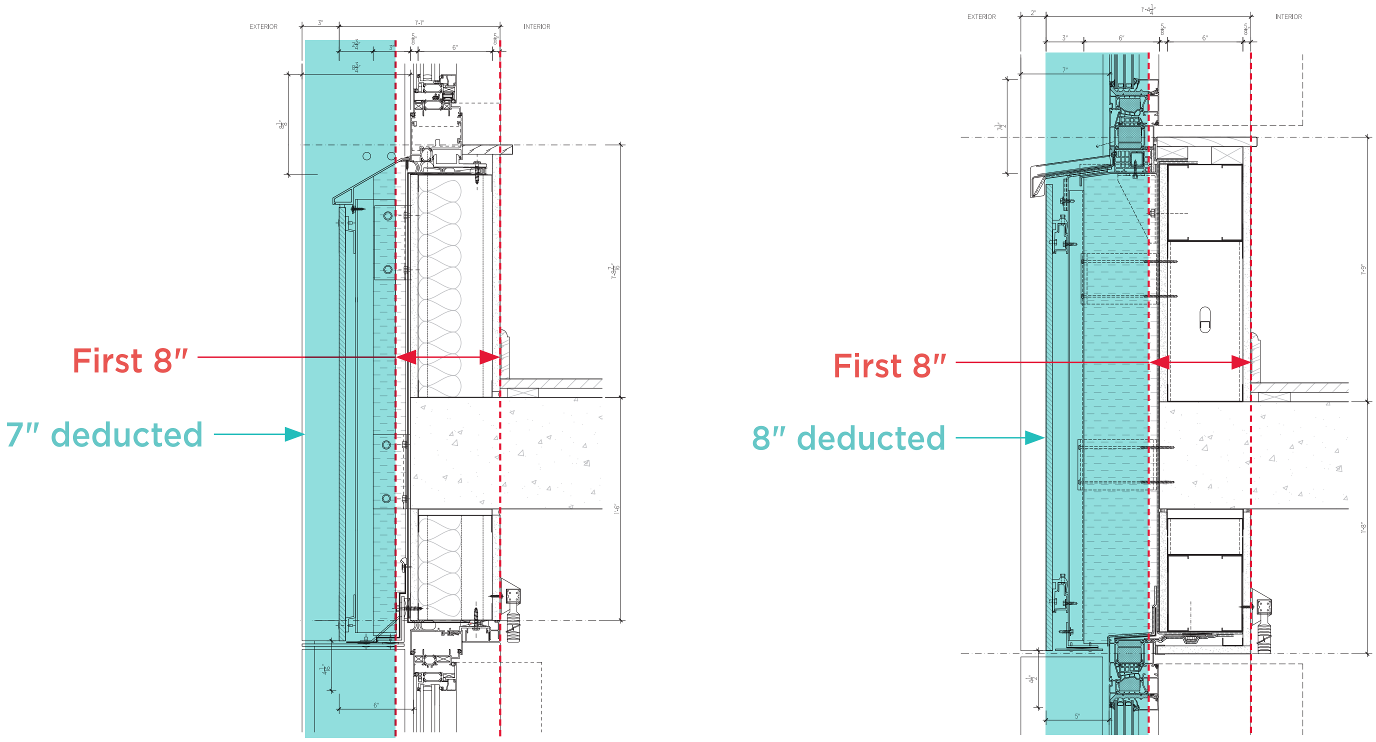
The Passivhaus design will improve overall building resiliency. Increased insulation, Passivhaus certified windows and significantly improved air tightness will enable the building to remain comfortable to residents for a longer period during a power outage. Increased air tightness will also improve durability of the exterior wall and interior finishes by reducing moisture penetration and condensation risk.

The emergency generator in the base case building provides sufficient power to run all energy recovery ventilators in addition to all emergency loads as required by code. This means that continuous ventilation can be provided. Due to the high energy recovery rates of these units, the supply air temperatures even at peak heating and cooling conditions will provide reasonable thermal comfort levels in the apartments during a power outage.

Due to the R-2 occupancy of the building, either a gas generator or fuel oil generator can be installed. With a gas generator, provided gas service is not interrupted, the generator is capable of providing power for as long as needed, and also does not require additional equipment such as a storage tank and transfer pump that a fuel oil generator requires. There is also the potential for using a cogeneration system to address the domestic hot water load of the building, while also being capable of providing emergency power.

Security

Given that there are relatively small changes to the overall building design, security is minimally impacted. Improved windows and elimination of air intakes on the facade provide greater integrity and continuity of the exterior wall, which could be perceived as a security benefit. Per the base case building, all major MEP equipment is installed in the mechanical room on the upper most floor, with access available only to building maintenance staff.



Base Case Building

Passivhaus Design

Figure 4.2:
Changes in thickness of main enclosure assembly between Base Case and Passivhaus Design - lightweight rainscreen

4.5. ZONING IMPACT

The Passivhaus design results in a small increase in overall gross floor area, and small reductions in usable floor area and zoning floor area. If the New York City Zone Green[22] amendment is applied, an increase of 2,640 ft^2 of allowable zoning floor area results. A summary of the area changes of the base case compared to the Passivhaus design can be found in Table 3.11 on page 67.

The Zone Green amendment allows for a deduction of up to eight inches of the exterior wall beyond the first eight inches if the overall solid wall portion of the envelope has a U-value that is at least 20% better than the New York City Energy Conservation Code (NYECC) minimum of R—15.625 (U-value 0.064), and if the aggregate U-value of the entire envelope including windows is at least 10% better than code. The base case building exterior wall is already able to benefit from Zone Green with a deduction of seven inches, and a total deduction of 11,723 ft^2. The Passivhaus design was able to deduct the maximum of eight inches resulting in a total deduction of 13,528 ft^2. This is roughly equivalent to 3/4 of the total gross floor area of one residential floor.

Although the Passivhaus design improves the U-values of the wall by 66% and the glazing by more than 200% above code requirements, only one additional inch can be deducted due to the eight inch limit. Given that the improvements in the Passivhaus design are significantly beyond the 20% and 10% thresholds, we recommend that future iterations of Zone Green allow for incremental increases in deductions for exterior walls in accordance with overall improvements from the NYECC base case.

22 New York City Department of City Planning. 2012. “Zone Green Text Amendment”. Retrieved from http://www1.nyc.gov/assets/planning/download/pdf/plans/zone-green/zone_green.pdf

4.6 REGULATIONS

Building Code

Both the Passivhaus standard and the NYC Energy Conservation Code share the common goal of making buildings more energy efficient. However, Passivhaus targets a much higher level of efficiency than code. Generally, NYC Building Code requirements do not create a conflict with Passivhaus. However, in some cases code requirements cause challenges to achieving Passivhaus targets.

Passivhaus energy targets require ventilation rates that are lower than code, NYC Department of Housing, Preservation and Development requirements, and other sustainable standards. Even with the reduced ventilation rates introduced in the 2014 NYC Mechanical Code, there is a challenge meeting Passivhaus targets. High rates stipulated in the code improve indoor air quality, but they also increase energy consumption to heat or cool outside air.

The code requires 25 CFM of continuous airflow for kitchen exhaust. It should be noted that even though the apartment kitchens do not meet the code's stipulated exhaust airflow rate for mechanical ventilation, apartment kitchens are within 30 feet of adequate operable windows. As such, they meet code requirements for natural ventilation. Mechanical ventilation of kitchens is a Passivhaus requirement, which is why such a system has been designed for this building. The 10 CFM exhaust airflow rate meets the Passivhaus requirement for kitchen ventilation.

NYC code prohibits toilet exhaust systems from being connected to other exhaust systems in the building. The intent of this requirement is primarily to avoid cross contamination, but this results in lost energy recovery and unbalanced ventilation. The ventilation system utilized in the Passivhaus design includes energy recovery units that recover return air from all spaces in the apartments including toilets. This is done by segregating kitchen and bathroom exhaust in separate ducts, then combining them just before the ERV. Cross contamination is avoided because combined exhaust does not pass by any apartment return air openings. A variance has been obtained from DOB for The House at Cornell Tech that considers such a system to be acceptable[23]. We believe similar variances can be obtained for future Passivhaus buildings.

Passivhaus buildings have several aspects of MEP design that are different from typical new construction. Very high energy efficiency targets require more efficient MEP equipment and lighting than base case NYC energy code requirements. Set point temperatures are 77F and 68F for cooling and heating respectively. These vary from the typical standards of 75F and 70F, but they still fall within the limits of 78F and 68F for habitable spaces in NYC Building Code.

Passivhaus also focuses on certain important aspects of building construction that the building code currently does not address adequately. One such aspect is envelope leakage and airtightness. Airtightness requirements are more than 10 times more stringent in Passivhaus than in the NYC Building Code. Blower door testing is required to ensure Passivhaus compliance while it is only required by code for buildings under 50,000ft^2. Wall and roof penetrations of ducts and pipes require a greater level of sealing. Sealing of duct systems is required to prevent leakage. Passivhaus building envelope and window insulation values are significantly higher than current energy code requirements. Passivhaus takes thermal bridge degradation factors into account, which are not explicitly in the NYC Energy Conservation Code.

Figure 4.3:
Alternate thermally broken rainscreen clip - GREENGIRT.

Building code fire-safety requirements have some impact on the Passivhaus design. All enclosure materials must comply with NFPA 285 requirements. All materials in the proposed design comply including the rainscreen fiberglass clips, however, some alternate european products may not comply. Also, fire dampers are required for the additional supply air ducts to the residential units and corridors to meet code requirements.

Accessibility

The Passivhaus design maintains accessibility as designed in the base case building. However, Passivhaus door requirements pose accessibility challenges. Passivhaus doors generally require high thermal and air-tightness performance,

23 Luke Falk, Deborah Moelis, Lois Arena 2015. "The World's Largest Passive House Building". Presentation at Greenbuild 2015.

which require heavy triple glazing, tall door sills and multi-stage gaskets. Heavy triple glazed door weights cause difficulty in meeting maximum opening pressure requirements. Tall door sills conflict with maximum accessibility roll-over heights. It is our understanding that there are no Certified Passivhaus doors that meet US accessibility requirements, especially for commercial applications.

The Passivhaus design provides non-Passivhaus Certified accessible entrance, service and egress doors. Since these doors are not in residential living spaces, and the energy model could acommodate their lower performance, Passivhaus interior comfort requirements could be slightly relaxed.

Apartment balcony doors have a large influence on comfort requirements for living spaces. As such, Passivhaus certified products are important for maintaining comfortable radiant temperature differentials, to avoid drafts, and to achieve balanced ventilation. Accessibility requirements were fulfilled in the Passivhaus design through an exception that allows step-over conditions at door sills due to the difficulty of waterproofing sills at solid concrete balconies. The trade off between performance and accessibility can be overcome through design and engineering and development of Passivhaus certified accessible doors should be encouraged.

Multiple Dwelling Law and HPD Standards for subsidized units

The Passivhaus design generally complies with New York's Multiple Dwelling Law. The design heating set point of 68F meets the 68F requirement for habitable spaces. Ventilation and window requirements for kitchens should comply with the Passivhaus design given that they are open to the ventilated living rooms. Ventilation requirements for the largest bathrooms may pose conflicts with the Passivhaus design and may in some cases require the ceiling to be lowered marginally to meet the air change/ hour (ACH) thresholds. All other MEP requirements, such as plumbing & drainage systems, smoke control devices and fire protection systems do not pose a conflict for the Passivhaus design. Room size requirements are also compatible with the Passivhaus design.

The Passivhaus design meets HPD Standards for room sizes, but is at the threshold for minimum room areas due to the increased depth of the exterior wall. Further high-rise Passivhaus projects should be cautious by establishing estimated exterior wall dimensions before developing the unit layouts.

The ventilation rate required by HPD in apartment kitchens is 5 ACH per ASHRAE 62.2-2007, but the Passivhaus design targets 10 CFM. At 5 ACH for a typical kitchen, required exhaust would be 60 to 70 CFM (cubic feet per minute), which may pose an issue in meeting Passivhaus targets. In this instance, we recommend requesting a variance from HPD, similar to the DOB ventilation code variance described earlier. There are no conflicts for all other HPD requirements.

4.7. CONSTRUCTION ANALYSIS

The research team was unable to secure a large scale contractor to analyze construction means and methods for the study. Until very recently, large scale contractors have generally been absent from the advancement of Passivhaus in the New York City area. Reasons for this are unclear. Builders may be preoccupied with current projects in the booming New York City construction market, they may perceive it to be too expensive to implement, or they may see no strategic benefit of being knowledgeable about the standard. It is the hope of the research team that the findings of this study will illustrate a viable model for large scale Passivhaus construction, and help create a market for this type of low energy building. Builders will quickly acknowledge Passivhaus when owners and developers demand it.

In the absence of large scale contractor input, the following construction analyses was developed by the team, based on the field expertise of several senior project architects who reviewed the proposed design and details.

Procurement

The revised design incorporated commonly used products and assemblies as much as possible. As a result, procurement is generally similar as compared with the base case building. For example, most products used for insulation, weather barriers, cladding and MEP equipment are common in typical construction. Some unique products such as rainscreen attachments were selected. Procurement may be a challenge for these unique products because there are few competitive options and little demand in the current market. NYSERDA and other organizations can help incentivize these companies to make their products available and to encourage competition from other companies. Main products with procurement challenges are described below.

While many small scale Energy Recovery Ventilators (ERVs) are available in the US market, there is only one Passivhaus certified commercial scale ERV option available. This lack of options is an impediment to widespread Passivhaus adoption, as restricted availability may cause higher prices and long lead times. European ERV manufactures will likely make their large scale products available in the US when there is a clear demand. US manufacturers will likely follow and develop products as demand increases.

Passivhaus certified windows and doors for commercial use are predominantly imported from Europe. Only a few manufacturers of these systems have made their products available to the US market. As such, lead times, the cost of shipping, language barriers and other difficulties may impact efficient procurement of these products.

Cellular glass insulation, which is used as a thermal break between brick and foundation walls, is a single-source product that was withdrawn from the US market after the details for this study were developed. The manufacturer explained that there is currently not enough interest in the product in the US to justify efforts to keep it available. However, the manufacturer is open to making the product available again if interest increases. Substitute products are available with different properties such as aerated concrete block and ultra high density polyurethane, but these products are not widely used, poorly understood and have limited competitive options.

Thermally broken rainscreen clip technology is advancing rapidly. Currently, the most thermally efficient clips available at depths required by this study result in a 20% thermal

Figure 4.4:
Street level view

loss through insulation. Fortunately, other manufacturers are bringing more efficient products to market (SMARTci; GREENGIRT). Some products are available in Europe but not available here.

Insulating concrete masonry units that are fully thermally broken are currently only available from a small number of manufacturers. As with the products listed above, a lack of supply and market competition may pose procurement challenges.

A list of main products used in the enclosure and MEP systems is included in Appendix A.

Labor, Installation, Sequencing & Speed
Most aspects of the Passivhaus design utilize typical New York City commercial construction practices. The main difference between Passivhaus and typical construction is quality. Passivhaus requires much less tolerance for error or shortcuts that are unfortunately too common in typical construction. Attentiveness of the labor force and coordination between trades can be difficult to accomplish, but measures can be taken to make sure all parties involved in the construction process are aware of project goals and work together toward them. We recommend that Passivhaus tradesperson and ABAA certification training be expanded and incentivized to grow a well trained workforce.

The additional time and effort needed for airtight construction impacts the sequence and speed of some installation tasks. As such we estimated eight weeks of additional time during construction to account for this higher level of craftsmanship and quality control in the Energy Cost Measures and Life Cycle Cost Report (Appendix D).

General elements of the air tightness construction procedure were described in Section 3.1. The recommendations to follow ABAA procedures, prepare mock-ups and incorporate blower door testing include steps that are additional to standard construction. Blower door testing at certain stages of construction may add complexity to installation sequencing. Inclusion of a third party air barrier consultant adds another party to shop drawing review and other coordination efforts. Finally, correction of work to meet higher Passivhaus standards may require additional time.

Construction of a Passivhaus thermal barrier is slightly more complex than normal, but not significantly. Some additional complexity is introduced by the use of structural thermal breaks at balconies and parapets. These require coordination of specialty products that must be included in shop drawings, and potentially an additional step in the concrete pour process. Otherwise, installation of additional insulation and execution of thermal break details around windows, pipe penetrations and other elements may require slightly more time to install.

4.8. TENANT EDUCATION AND GUIDELINES

Residential Tenant Education
Individuals renting apartments in a Passivhaus building may be unaware of the nuances of Passivhaus HVAC systems that include constant fresh air ventilation and small locally controlled heating and cooling equipment. For example, a tenant used to uncontrollable overheating steam radiators may automatically open a window in winter when the Passivhaus heating system can easily be turned down. While this kind of misuse may seem trivial, the cumulative effect of multiple tenant misuse may cause larger problems. Simple brochures and introductory explanations to new residents should be sufficient to inform tenants about proper procedures. Examples include encouraging tenants to open windows during days with mild temperatures, while closing windows when heating or cooling are required.

Because a Passivhaus building differs from what most tenants are accustomed to, education should also explain differences in how building systems will function. For example, it is important to make tenants aware that fan coil units will operate intermittently based on load, and there will be many occasions when they will not hear their unit running due to reduced need for heating or cooling.

Retail Tenant Guidelines
Retail tenants are typically responsible for fitouts including HVAC systems. Tenants must be made aware of Passivhaus building requirements and energy use limits through tenant requirements, guidelines, and/or other means. If a building owner is anticipating a retail tenant with a high receptacle load beyond the assumptions made for this study, the design would have to be re-evaluated and likely revised to achieve Passivhaus targets.

4.9. MARKET ANALYSIS

The approach taken towards the Passivhaus design was to meet the standard while minimizing aesthetic changes to the base case building. This was done to demonstrate to developers, owners and renters that a Passivhaus high-rise need not look different than a typical sustainable residential building, and that visual connections to the exterior can remain unchanged.

In querying a selection of New York City residential brokers and development advisors, the consensus was that the level of sustainability of a building is not the main driver for renters or buyers. Only a niche of residents are focused on health and wellness and are interested in sustainable buildings. For these residents, indoor environmental quality is a high priority, with features such as thermal comfort and controls, green spaces, natural light, air and water filtration, and healthy materials. Energy savings is not typically a primary concern. Resiliency is also not currently a prime concern. Even those interested in sustainability are not typically willing to pay a premium for it.

There is some familiarity among renters and buyers with LEED, though primarily with respect to the name and not the specifics of various credits. More residential high-rise buildings are becoming LEED certified, particularly in congested mid-town Manhattan where residential buildings are targeted to a more international clientele. In these cases, emphasizing healthy buildings serves as a differentiator for developers. Residential buildings in this neighborhood tend to utilize floor-to-ceiling glass as they are often shaded by other buildings and seek to let in natural light and provide views. High glazing ratios limit the possibility of Passivhaus high-rises being in neighborhoods such as midtown Manhattan. Buildings in other neighborhoods tend to lower glazing ratios, but fewer are pursuing LEED certification.

One of the brokers queried indicated that LEED is becoming less important to the branding of residential buildings and that other standards are garnering interest, such as the WELL Building Standard®. The broker's impression was that Passivhaus could be promoted to the high-end residential market in the context of "High Performance Living," with an emphasis on high-tech controls, exceptional indoor environmental performance, green spaces, and high levels of building service. The high air-quality, thermal comfort and superior acoustics of Passivhaus buildings align with this approach.

As the Financial Analysis section will outline, there is a potential marketing incentive of reducing tenant utility costs. Maintenance and capital replacement cost reductions will also benefit the owner.

The importance of providing financial incentives to developers to offset first costs cannot be overstated due to pressures of competitive financing and tight construction schedules. A development advisor suggested that the best way to drive development of Passivhaus buildings was through government incentives. He recommended that meaningful financial incentives be provided to a select group of ten to twenty "early adopter" developers of high-rise Passivhaus residential buildings to help shift the market towards the Passivhaus standard.

Finally, in order to transform the market and drive demand, there was a consensus among those queried that public awareness and consciousness about climate change issues needs to be heightened through government initiatives, public education, and the media.

4.10. FINANCIAL ANALYSIS

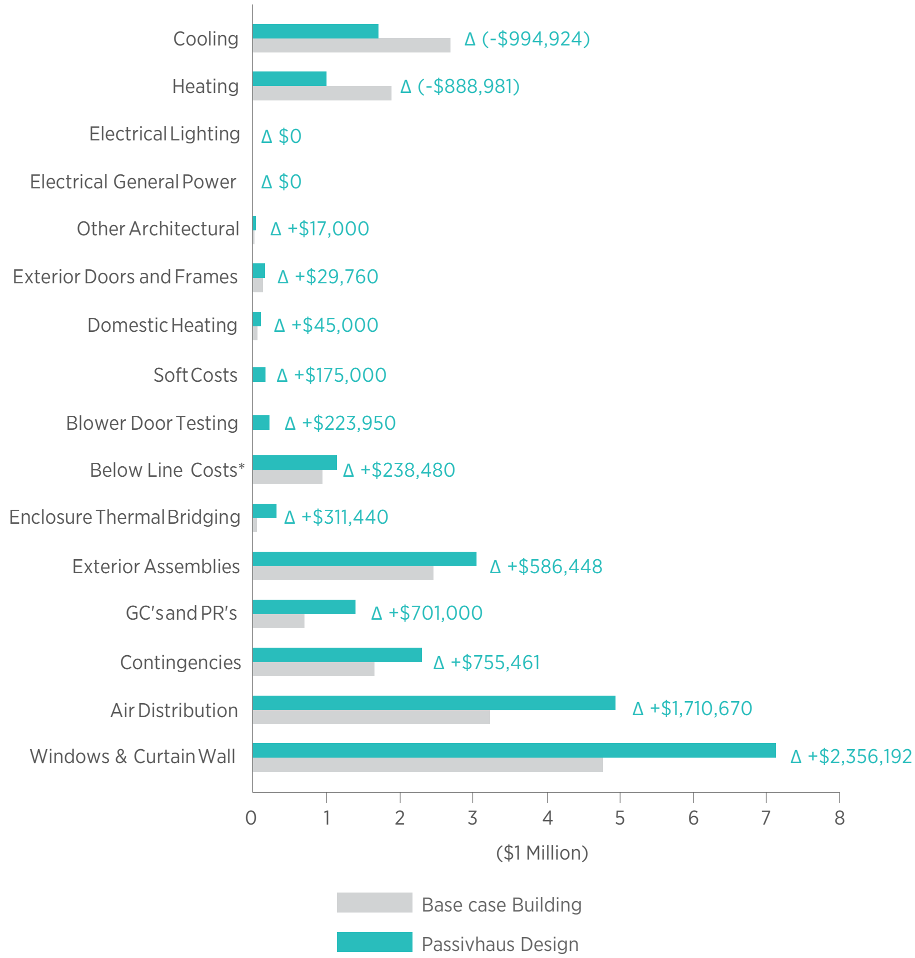
Capital Cost & Life Cycle Cost Analysis
The Passivhaus design was compared to the base case building design with respect to initial capital costs, annual maintenance costs, capital replacement costs, payback period and Net Present Value (NPV). The full cost report is included in Appendix D.

The Passivhaus design results in increased initial capital costs for the project of $5.27 million, representing a 2.4% increase over the base case building. This is based on an initial construction cost assumption of $375/ft². The most significant cost increases result from the Passivhaus certified windows and additional duct work for fresh air delivery to the units. The most significant cost savings result from a reduction in heating and cooling equipment.

An estimated annual energy cost savings of $226,356 in the Passivhaus design as compared to the base case results in a 24 year simple payback and a Net Present Value (NPV) savings of $5.2 million after 40 years, based on an average discount rate of 5% and a nominal annual energy inflation rate of 5%. A matrix of 40 year NPV results with varying discount and energy inflation rates is included Table 4.3.

The first cost result of the financial analysis is encouraging for projects of this scale. While the payback period is long, the 40 year NPV savings is favorable from an investment perspective.

The simple payback result is affected by the current low cost of natural gas in the United States. Most energy savings in the Passive House design is from reduced heating, and natural gas consumption. Payback periods for Passive House projects in Europe are



*"Below line costs" refer to the Gross cost of a construction cost and include all general conditions , general requirements, project requirements, insurances, permits , bonds, fees and escalation if applicable.

Figure 4.4:
Initial capital cost comparison between Base case building and Passivhaus Proposal

generally shorter than in the US because of higher European fuel costs. If the cost of natural gas in the US reverted to its historical norm, the simple payback period would be reduced.

It should also be noted that first cost estimates for the Passivhaus design were conservative and can be reconsidered to lower costs even further. For example, less expensive but still high performing window frames could be selected to reduce costs. Increased costs for general conditions were also conservatively estimated and could be reduced with a knowledgeable contractor.

Financial Incentives

New financing options such as the NY Green Bank could help incentivize development of Passivhaus high-rise buildings by leveraging private sector capital to bridge the cost differential gaps. Select Energy Service Companies (ESCO's) may also consider financing options where they could provide up-front capital in exchange for monthly fees paid by owners or tenants based on the significant energy savings that a Passivhaus high-rise would provide. Incentives through NYSERDA and others could be developed specifically for Passivhaus windows, and other high cost Passivhaus measures such as ducted air delivery, similar to current targeted incentives for Combined Heat and Power. A dedicated Passivhaus incentive for "early adopters," as mentioned in the Market Analysis section, would be another means to accelerate market transformation.

For further financing research, the Building Energy Exchange recently published a briefing which includes resources for financing and incentive programs for low energy buildings[24].

	Annual Energy Cost Savings	Payback Years	NPV Net Present $
10 Year Review Period	$226,356	-	$(2,833,100)
20 Year Review Period	$226,356	-	$(724,881)
40 Year Review Period	$226,356	24	$5,194,948
Typical Initial Building	$/ft^2	($375)	($223,984,875)
Initial Passivhaus Capital	$/ft^2	(9)	**($5,266,496)**
Percentage of Build Cost			**2.4%**
Annual Maintenance Savings			$20,712
30 Year Capital Replacement Savings			**$934,800**

Table 4.2:
Summary level lifecycle cost analysis results

	3% Energy Inflation*	5% Energy Inflation*	7% Energy Inflation*
4% Discount Rate	$3,970,386	$7,580,769	$13,604,371
5% Discount Rate	$2,396,520	$5,194,948	$9,789,418
6% Discount Rate	$1,172,477	$3,365,570	$6,906,325

*Energy inflation rates are nominal and include annual market inflation

Table 4.3:
40 year Net Present Value matrix - Discount rates & Energy inflation

24 Building Energy Exchange. "Passive NYC, A snapshot of low energy building opportunities, barriers, & resources". www.be-exchange.org.

SECTION 5

CONCLUSIONS

5.1. FEASIBILITY OF PASSIVHAUS HIGH-RISE BUILDINGS IN NEW YORK

The findings of this study suggest that meeting the Passivhaus standard is viable for high-rise residential buildings in New York City, both technically and financially. In fact, it is easier for this project typology and scale to meet Passivhaus requirements than smaller buildings or projects with different programs. While there are some outstanding code and regulatory requirements that must be aligned with Passivhaus, the research team is confident that they can be resolved by working collaboratively with agencies and manufacturers.

Key to achieving the Passivhaus standard is a highly integrated design process beginning at the onset. Ongoing collaboration between the client, MEP engineer, architect, and construction manager is necessary. An air tightness consultant should also advise the team about enclosure details and construction procedures, and be present for inspections during construction of the enclosure. Engaging the Passivhaus certifier early in the design will facilitate a simpler certification process. Providing an allowance for pre-bid mock-ups from select enclosure subcontractors will also help streamline the process technically and financially.

Current challenges to broad deployment of the Passivhaus Standard are limited availability of large high performance energy recovery ventilators (ERVs), lack of experienced contractors and manpower, and a scarcity of Passivhaus energy modelers and certifiers. If more than a few large buildings take on certification at the same time, there may not currently be sufficient capacity to meet project needs.

5.2 . LIMITATIONS OF RESULTS

This study is limited to a design phase analysis. There is much to be learned in the construction process that could further elaborate where additional challenges exist. Limited availability of large general contractors to participate in this study inhibited a more detailed understanding about procurement of select products, and whether alternative strategies such as pre-purchase would be required. As well, the study did not address current training or skills of exterior wall subcontractors, a key to successful achievement of the Passivhaus standard. Further investigation into exterior wall contractor skills and training is merited.

Finally, cost estimates were carried out based on 2016 New York City market conditions and energy costs – these are subject to supply and demand fluctuations and should be normalized accordingly when planning for future projects.

5.3 RECOMMENDATIONS

To successfully scale up the Passivhaus standard to wide adoption among new high-rise residential buildings in New York, the research team recommends the following:

Legislation
State and City agencies should include energy use intensity (EUI) requirements into current legislation, working incrementally towards the source energy Passivhaus target of 38 kBtu/ft^2/yr. These initiatives are already in progress; New York City passed Local Law 31 2016 which targets either a 50% reduction in EUI below a similar base case building, or the Passivhaus EUI target for new municipal buildings. New York City's 80x50 Technical Working Group is investigating substantial energy code improvements over the next several code cycles, and shifting towards performance based codes. Codes could be further improved by increasing air-tightness standards and requiring blower door test results before providing the final certificate of occupancy.

Education and training
Training should be expanded to increase the number of Passivhaus certifiers, Passivhaus designers, and Passivhaus energy modelers. Training should be targeted toward existing sustainability consulting, architecture and engineering firms. In addition, tradesperson training for enclosure sub-contractors and air barrier installers should be deployed via trade unions and building contractor associations. These trainings can be carried out through an organization such as the Association for Energy Affordability (AEA), who is already providing courses in these areas. However, to achieve the workforce numbers necessary, training should be expanded through technically-oriented trade schools and academic institutions. Publicly-funded projects that require low-energy targets should include designer and tradesperson training requirements into Requests for Proposals and project contracts. Current financial incentives for reduced course rates being funded by NYSERDA should also continue.

Product Access
Passivhaus enclosure products such as tapes, air barriers, exterior wall system supports and windows are increasingly available, while curtain walls and ADA compliant doors are still difficult to procure locally. While availability is increasing, seed funding, research and development support, and resources for testing and certification of locally engineered and manufactured products would expand the market and reduce product costs, as well as provide economic stimulus within the State.

Availability of large highly efficient Energy Recovery Ventilators (ERV's) is currently limited. Due to lack of market demand, European ERV manufacturers are not incentivized to undertake the effort and cost of certifying to US standards. As with enclosure products, support for development of locally engineered and manufactured products is needed. In the short term, financial incentives for US certification should be provided to foreign manufacturers to jump-start the market. As well, dedicated developer rebates from NYSERDA or local utilities for installation of Passivhaus certified products will drive demand.

Developer Incentives
While the financial analysis for the Passivhaus tall building design shows reasonable increases over the LEED base case, the additional investment still represents a substantial $5.27 million dollars, which results in a relatively long payback period. Providing upfront incentives for specific products such as Passivhaus certified windows, additional ductwork, air-barrier quality assurance supervision, blower door testing, and Passivhaus design fees would help motivate an initial group of developers to pursue the Standard. Comprehensive integrated incentive programs such as the "Exemplary Buildings" program carried out in Brussels[25] provided not only financial support but labelled buildings as "Exemplary", providing a marketing advantage to the building owners.

Branding and Marketing
In order to drive demand for Passivhaus high-rise residential buildings, a dedicated branding and marketing effort is required, similar to the US Green Building Council's efforts with LEED. Broker engagement and education will also help better sell the benefits of Passivhaus to buyers as healthy, quiet and comfortable environments in addition to the energy benefits.

Further Research
Given that residential buildings are responsible for 34% of New York City's total GHG emissions and that multi-family residential buildings present the greatest typological opportunity for energy savings[26], research into existing high-rise residential buildings is critical. In 2030, 85% of buildings in New York will be buildings that currently exist today[27]. Applying the Passivhaus standard to existing buildings will be significantly more challenging due to enclosure and airtightness requirements. The Passivhaus Institute does consider the challenges of existing buildings through their EnerPhit certification program, which relaxes the requirements slightly. Investigating how these requirements apply to a selection of standard existing high rise residential typologies would be important to the city's overall GHG reduction goals.

25 Building Energy Exchange. 2016. Passive NYC pgs.15-16

26 City of New York. 2015. One City Built To Last, p. 10. retrieved from: http://www.nyc.gov/html/builttolast/pages/home/home.shtml

27 http://www.nyc.gov/html/gbee/html/about/about.shtml

APPENDIX A

LIST OF PRODUCTS

LIST OF PRODUCTS - ENCLOSURE

Hot Rubberized Asphalt Protected Membrane Roofing & Related System
- American Hydrotech, Inc; Monolithic Membrane 6125
- Henry Company; 790-11

Liquid Applied Air & Vapor Barrier Membrane
- Henry Company; Air-Bloc 31MR
- Grace Construction Products; Perm-A-Barrier VP

Self-Adhesive Air & Vapor Barrier Membrane
- Henry Company; Blueskin SA
- Grace Construction Products; Perm-A-Barrier Wall Membrane

Air & Vapor Barrier Compatible Through-Wall Flashing
- Henry Company; Blueskin TWF
- Grace Construction Products; Perm-A-Barrier Wall Flashing

Insulation at Roof, Foundation & Slab
- The Dow Chemical Company
- Owens Corning

Mineral Wool Insulation at Rainscreen & Brick Cavity
- Roxul; CAVITYROCK DD
- Thermafiber, Inc.; RainBarrier 45

Mineral Wool Insulation at Interior of Wall
- Roxul; COMFORTBATT
- Thermafiber, Inc.; UltraBatt

Mineral Wool Insulation at Garage Ceiling
- Roxul; ROCKBOARD
- Thermafiber, Inc.; VersaBoard

Rainscreen Clips
- SMARTci; GREENGIRT
- Cascadia Windows; Cascadia Clip

Stand-off Brick Shelf
- Halfen; FK-4
- Fero; FAST

Brick Ties
- Hohman Barnard; #180 S.I.S Dub'l Loop-Lok
- Wire-Bond; Series 800 Ladder Level-Eye

Insulated Concrete Masonry Units
- Niagra Regional Group; NRG ICMU
- Omni Block; The System 8

Aluminum Windows
- Schuco; AWS 90SI+
- Raico; FRAME+ 90
- Alumil; S91
- Pural; eco90

Curtain Wall
- Schuco; FWS 50+.SI
- Raico; THERM+ A-V
- Reynaers; CW 50-HI

Doors at Balconies
- Schuco; ADS 112.IC
- Raico; FRAME+ Series

Doors at Entrances
- C.R. Lawrence Co., Inc.; Aluminum Series 650-T

Doors at Egress
- C.R. Lawrence Co., Inc.; Aluminum Series 650-T
- Plyco Corp.; Series 92

Gasket System for Egress Doors
- Zero International; "Hurricane Protection" or "Safe Haven" gasket systems

Coating for Triple Pane Insulated Glass with Warm Edge Spacers – Residential Tower Windows
- PPG; Solarban 60 on Clear Glass
- Guardian; Sunguard SN68 on Clear Glass

Coating for Triple Pane Insulated Glass with Warm Edge Spacers – Commercial Curtain Wall
- PPG; Sungate 400 on Clear Glass
- Guardian; Sunguard N78/65 on Clear Glass

Interior Air Barrier Tape for Windows
- Siga; Fentrim IS-20 (Confirm)
- Pro Clima; Tescon Profil (Confirm)

Plastic Sill Pan Flashing with End Dams
- Astro Plastics; Astropan
- Jamsill, Inc; Jamsill Guard

Alternate Sill Pan Flashing & End Dam materials
- Grace Construction Products; Vycor Plus
- DuPont; StraightFlash

Structural Thermal Break Products for Concrete Balconies
- Schock; Isokorb-CM
- Halfen; HIT-BX

Structural Thermal Break Products for Concrete Parapets
- Schock; Isokorb
- Halfen; HIT-AT

Structural Thermal Break Products for Steel Canopies, Dunnage, and Other Applications
- Schock; Isokorb-S
- Armadillo; Armatherm Grade FRR
- Fabreeka; TIM
- General Plastics; LAST-A-FOAM R-9300 Series

Cellular Glass Insulation at Brick Base Course
- Foamglas; Perinsul
- Armadillo; Armatherm 500
- Aercon AAC; Standard Block

LIST OF PRODUCTS - MEP

Energy Recovery Ventilator
- Swegon; Gold RX (Passivhaus certified, for > 200 CFM)
- Zehnder; Focus 200 (Passivhaus certified, for < 200 CFM)

Cooling Tower
- Baltimore Aircoil Company, Inc.; New Series 1500

Boiler
- Aerco; BMK Series

Chiller
- Daikin; MAGNITUDE

Domestic Water Heater
- PVI Industries; Power VTX

Pump
- Armstrong; Series 4000

Booster Pump
- Syncroflo

Fan Coil Unit
- International Environmental; MPY (vertical)
- International Environmental; CHY (horizontal)

Duct Heating & Cooling Coil
- Greenheck; CW

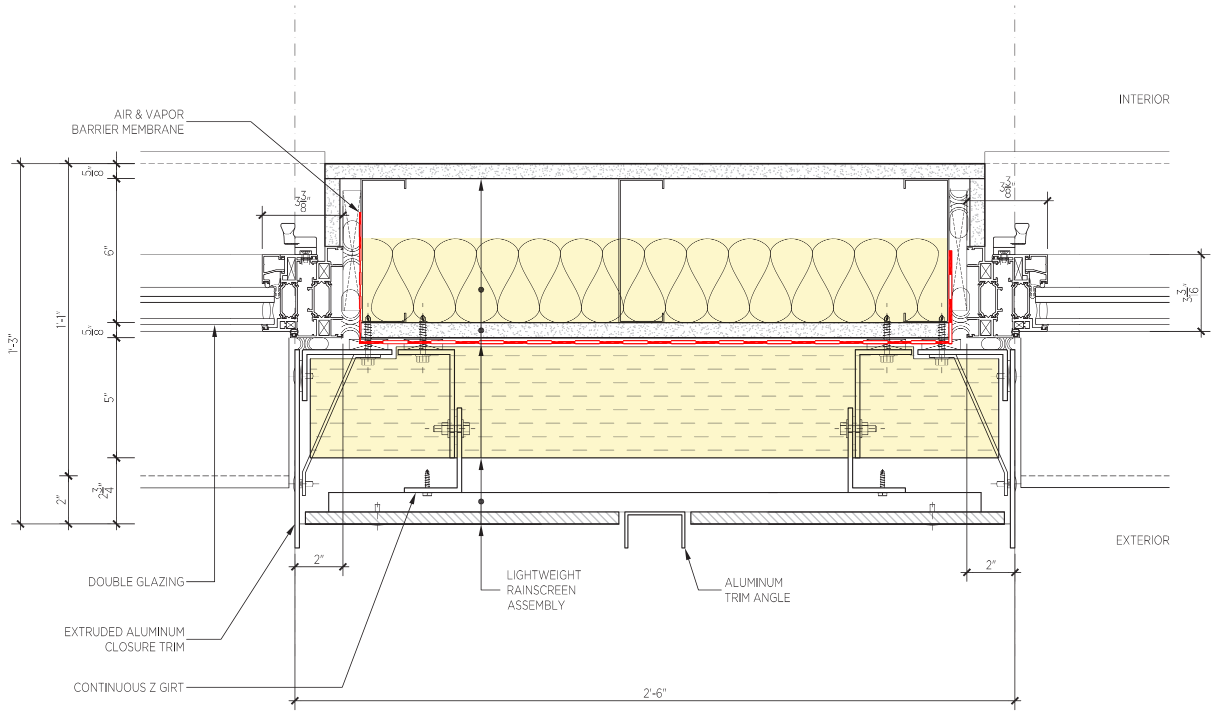
VFD (for cooling tower, pumps)
- Toshiba; Q9

Motorized Dampers
- Greenheck; ICD

Pipe Gasket Connections
- Jay R. Smith; No-Hub Connection - Y

APPENDIX B

ENCLOSURE DETAILS



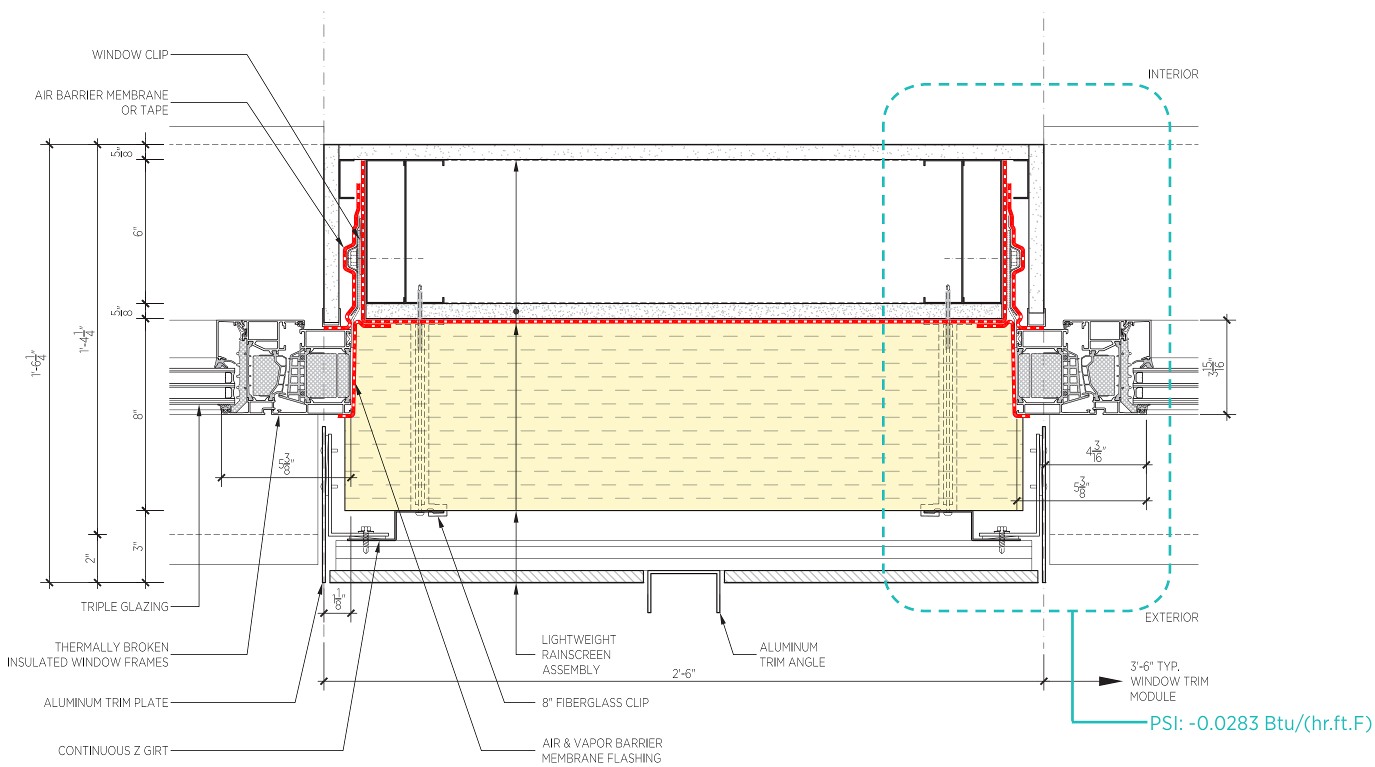
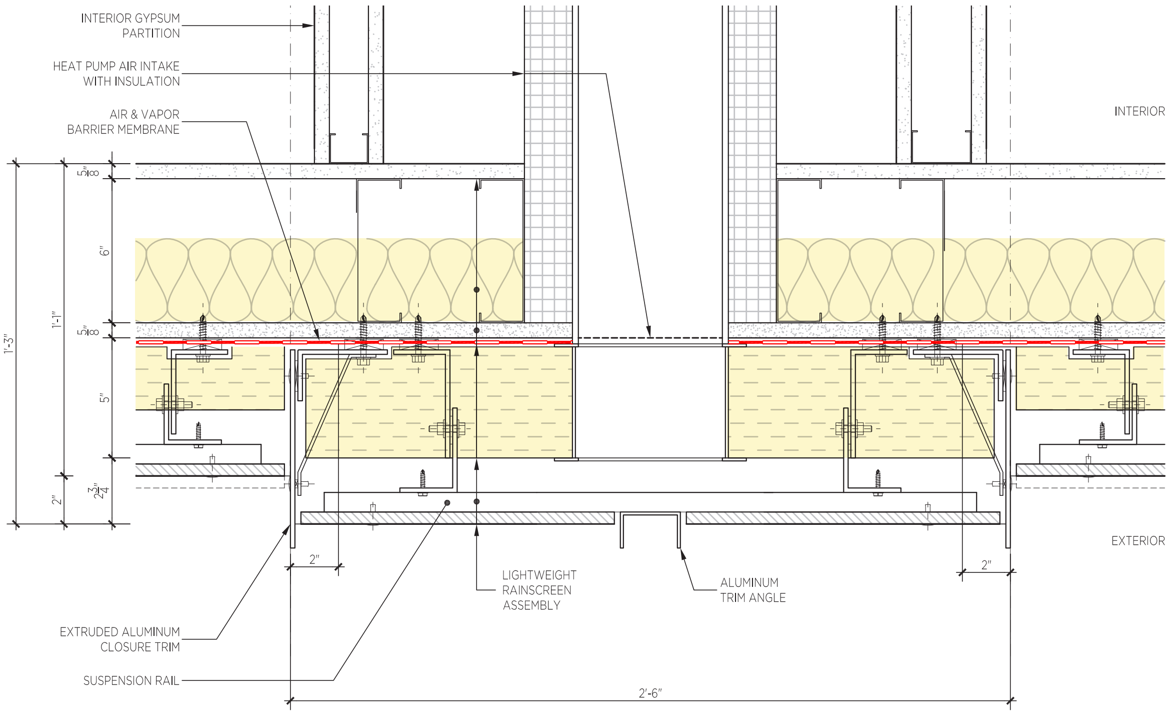


Figure B.1a:
Base case Building - Lightweight rain screen at window jamb

Figure B.1b:
Passivhaus Proposal - Lightweight rain screen at window jamb



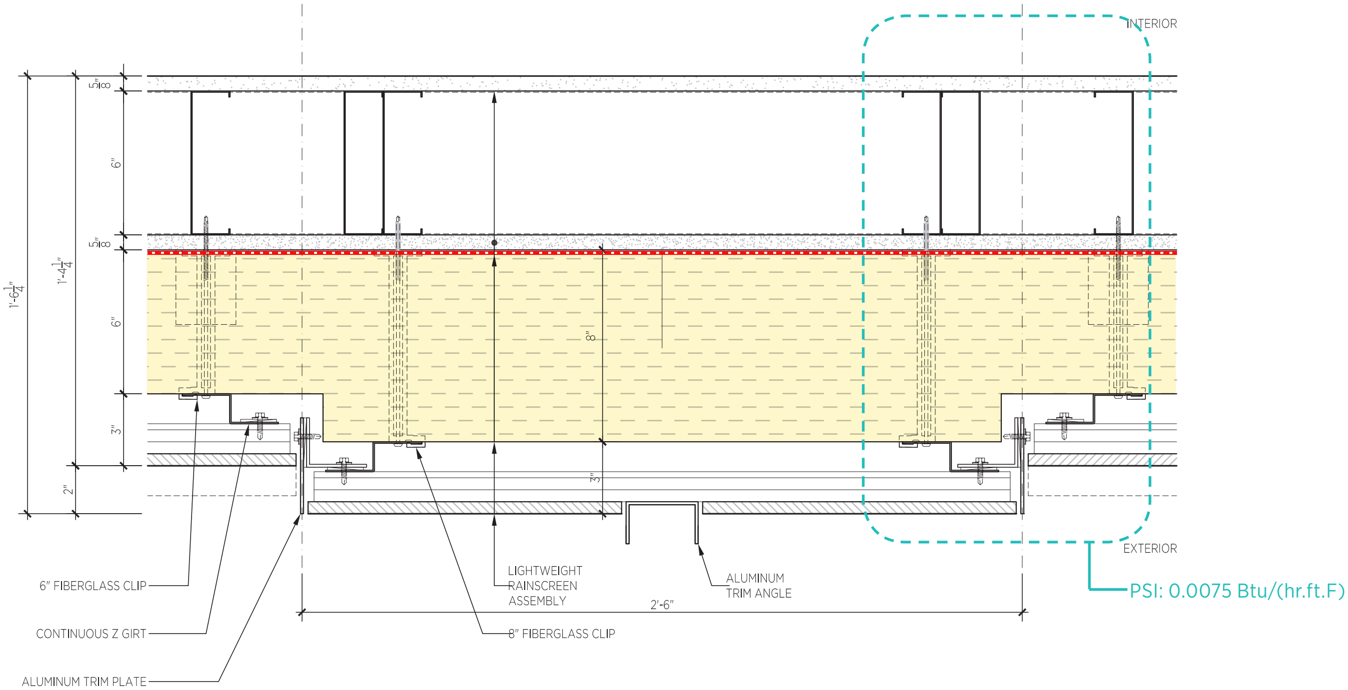


Figure B.2a:
Base case Building - Lightweight rain screen at wall above & below window

Figure B.2b:
Passivhaus Proposal - Lightweight rain screen at wall above & below window

Note: Tower condition shown with windows. Podium levels have curtain wall in rainscreen. See brick cavity wall details for proposed curtain wall attachment.

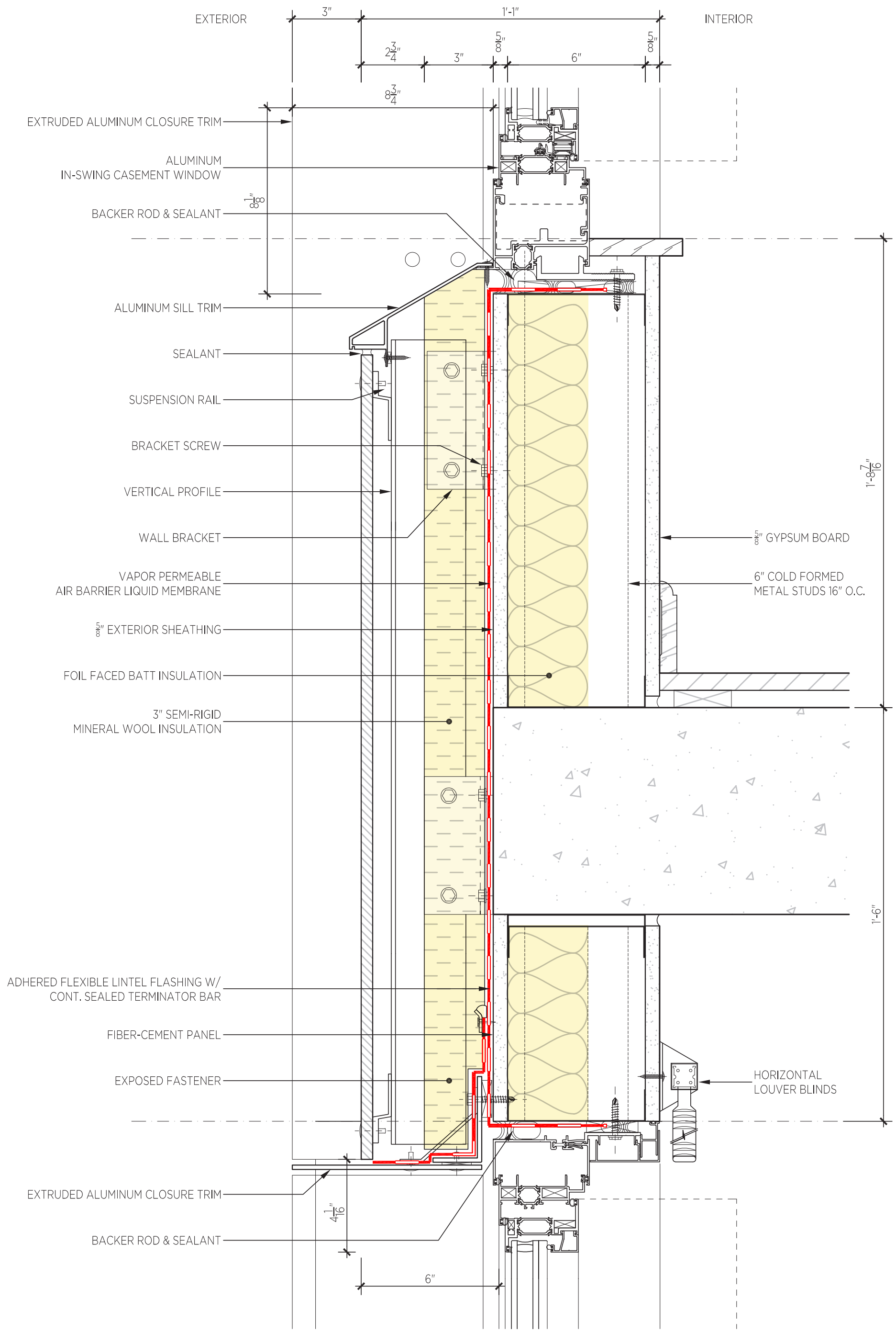


Figure B.3a:
Base case Building —Lightweight rain screen at window head & sill

Note: Tower condition shown with windows. Podium levels have curtain wall in rainscreen. See brick cavity wall details for proposed curtain wall attachment.

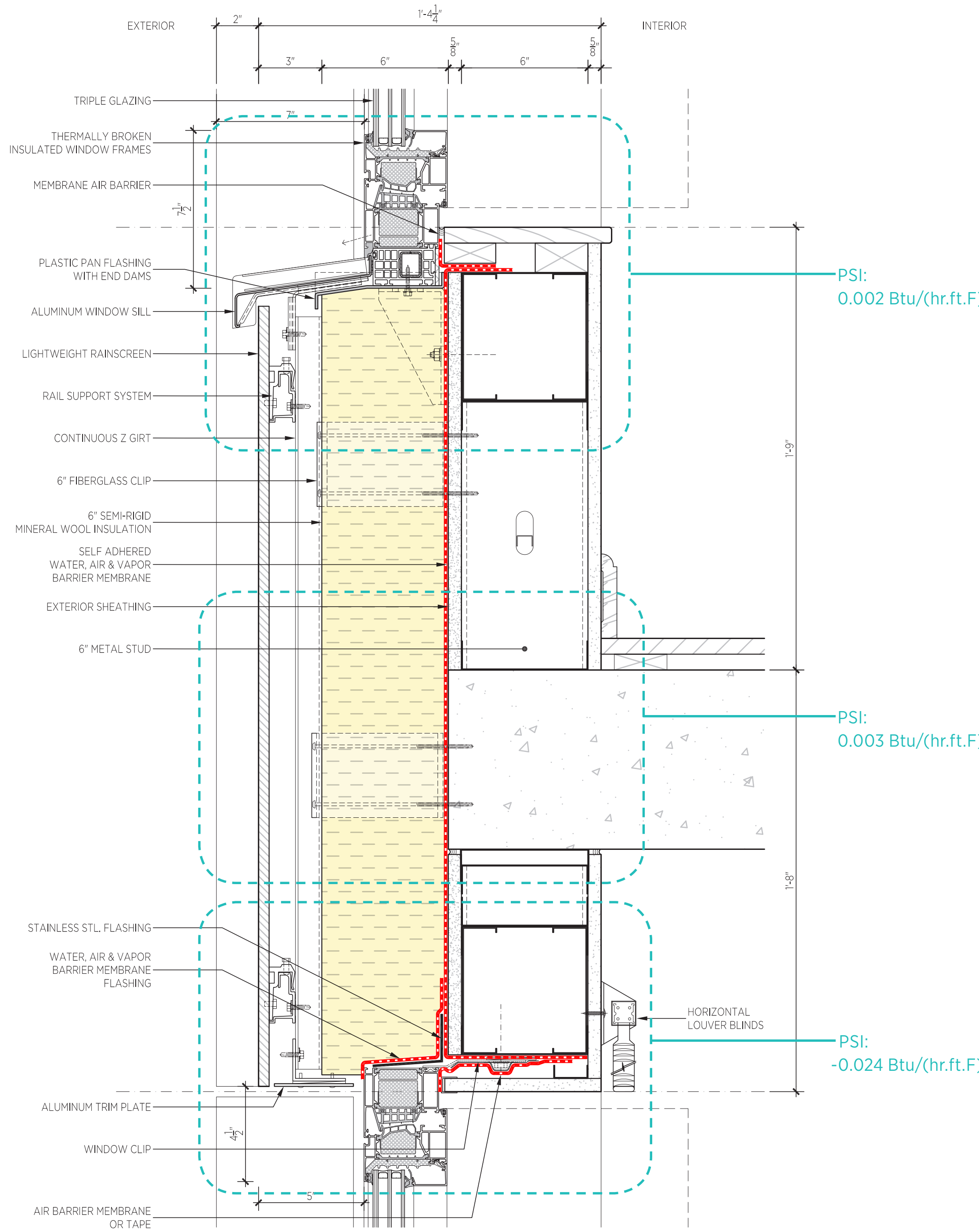


Figure B.3b:

Passivhaus Proposal —Lightweight rain screen at window head & sill

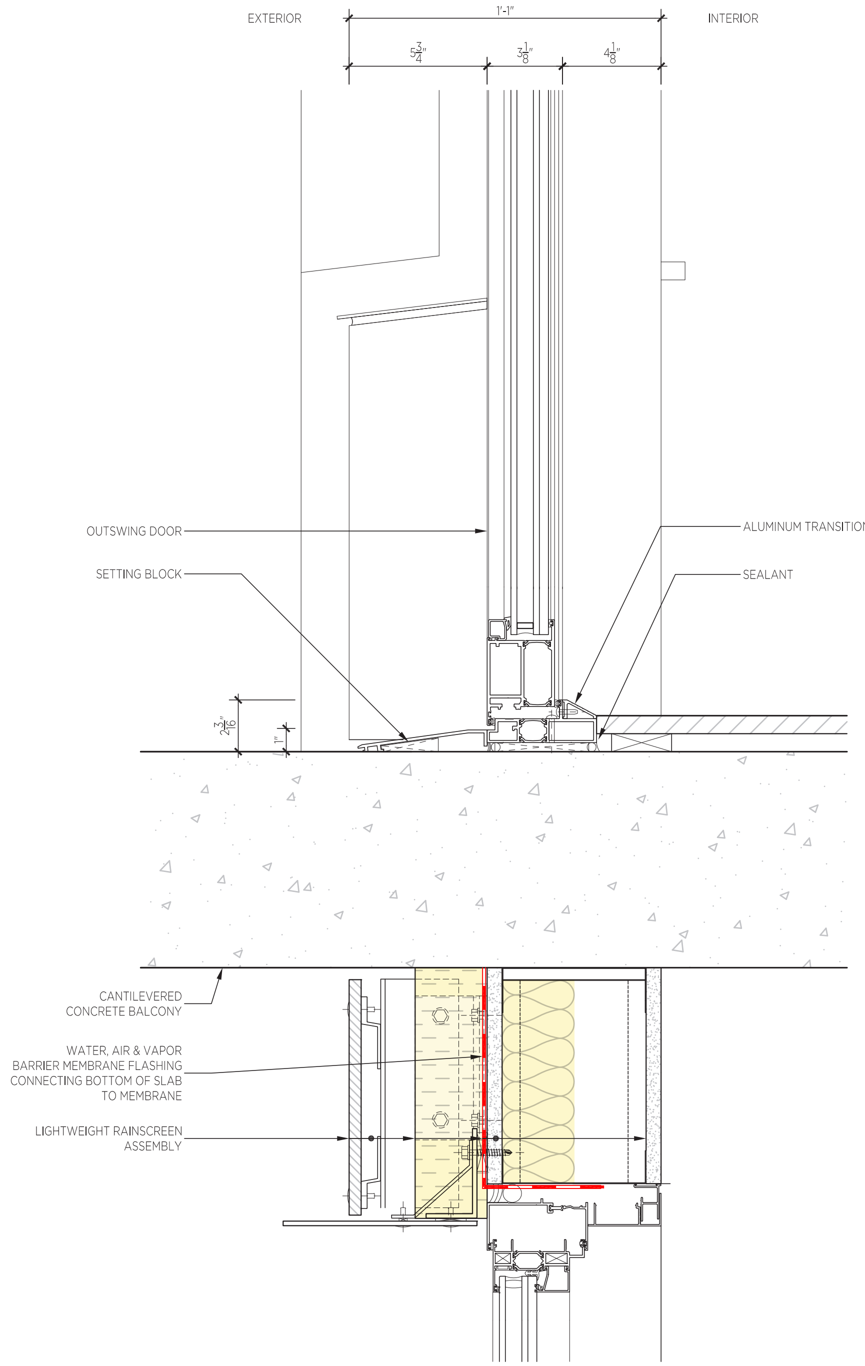


Figure B.4a:
Base case Building - Lightweight rain screen at balcony cantilever and door sill

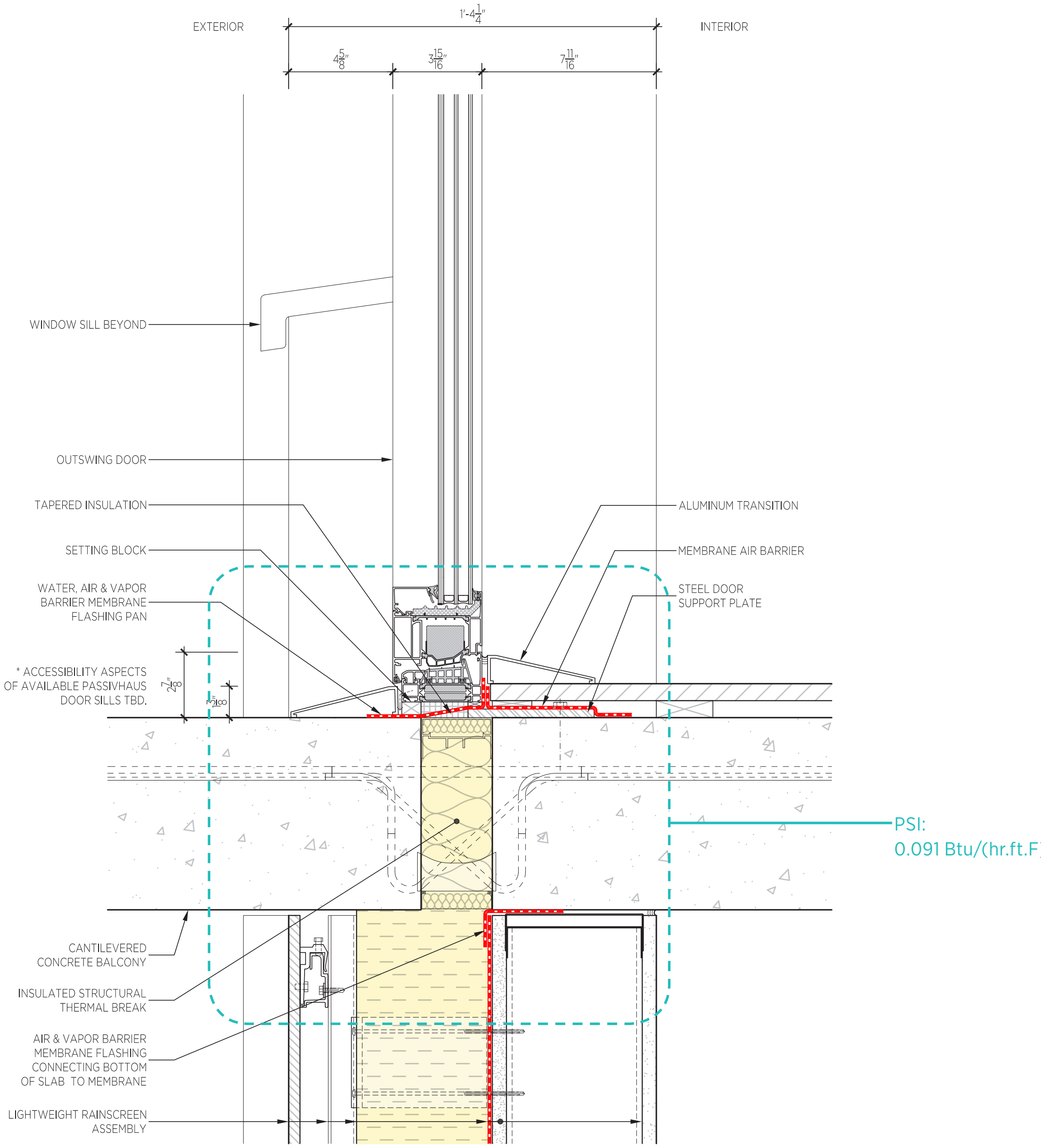


Figure B.4b:
Passivhaus Proposal - Lightweight rain screen at balcony cantilever and door sill

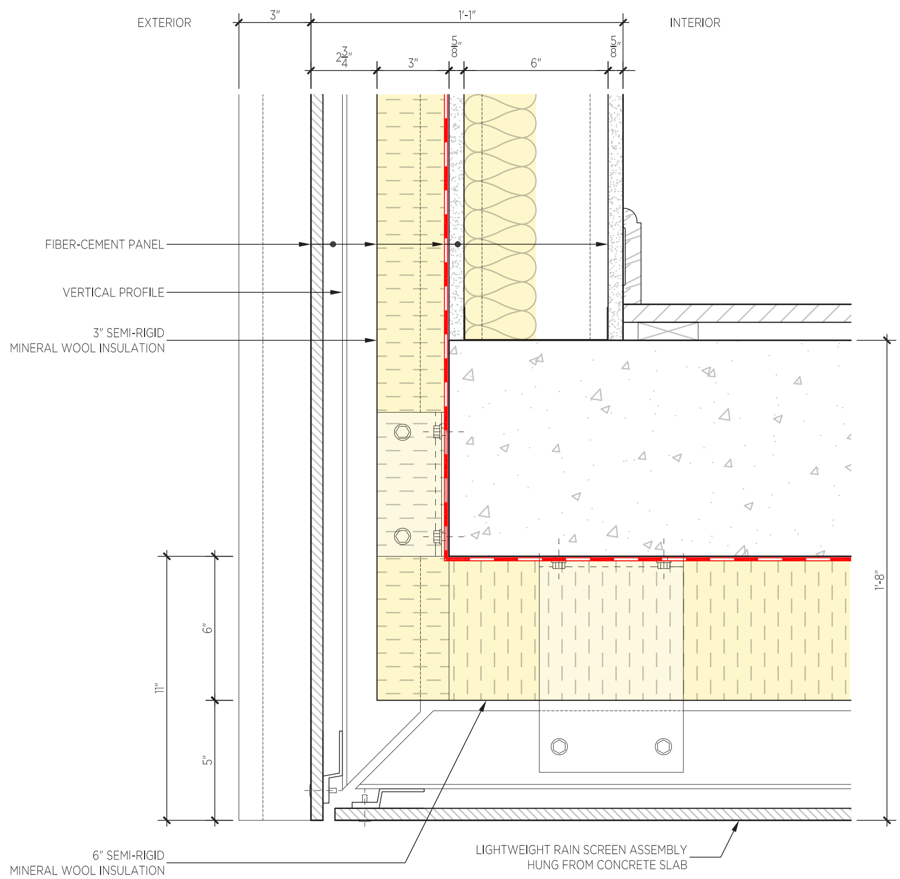


Figure B.5a:
Base case Building - Lightweight rain screen at soffit

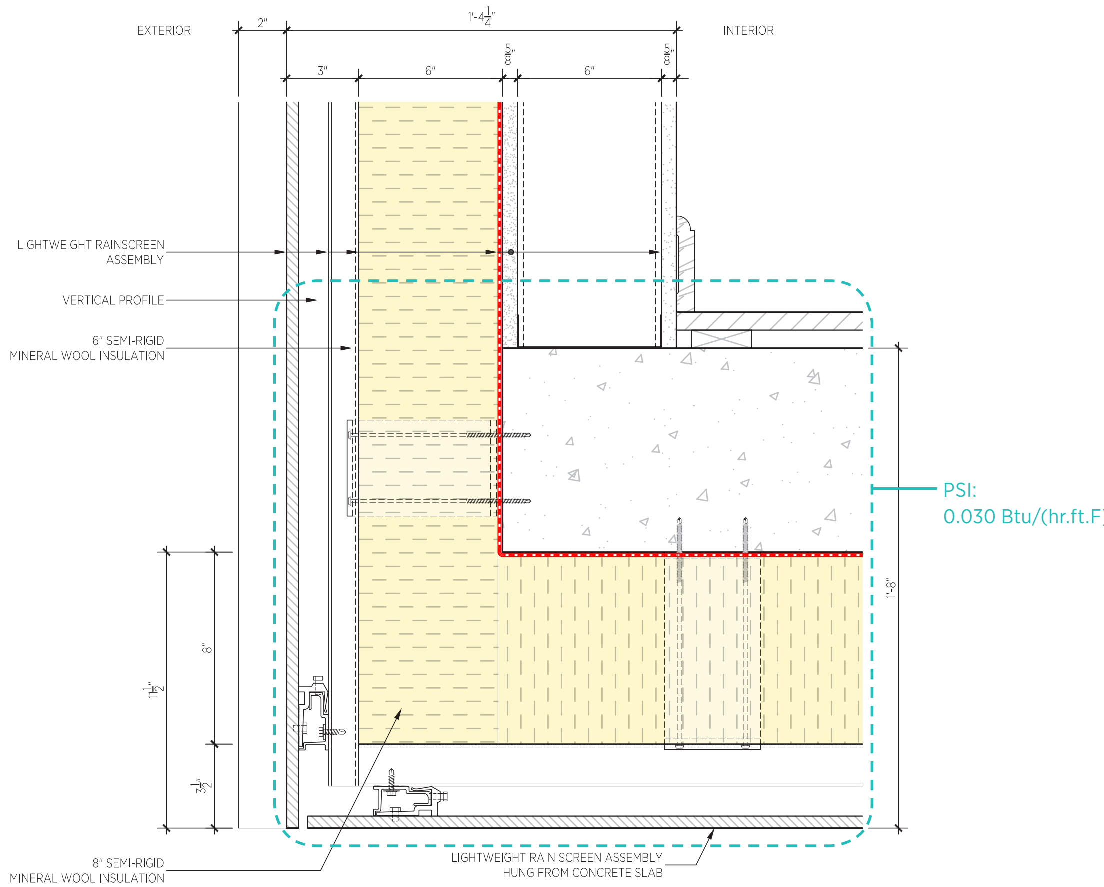


Figure B.5b:
Passivhaus Proposal - Lightweight rain screen at soffit

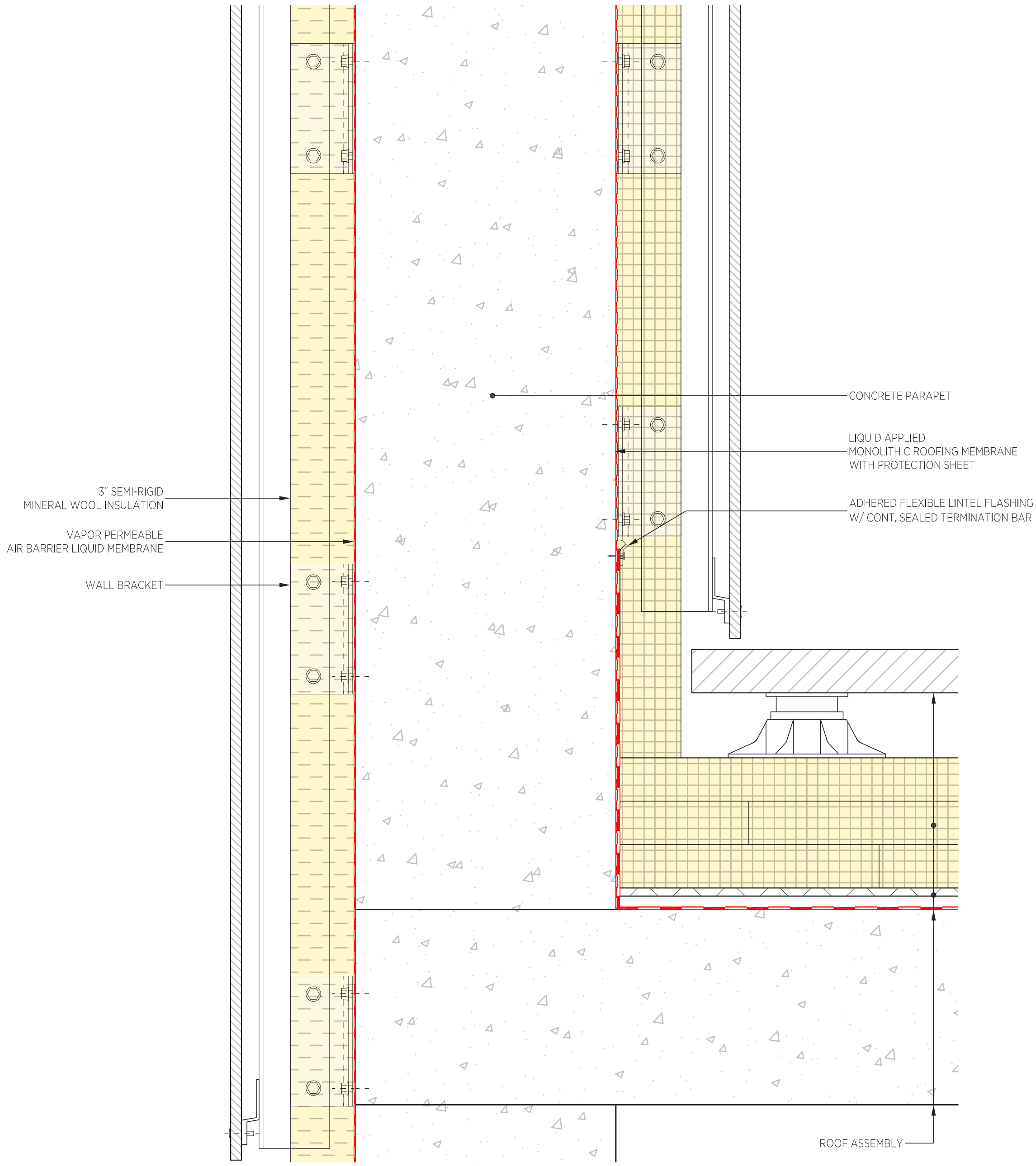


Figure B.6a:
Base case Building -Lightweight rain screen at roof parapet

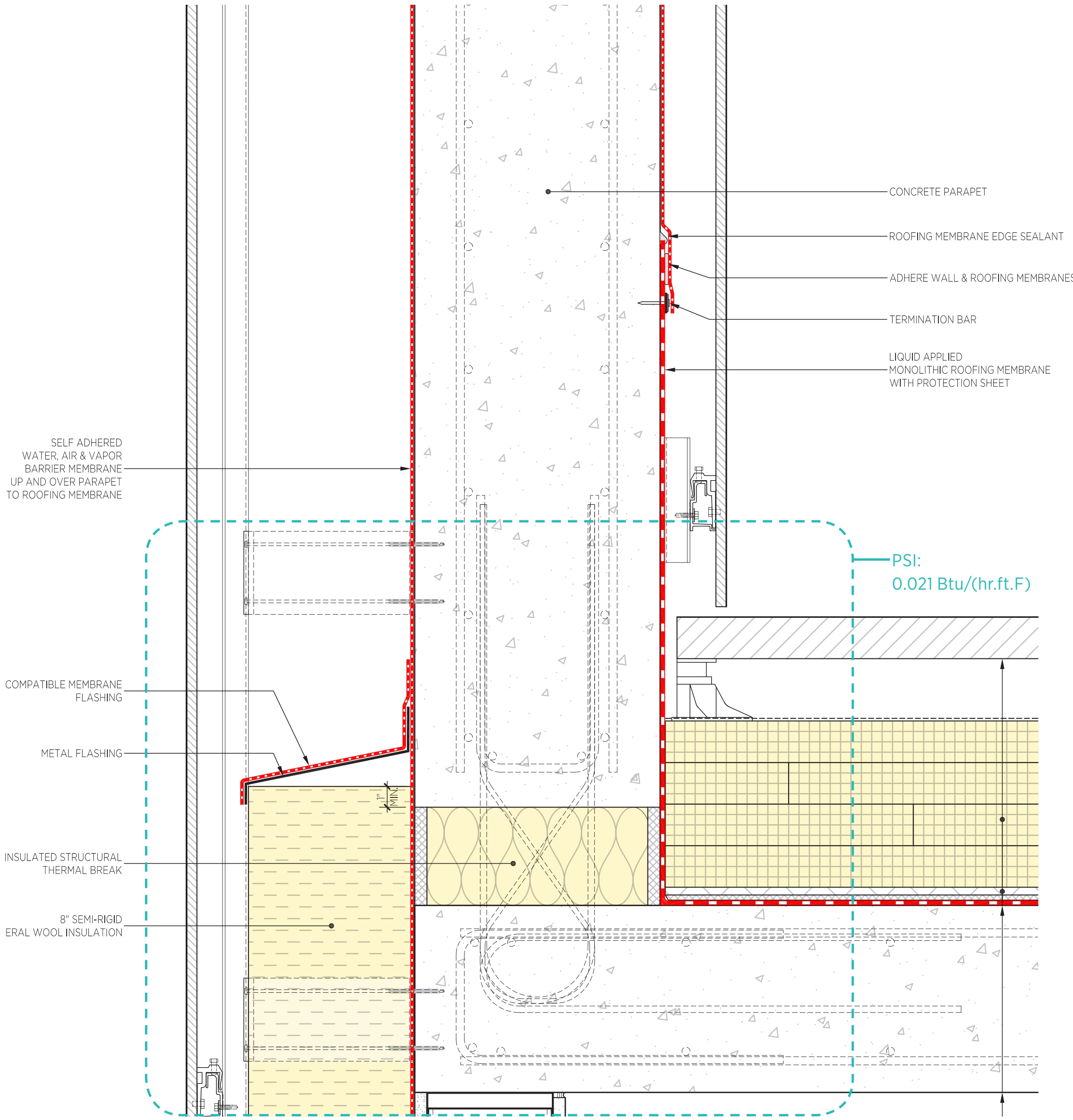


Figure B.6b:

Passivhaus Proposal -Lightweight rain screen at roof parapet

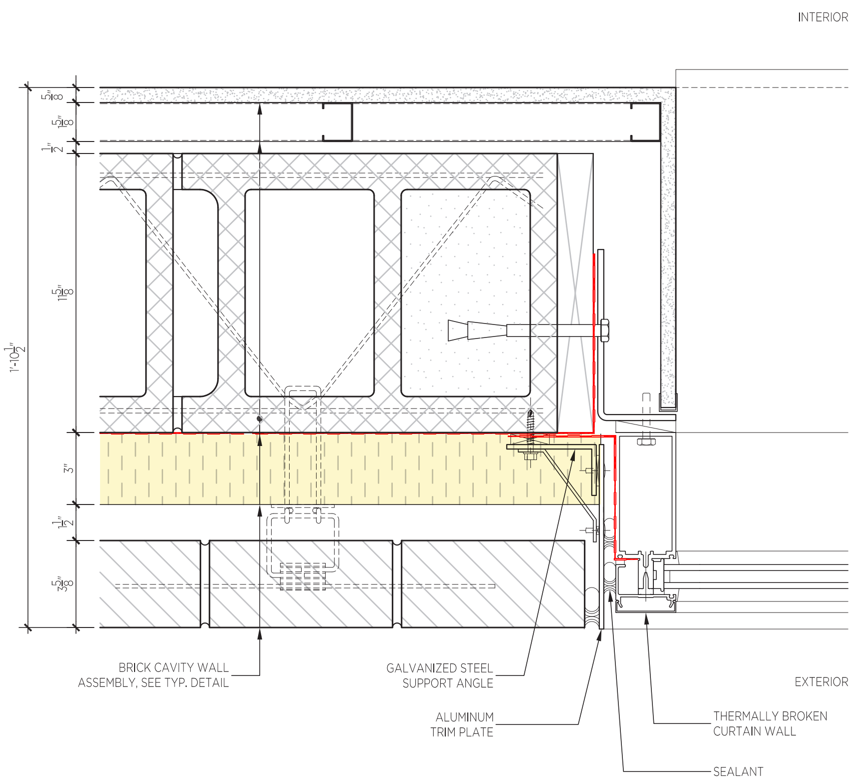


Figure 3.7a:
Base case Building - Brick cavity at curtain wall jamb

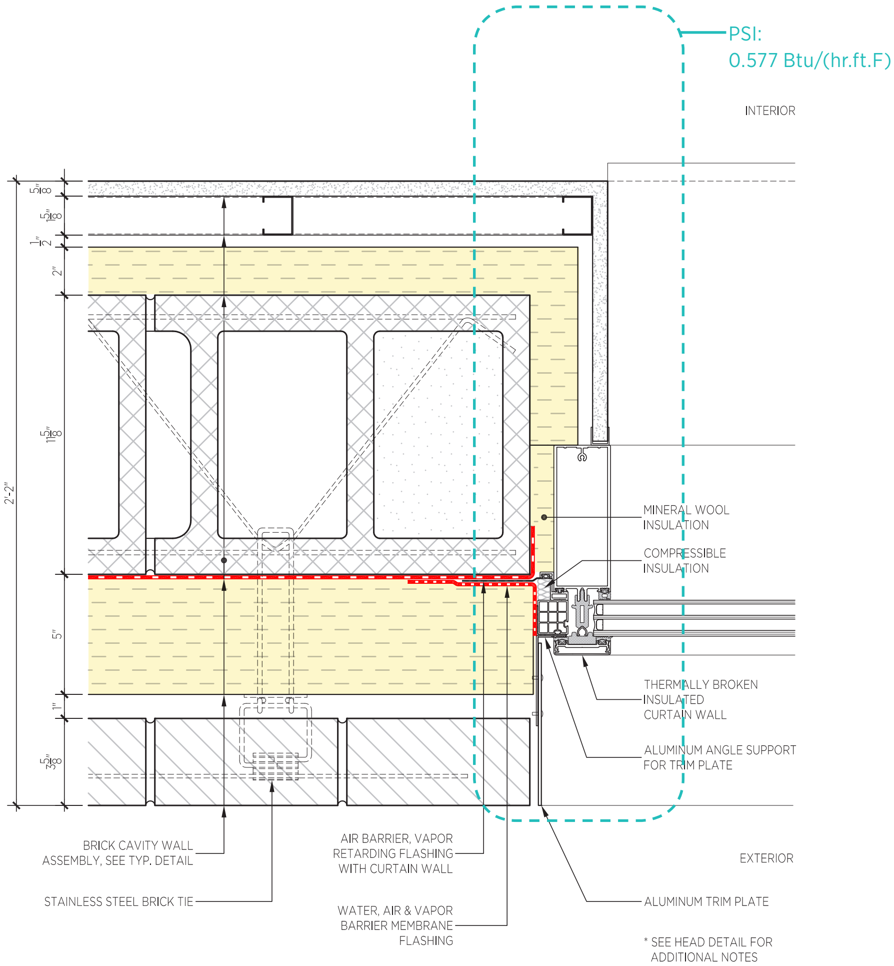


Figure 3.7b:
Passivhaus Proposal - Brick cavity at curtain wall jamb

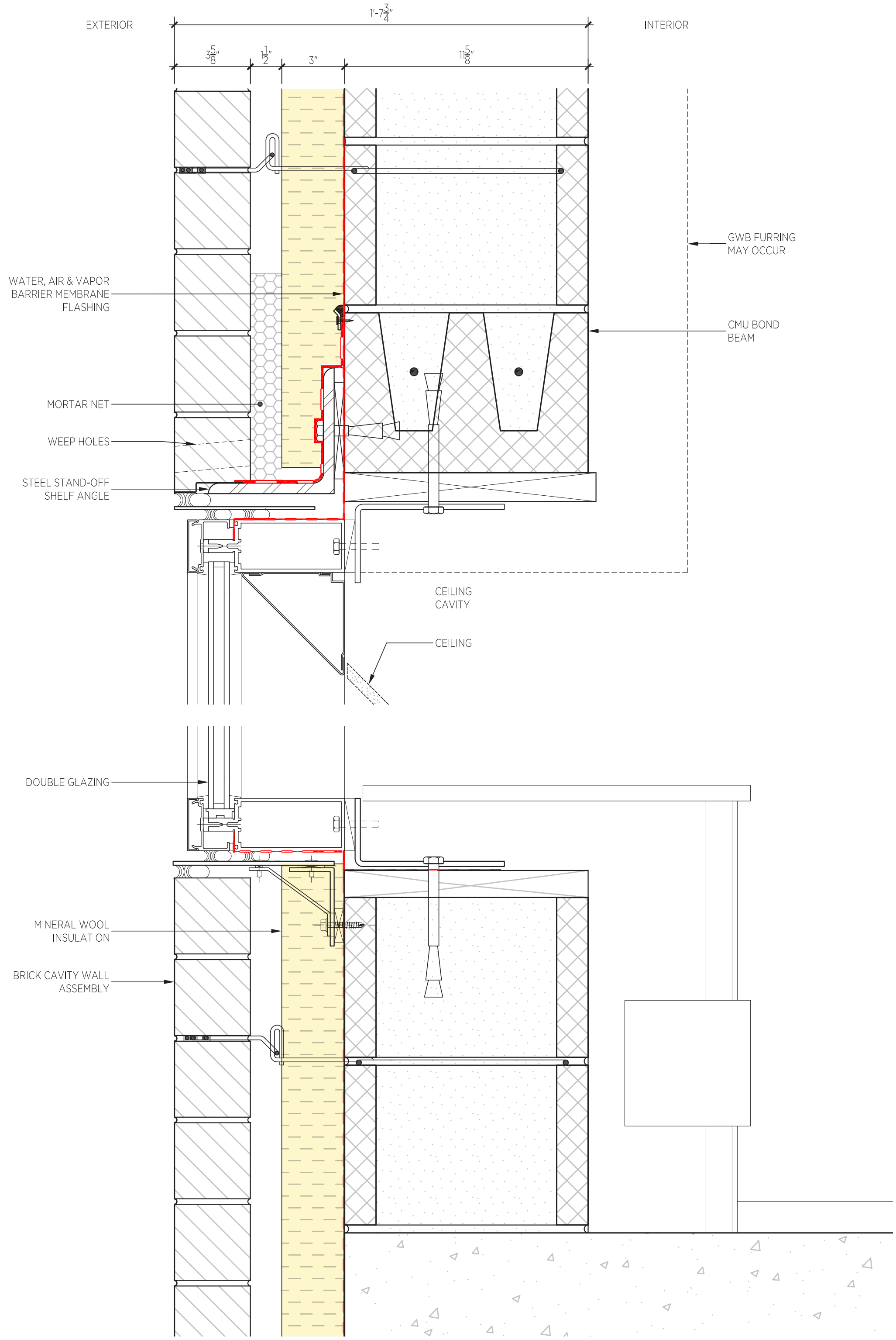


Figure 3.8a:
Base case Building - Brick cavity at curtain wall head & sill

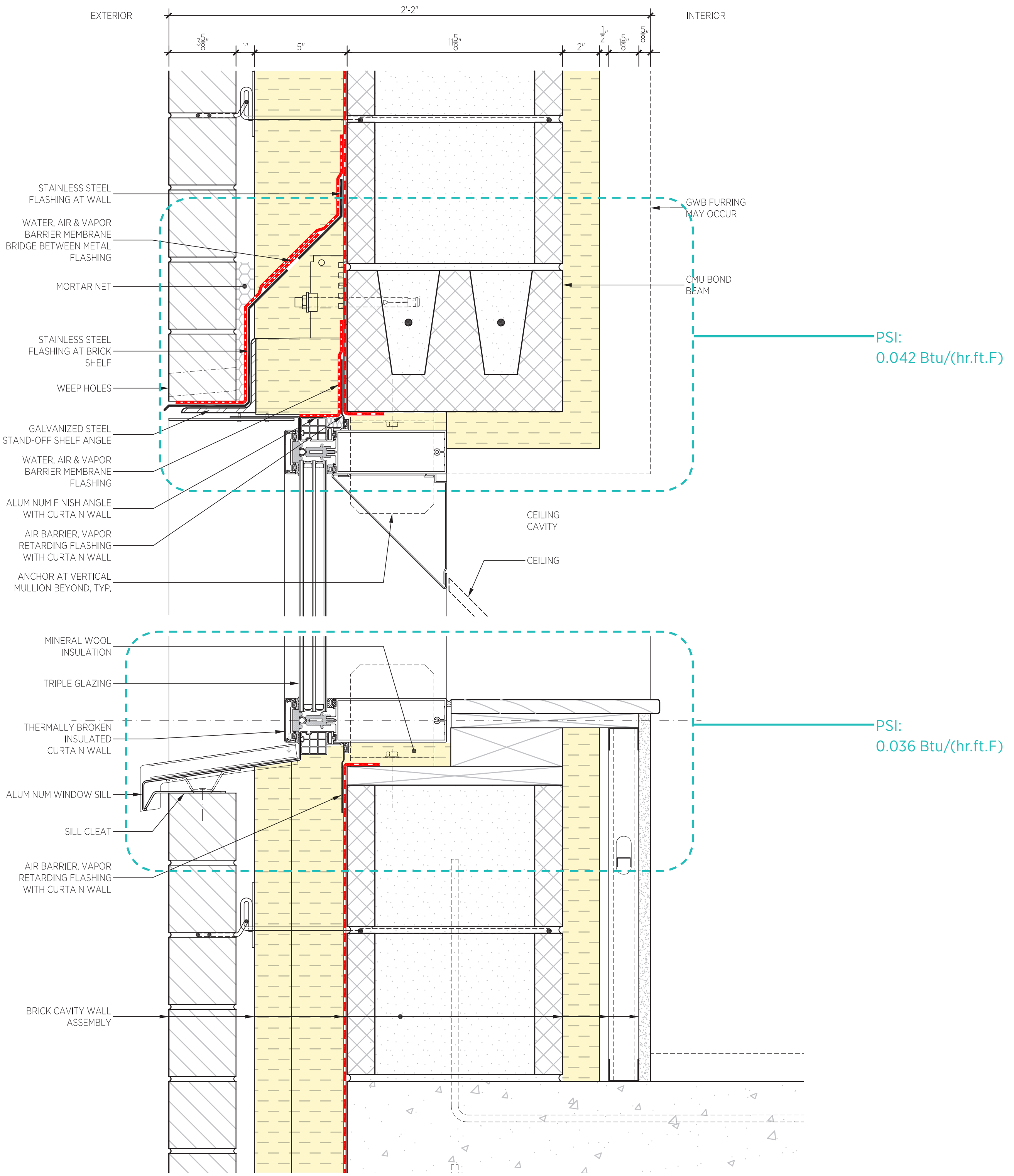


Figure 3.8b:
Passivhaus Proposal -Brick cavity at curtain wall head & sill

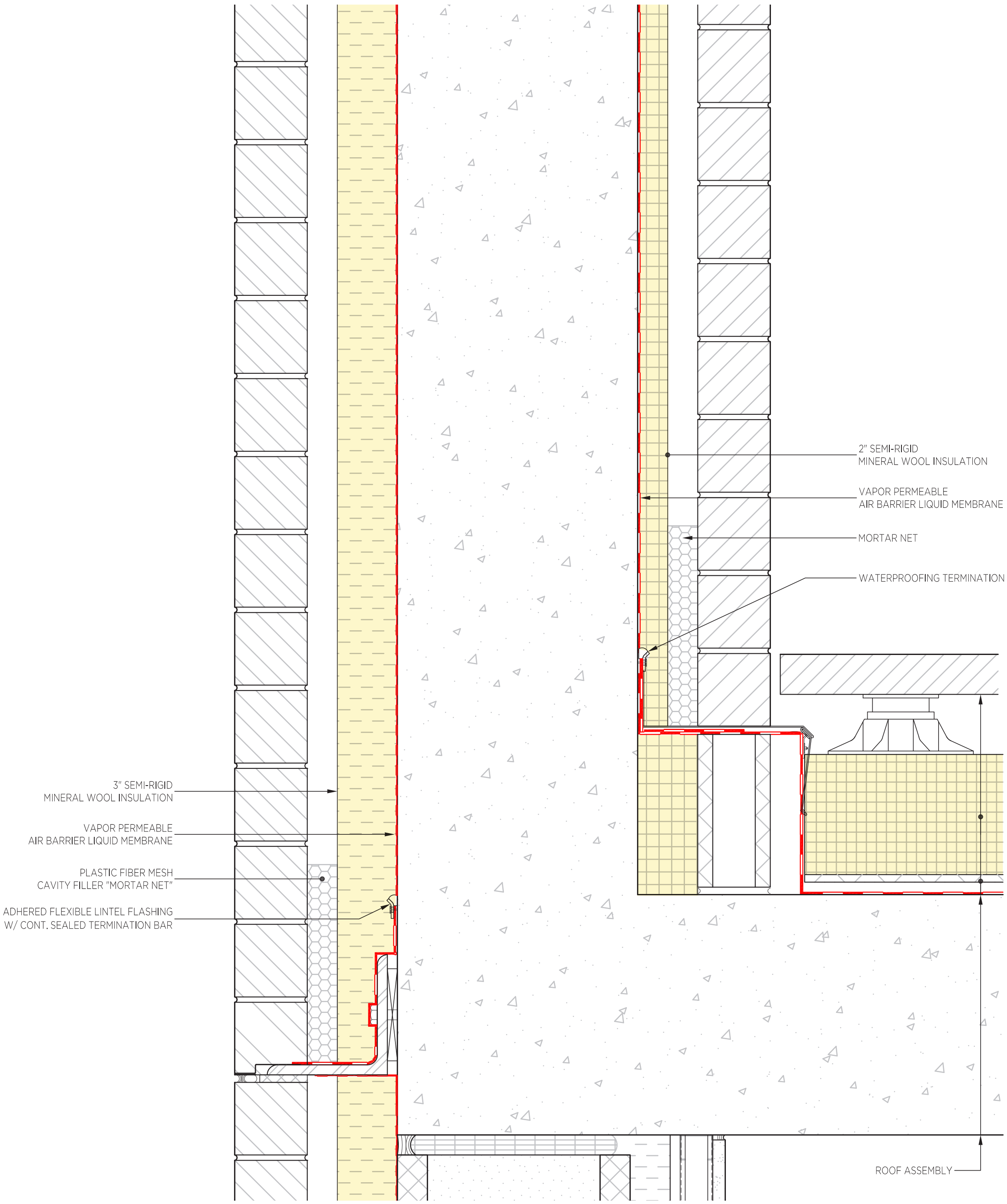


Figure B.9a:
Base case Building - Brick cavity at roof parapet

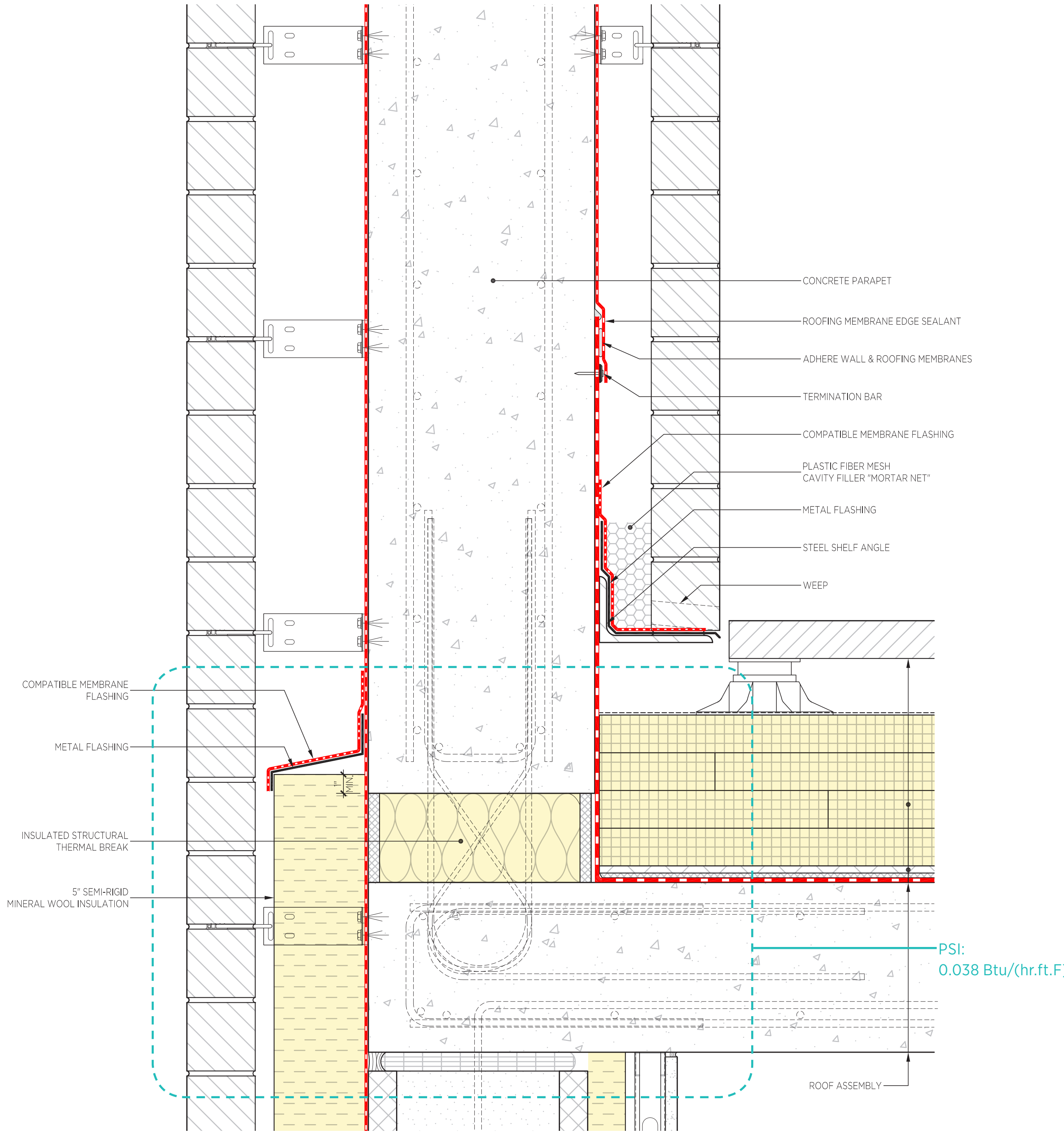


Figure B.9b:
Passivhaus Proposal -Brick cavity at roof parapet

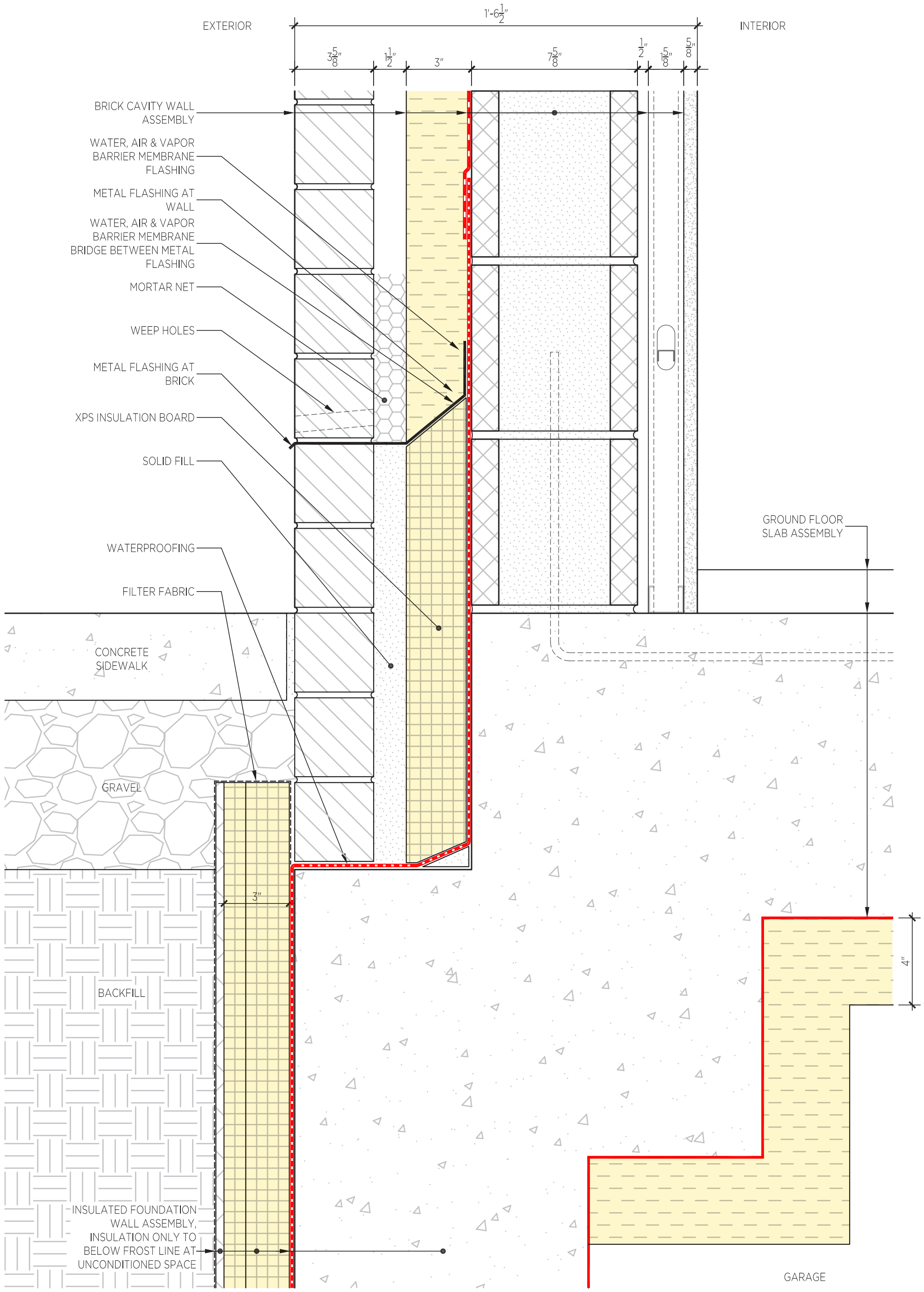


Figure B.10a:
Base case Building - Brick cavity at grade with foundation wall and ground floor slab

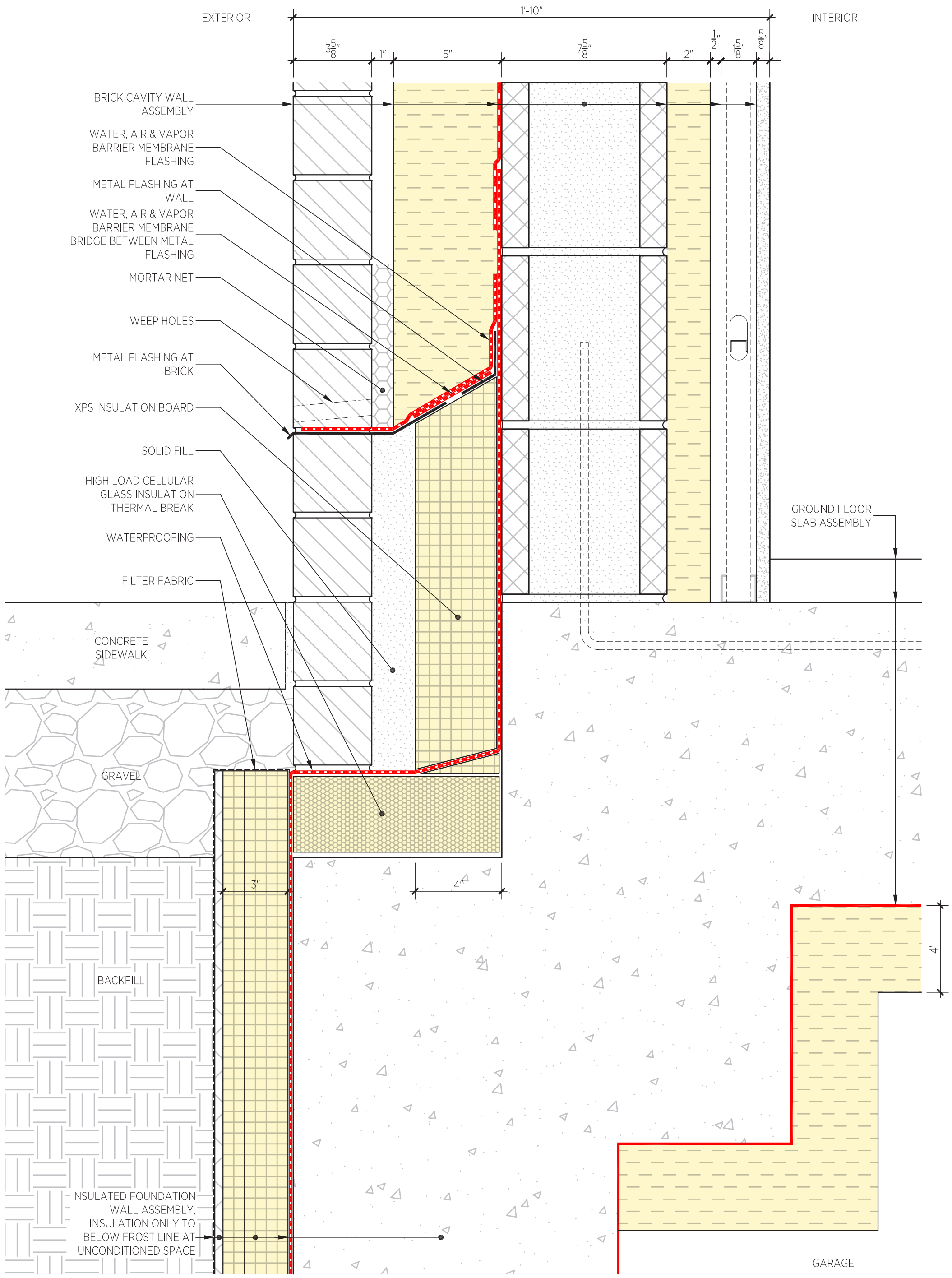


Figure B.10b:
Passivhaus Proposal - Brick cavity at grade with foundation wall and ground floor slab

APPENDIX C

THERMAL ANALYSIS

©

Psi Calculation

Client	FX Fowle	
Detail	Brick window sill	
Detail No.	**1**	www.passivehouseacademy.com

Psi value

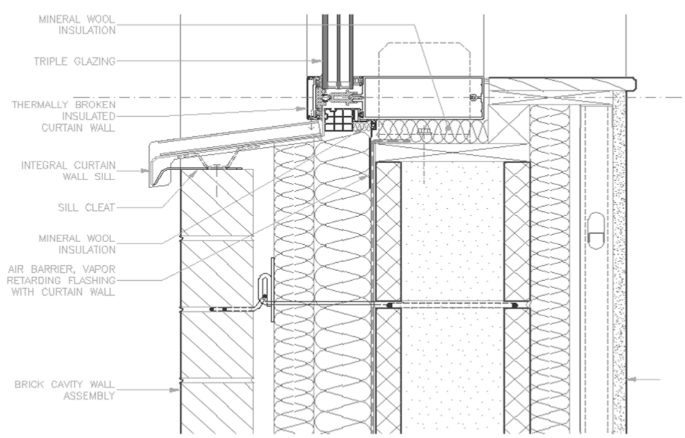
Full model Q-value (W/m)	dT (K)	L2d	
14.891	30	0.496	
Window Q value (W/m)	dT (K)	length in model (mm)	Window U-value
4.23	20	269.2	0.786
Wall model Q-value (W/m)	dT (K)	length in model (mm)	
1.951	30	395.9	0.164
Wall length in full model		1357.9	

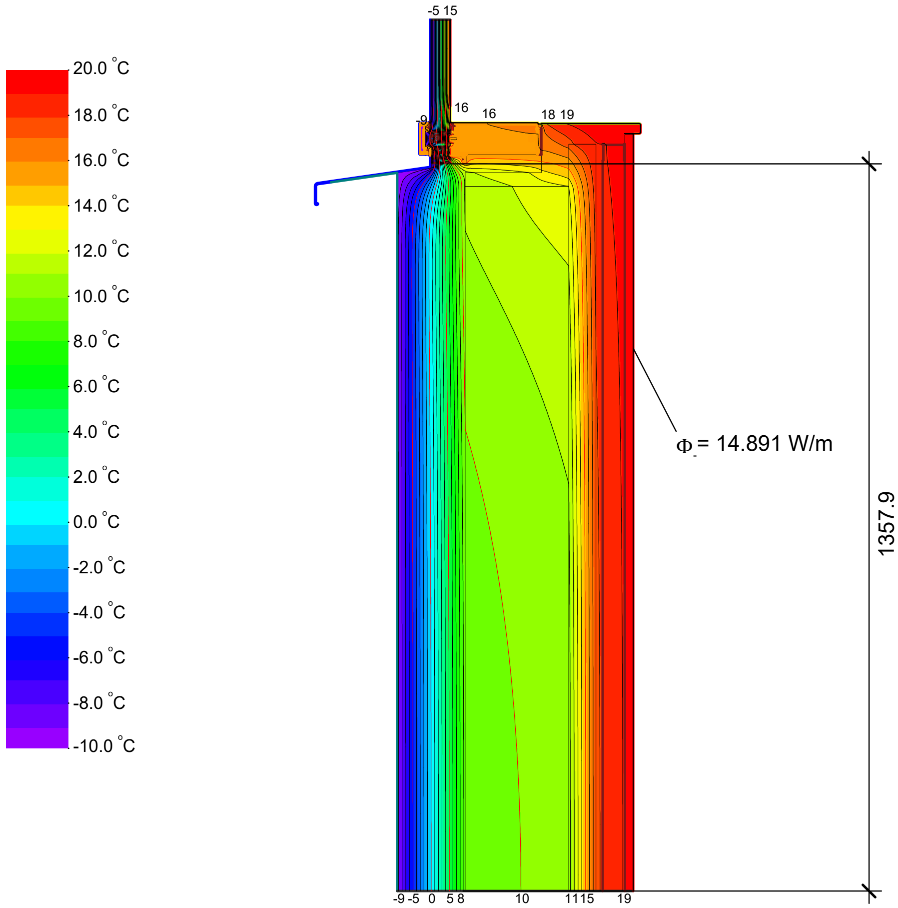
Psi	**0.062**	**W/mK**

fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***17.0***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor	**0.88**	**fRsi %**





Material	λ[W/(m·K)]	ε
Aluminum	160.000	0.900
Aluminum	160.000	0.300
CMU	0.801	
EPDM	0.250	0.300
EPDM	0.250	0.900
Gypsum board	0.250	0.900
Mineral wool 0.034	0.034	0.300
Mineral wool 0.034	0.034	0.900
PE foam	0.040	0.900
PVC	0.170	0.900
Panel	0.035	0.900
Silicone	0.350	0.900
Silicone	0.350	0.300
Slightly ventilated air cavity	anisotropic	
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	
Wood	0.130	0.900

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.3				0.300
Epsilon 0.9				0.900
Exterior, normal		-10.000	0.040	
Exterior, ventilated		-10.000	0.130	
Interior, frame, normal		20.000	0.130	
Interior, frame, reduced		20.000	0.200	
Interior, heat flux, downwards		20.000	0.170	
Interior, heat flux, upwards		20.000	0.100	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

01/04/2016
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flixo frame 7.0.625.1

Psi Calculation

Client FX Fowle
Detail Brick window head
Detail No. **2**

PHA Passive House Academy
www.passivehouseacademy.com

Psi value

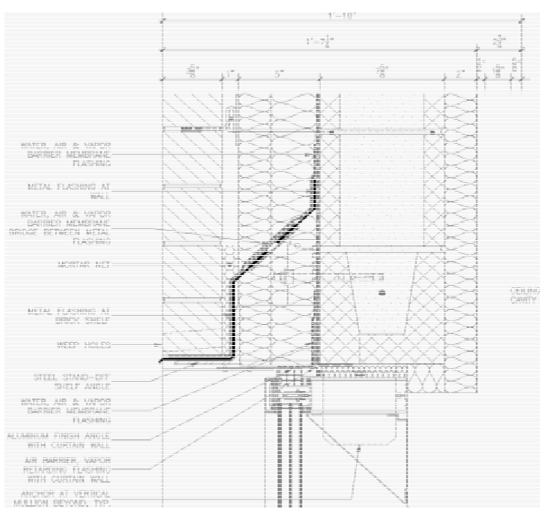
Full model Q-value (W/m)	dT (K)	L2d	
18.882	30	0.629	
Window Q value (W/m)	dT (K)	length in model (mm)	Window U-value
5.215	20	271.0	0.962
Wall model Q-value (W/m)	dT (K)	length in model (mm)	
1.951	30	395.9	0.164
Wall length in full model		1798.4	

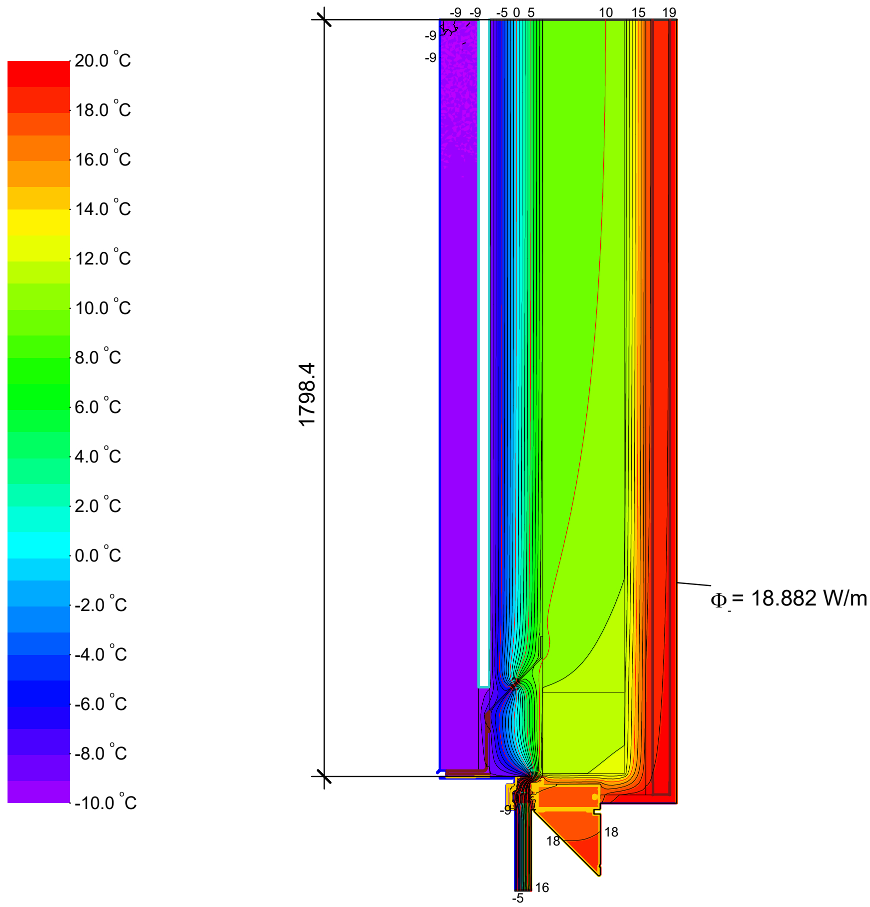
Psi **0.073** **W/mK**

fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***18.5***	°c
Internal Temp	Ti	***20.0***	°c
External Temp	Te	***-5.0***	°c
Critical temperature factor		**0.70**	

Temperature Factor **0.94** **fRsi %**





Material	λ[W/(m·K)]	ε
Aluminum	160.000	0.300
Brick	0.848	
CMU	0.801	
Concrete, 1% Steel	2.300	
EPDM	0.250	0.900
Gypsum board	0.250	0.900
Mineral wool 0.034	0.034	0.900
Mortar net	0.040	
PE foam	0.040	0.900
PVC	0.170	0.900
Panel	0.035	0.900
Slightly ventilated air cavity	anisotropic	
Stainless steel	17.000	0.900
Unventilated air cavity	anisotropic	
Wood	0.130	0.900

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.3				0.300
Epsilon 0.9				0.900
Exterior, normal		-10.000	0.040	
Exterior, ventilated		-10.000	0.130	
Interior, frame, normal		20.000	0.130	
Interior, frame, reduced		20.000	0.200	
Interior, heat flux, upwards		20.000	0.100	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

01/04/2016
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flixo frame 7.0.625.1

Psi Calculation

Client FX Fowle
Detail Brick window jamb
Detail No. **3**

PHA Passive House Academy
www.passivehouseacademy.com

Psi value

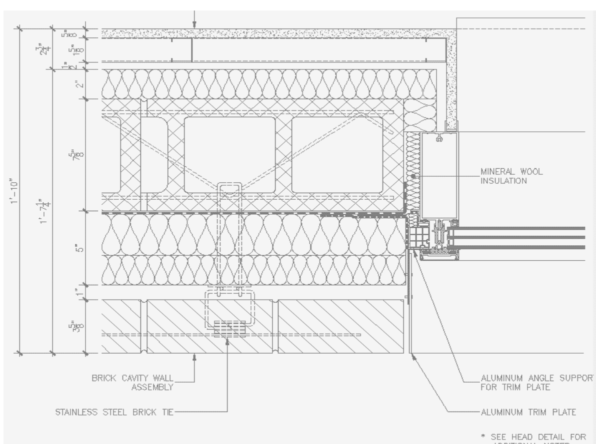
Full model Q-value (W/m)	dT (K)	L2d	
17.864	30	0.595	
Window Q value (W/m)	dT (K)	length in model (mm)	Window U-value
4.23	20	269.2	0.786
Wall model Q-value (W/m)	dT (K)	length in model (mm)	
1.943	30	393.5	0.165
Wall length in full model		1726.8	

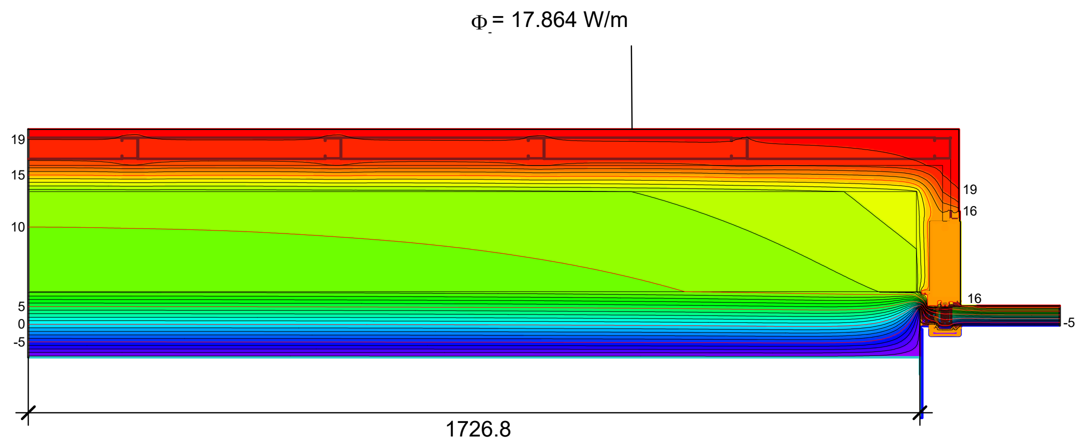
Psi **0.100** **W/mK**

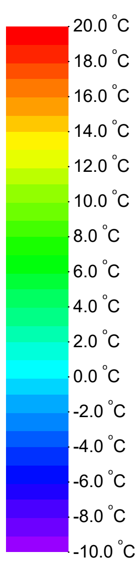
fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***16.4***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor **0.86** **fRsi %**







Material	λ[W/(m·K)]	ε
Aluminum	160.000	0.900
Aluminum	160.000	0.300
CMU	0.801	
EPDM	0.250	0.900
Gypsum board	0.250	0.900
Mineral wool 0.034	0.034	
PE foam	0.040	0.900
PVC	0.170	0.300
PVC	0.170	0.900
Panel	0.035	0.900
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	
Wood	0.130	0.900

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.3				0.300
Epsilon 0.9				0.900
Exterior, normal		-10.000	0.040	
Exterior, ventilated		-10.000	0.130	
Interior, frame, normal		20.000	0.130	
Interior, frame, reduced		20.000	0.200	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

01/04/2016
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flixo frame 7.0.625.1

Psi Calculation

Client FX Fowle
Detail Brick wall. Intermediate floor
Detail No. **4**

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Psi value

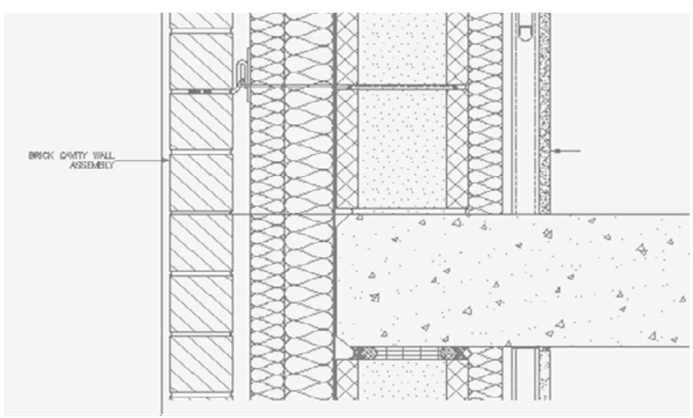
Full model Q-value (W/m)	dT (K)	L2d	
16.039	30	0.535	
Elemental 1	dT (K)	length in model (mm)	Element 1 U-value
1.945	30	393.5	0.165
Wall length in full model		2876.5	

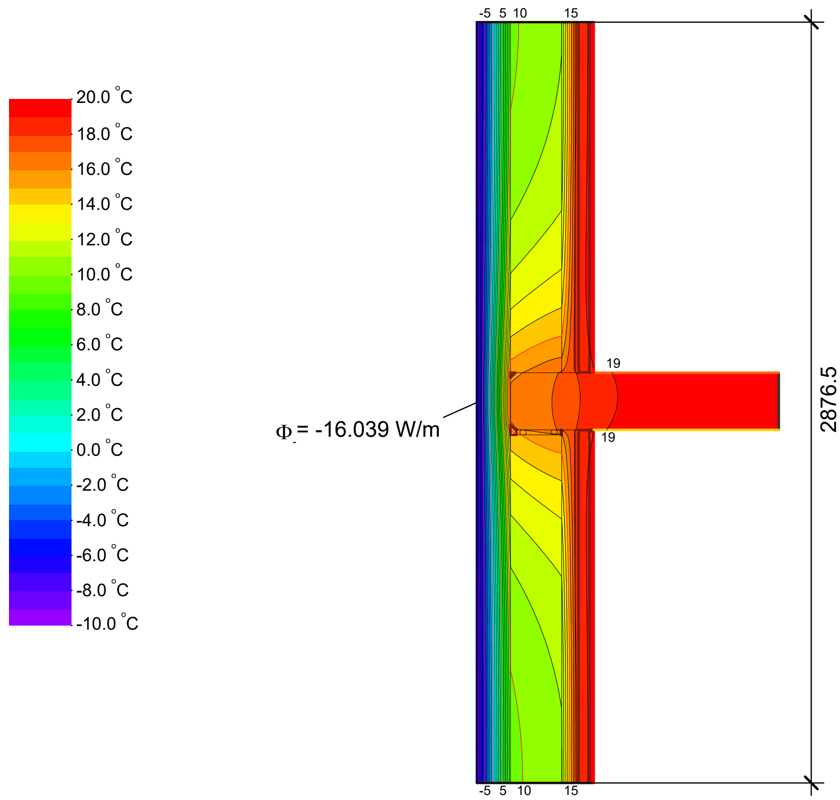
Psi **0.061** **W/mK**

fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***18.4***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor **0.94** **fRsi %**





Material	λ[W/(m·K)]	ε
CMU	0.801	0.900
Concrete, reinforced (with 2% of steel)	2.500	0.900
EPDM	0.250	
Gypsum board	0.250	0.900
Mineral wool 0.034	0.034	0.900
Neoprene (polychloroprene)	0.230	
Silicone foam	0.120	0.900
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	
Wood	0.130	0.900

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.9				0.900
Exterior, ventilated		-10.000	0.130	
Interior, heat flux, downwards		20.000	0.170	
Interior, heat flux, upwards		20.000	0.100	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

03/03/2016
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flixo frame 7.0.625.1

Psi Calculation

Client FX Fowle
Detail Parapet
Detail No. **5**

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Psi value

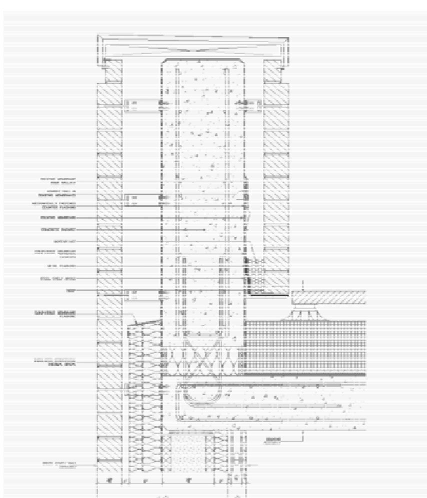
Full model Q-value (W/m)	dT (K)	L2d	
19.415	30	0.647	
Wall U-value (W/m^{2}K)		length in model (mm)	l_w* U'_w
0.164		1931.8	0.317
Roof U-value (W/m^{2}K)		length in model (mm)	l_R*U'_R
0.136		1941.3	0.264

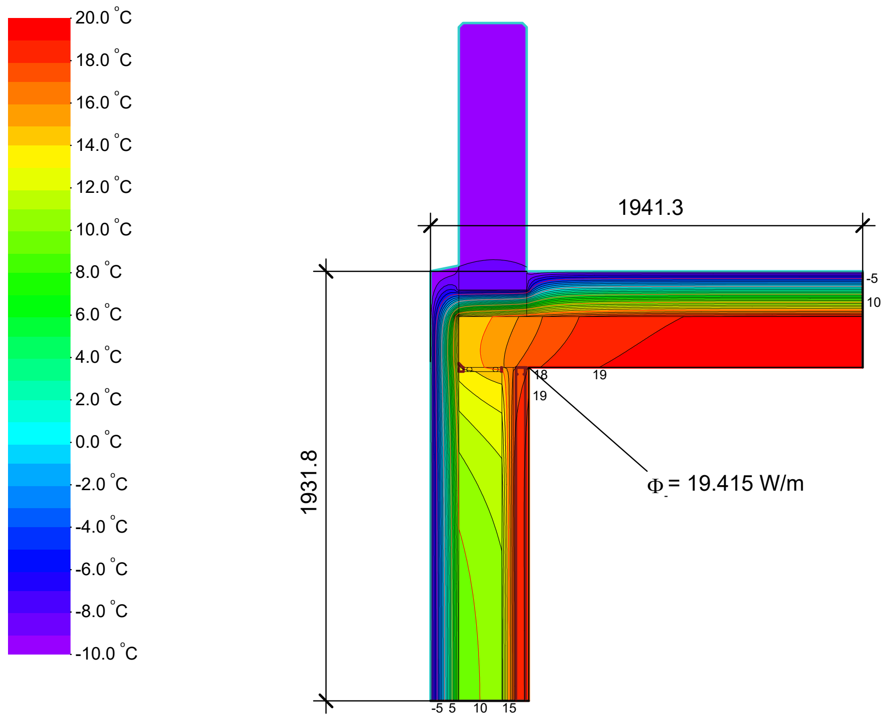
Psi **0.066** **W/mK**

fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***16.9***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor **0.88** **fRsi %**





Material	λ[W/(m·K)]	ε
CMU	0.801	0.900
Concrete, reinforced (with 2% of steel)	2.500	0.900
EPDM	0.250	
Gypsum board	0.250	0.900
Insulation EPS 0.057	0.057	
Mineral wool 0.034	0.034	0.900
Neoprene (polychloroprene)	0.230	
Rigid insulation 0.029	0.029	
Silicone foam	0.120	0.900
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	
Wood	0.130	0.900

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.9				0.900
Exterior, ventilated		-10.000	0.130	
Interior, heat flux, upwards		20.000	0.100	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

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flixo frame 7.0.625.1

Psi Calculation

PHA Passive House Academy

Client FX Fowle
Detail Rainscreen spandrel sill
Detail No. **6**

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Psi value

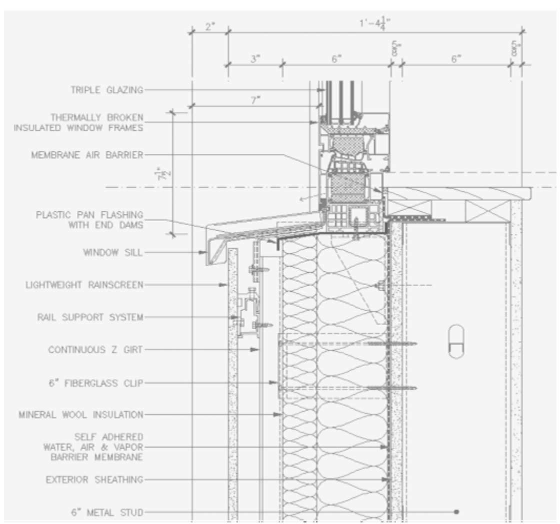
Full model Q-value (W/m)	dT (K)	L2d	
16.977	30	0.566	
Window Q value (W/m)	dT (K)	length in model (mm)	Window U-value
6.938	20	379.5	0.914
Wall model Q-value (W/m)	dT (K)	length in model (mm)	
2.361	30	400	0.197
Wall length in full model		1100	

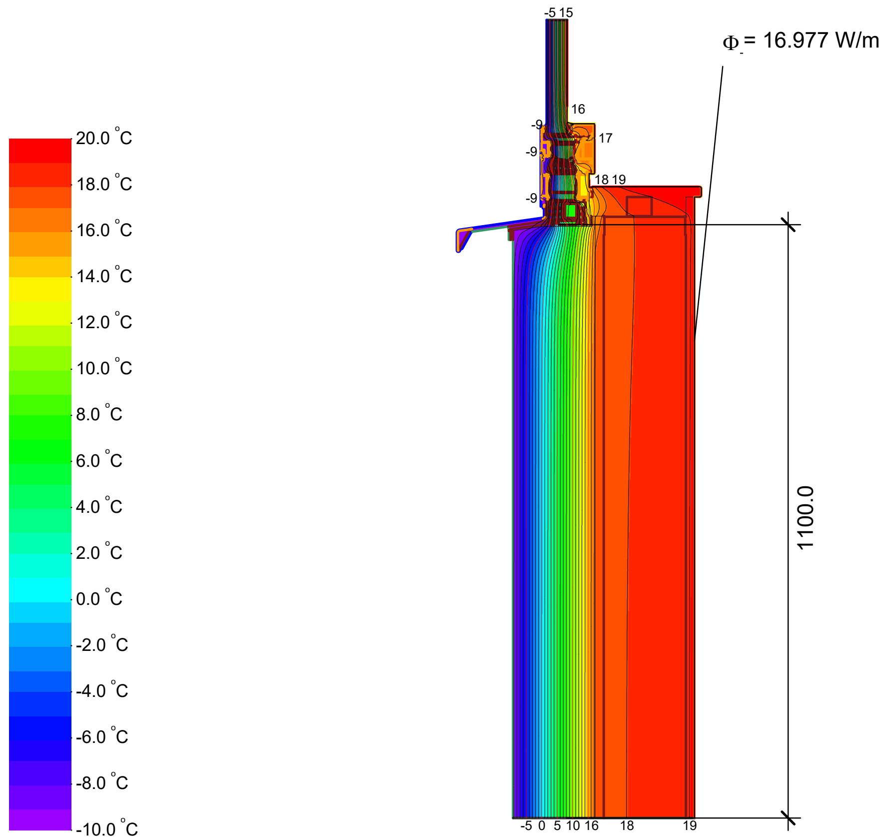
Psi **0.003** **W/mK**

fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***15.1***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor **0.80** **fRsi %**





Material	λ[W/(m·K)]	ε
Aluminum	160.000	0.900
Aluminum	160.000	0.300
EPDM	0.250	0.900
Foam Fill	0.040	0.900
Gypsum	0.250	0.900
Mineral wool 0.034	0.034	0.900
PVC	0.170	0.300
PVC	0.170	0.900
PVC flexible 0.14	0.140	0.900
Panel	0.035	0.900
Silicone foam	0.120	0.300
Silicone foam	0.120	0.900
Slightly ventilated air cavity	anisotropic	
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	
Wood	0.130	0.900

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.3				0.300
Epsilon 0.9				0.900
Exterior, normal		-10.000	0.040	
Exterior, ventilated		-10.000	0.130	
Interior, frame, normal		20.000	0.130	
Interior, frame, reduced		20.000	0.200	
Interior, heat flux, downwards		20.000	0.170	
Interior, heat flux, upwards		20.000	0.100	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

01/04/2016
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flixo frame 7.0.625.1

Psi Calculation

Client FX Fowle
Detail Rainscreen spandrel head
Detail No. **7**

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Psi value

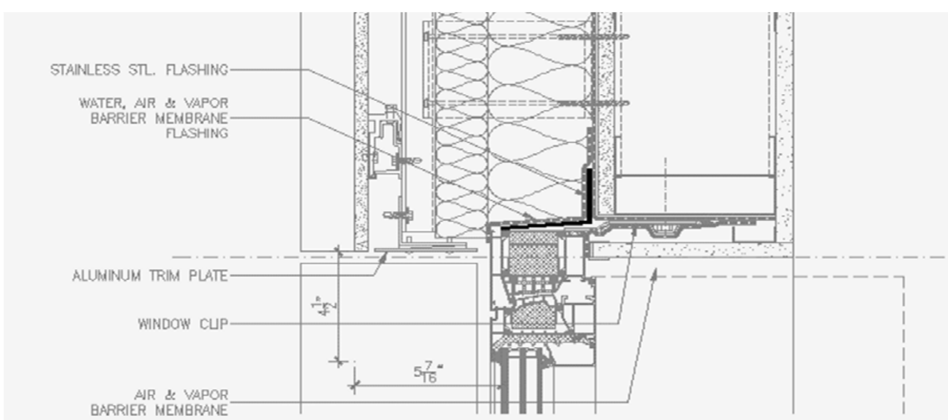
Full model Q-value (W/m)	dT (K)	L2d	
15.637	30	0.521	
Window Q value (W/m)	dT (K)	length in model (mm)	Window U-value
6.938	20	379.5	0.914
Wall model Q-value (W/m)	dT (K)	length in model (mm)	
2.361	30	400	0.197
Wall length in full model		1099.8	

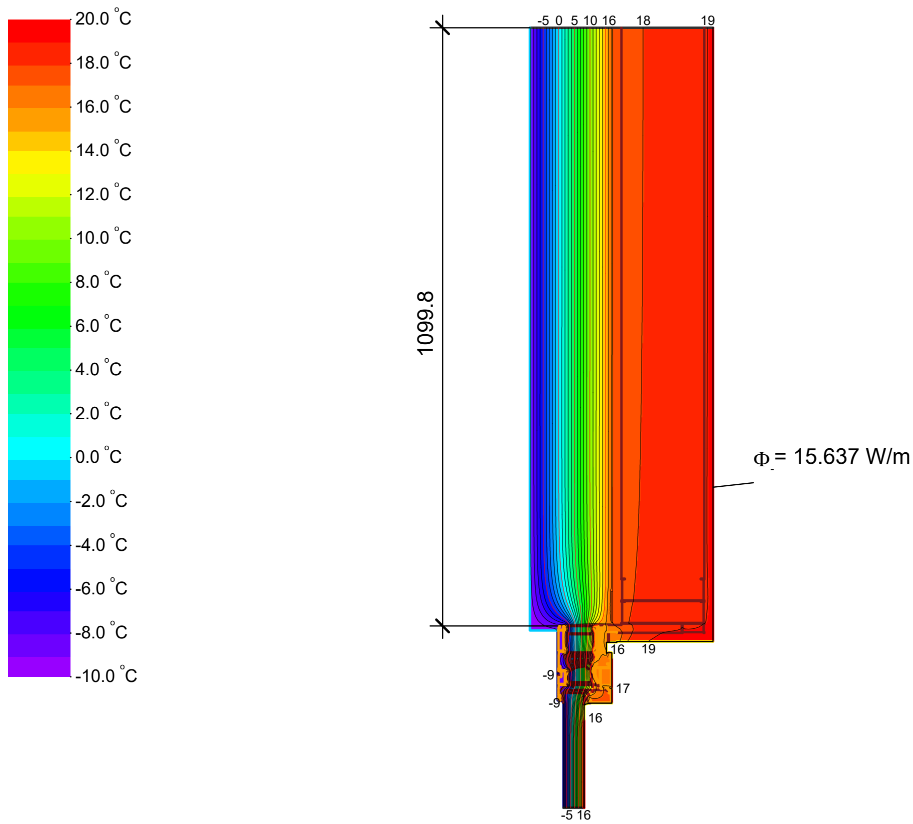
Psi **-0.042** **W/mK**

fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***16.7***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor **0.87** **fRsi %**





Material	λ[W/(m·K)]	ε
Aluminum	160.000	0.300
Aluminum	160.000	0.900
EPDM	0.250	0.900
Foam Fill	0.040	0.900
Gypsum	0.250	0.900
Mineral wool 0.034	0.034	0.900
PVC	0.170	0.900
PVC flexible 0.14	0.140	0.900
Panel	0.035	0.900
Slightly ventilated air cavity	anisotropic	
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.3				0.300
Epsilon 0.9				0.900
Exterior, normal		-10.000	0.040	
Exterior, ventilated		-10.000	0.130	
Interior, frame, normal		20.000	0.130	
Interior, frame, reduced		20.000	0.200	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

01/04/2016
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flixo frame 7.0.625.1

Psi Calculation

Client FX Fowle
Detail Rainscreen spandrel jamb
Detail No. **8 (insulation 8")**

www.passivehouseacademy.com

Psi value

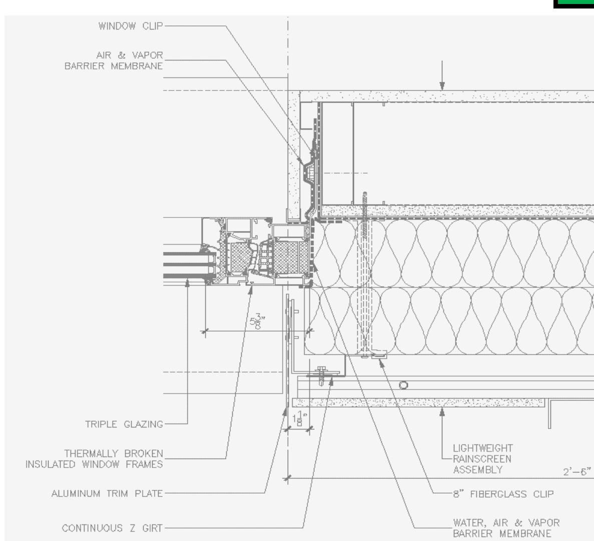
Full model Q-value (W/m)	dT (K)	L2d	
13.357	30	0.445	
Window Q value (W/m)	dT (K)	length in model (mm)	Window U-value
5.355	20	334.3	0.801
Wall model Q-value (W/m)	dT (K)	length in model (mm)	
1.856	30	406.4	0.152
Wall length in full model		1082.3	

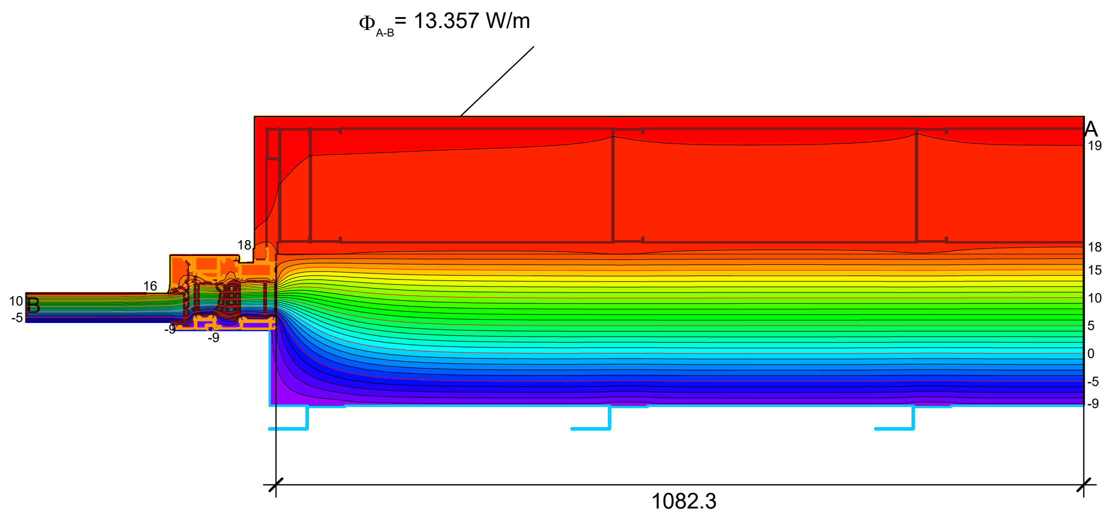
Psi **0.013** **W/mK**

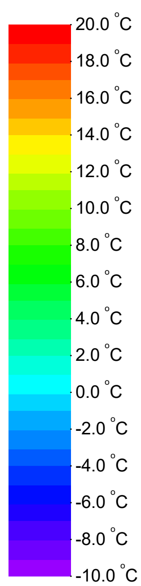
fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***17.5***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor **0.90** **fRsi %**







Material	λ[W/(m·K)]	ε
Aluminum	160.000	0.900
Aluminum	160.000	0.300
EPDM	0.250	0.900
Foam Fill	0.020	0.900
Gypsum	0.250	0.900
Mineral wool 0.034	0.034	0.900
PVC	0.170	0.900
PVC flexible 0.14	0.140	0.900
Panel	0.035	0.900
Slightly ventilated air cavity	anisotropic	
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.3				0.300
Epsilon 0.9				0.900
Exterior, normal		-10.000	0.040	
Exterior, ventilated		-10.000	0.130	
Interior, frame, normal		20.000	0.130	
Interior, frame, reduced		20.000	0.200	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

04/03/2016
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flixo frame 7.0.625.1

Psi Calculation

Client	FX Fowle	
Detail	Rainscreen spandrel jamb	
Detail No.	**8 (insulation 6")**	www.passivehouseacademy.com

Psi value

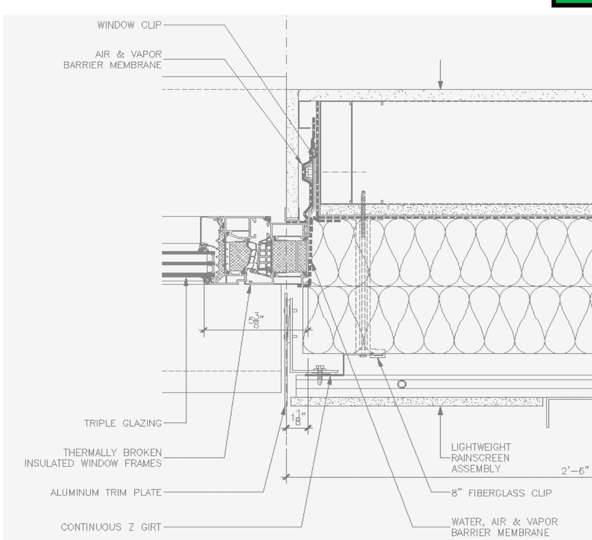
Full model Q-value (W/m)	dT (K)	L2d	
15.337	30	0.511	
Window Q value (W/m)	dT (K)	length in model (mm)	Window U-value
6.938	20	379.5	0.914
Wall model Q-value (W/m)	dT (K)	length in model (mm)	
2.404	30	406.4	0.197
Wall length in full model		1082.3	

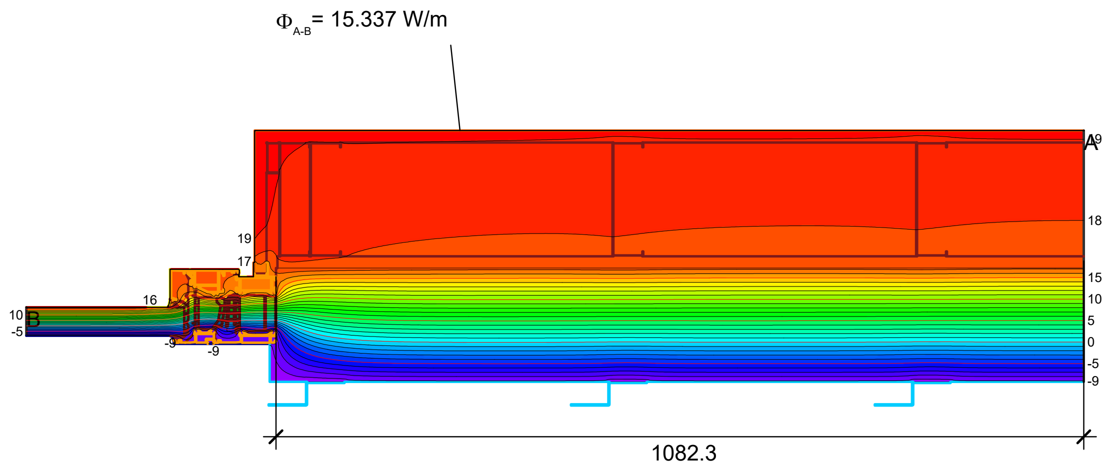
Psi **-0.049** **W/mK**

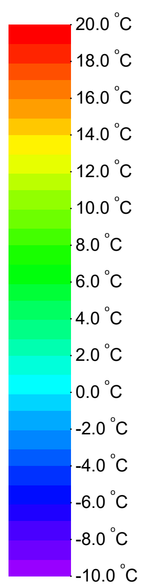
fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***17.0***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor **0.88** **fRsi %**







Material	λ[W/(m·K)]	ε
Aluminum	160.000	0.900
Aluminum	160.000	0.300
EPDM	0.250	0.900
Foam Fill	0.040	0.900
Gypsum	0.250	0.900
Mineral wool 0.034	0.034	0.900
PVC	0.170	0.900
PVC flexible 0.14	0.140	0.900
Panel	0.035	0.900
Slightly ventilated air cavity	anisotropic	
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.3				0.300
Epsilon 0.9				0.900
Exterior, normal		-10.000	0.040	
Exterior, ventilated		-10.000	0.130	
Interior, frame, normal		20.000	0.130	
Interior, frame, reduced		20.000	0.200	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

01/04/2016
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flixo frame 7.0.625.1

Psi Calculation

Client FX Fowle
Detail Rainscreen wall. Intermediate floor
Detail No. **9**

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Psi value

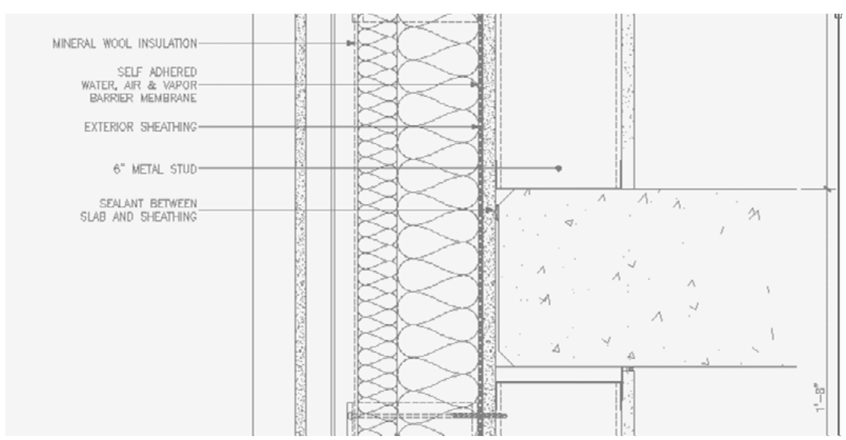
Full model Q-value (W/m)	dT (K)	L2d	
14.416	30	0.481	
Elemental 1	dT (K)	length in model (mm)	Element 1 U-value
2.361	30	400	0.197
Wall length in full model		2411.7	

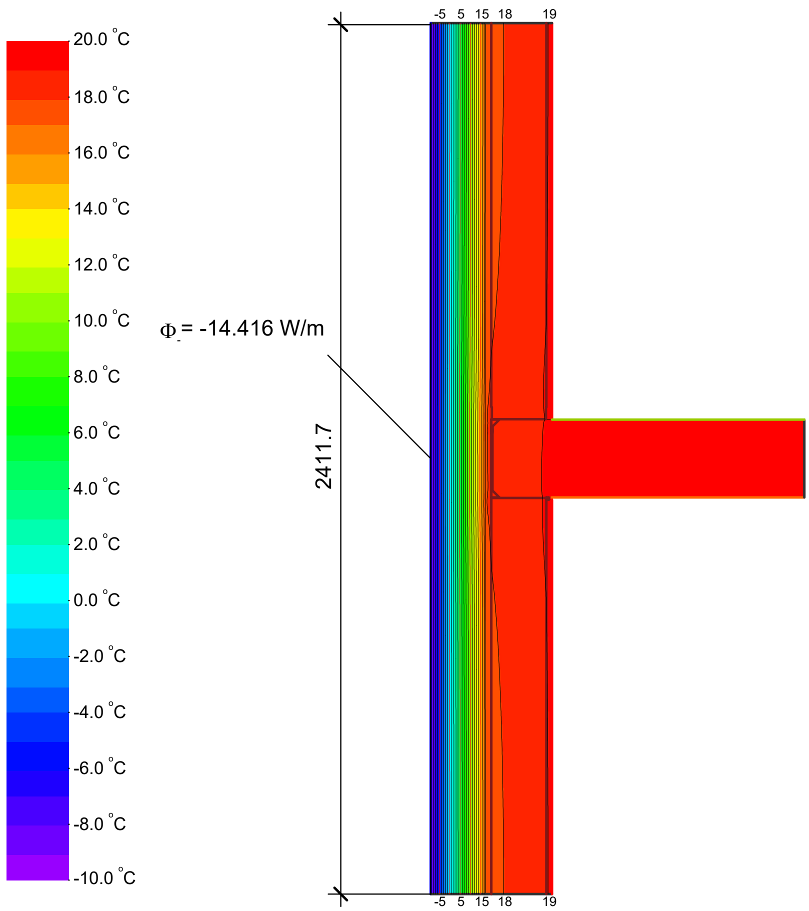
Psi **0.006** **W/mK**

fRsi

Lowest Surface temp @0.25 Rsi	Tsi	18.9	°C
Internal Temp	Ti	20.0	°C
External Temp	Te	-5.0	°C
Critical temperature factor		0.70	

Temperature Factor **0.96** **fRsi %**





Material	λ[W/(m·K)]	ε
Concrete, reinforced (with 2% of steel)	2.500	0.900
EPDM	0.250	0.900
Gypsum	0.250	0.900
Mineral wool 0.034	0.034	
Silicone foam	0.120	0.900
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.9				0.900
Exterior, ventilated		-10.000	0.130	
Interior, heat flux, downwards		20.000	0.170	
Interior, heat flux, upwards		20.000	0.100	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

03/03/2016
Q:\0000 Jobs 5100 Studies\5108 FX FOWLE\5108 CONSULTANT\Task 5 - Thermal Bridge Details\9_Junction (Ext.wall - intermediate floor).flx

flixo frame 7.0.625.1

Psi Calculation

Client FX Fowle
Detail Function between rainscreen walls
Detail No. **10**

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Psi value

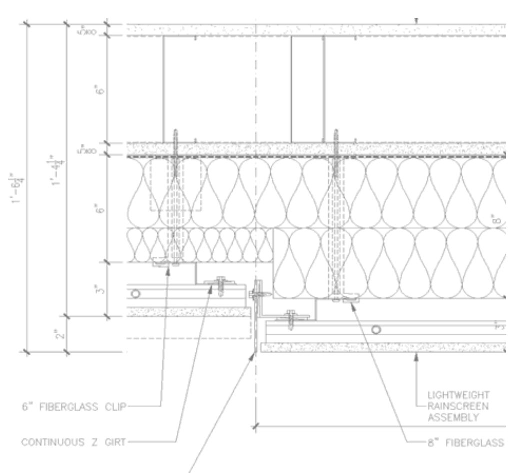
Full model Q-value (W/m)	dT (K)	L2d	
13.696	30	0.457	
Wall 1 model Q-value (W/m)	dT (K)	length in model (mm)	Window U-value
2.404	30	406.4	0.197
		length in the full model (mm)	$l_w * U'_w$
		1135.2	0.224
Wall 2 model Q-value (W/m)	dT (K)	length in model (mm)	$l_w * U'_w$
1.856	30	406.4	0.152
		length in the full model (mm)	
		1506.4	0.229

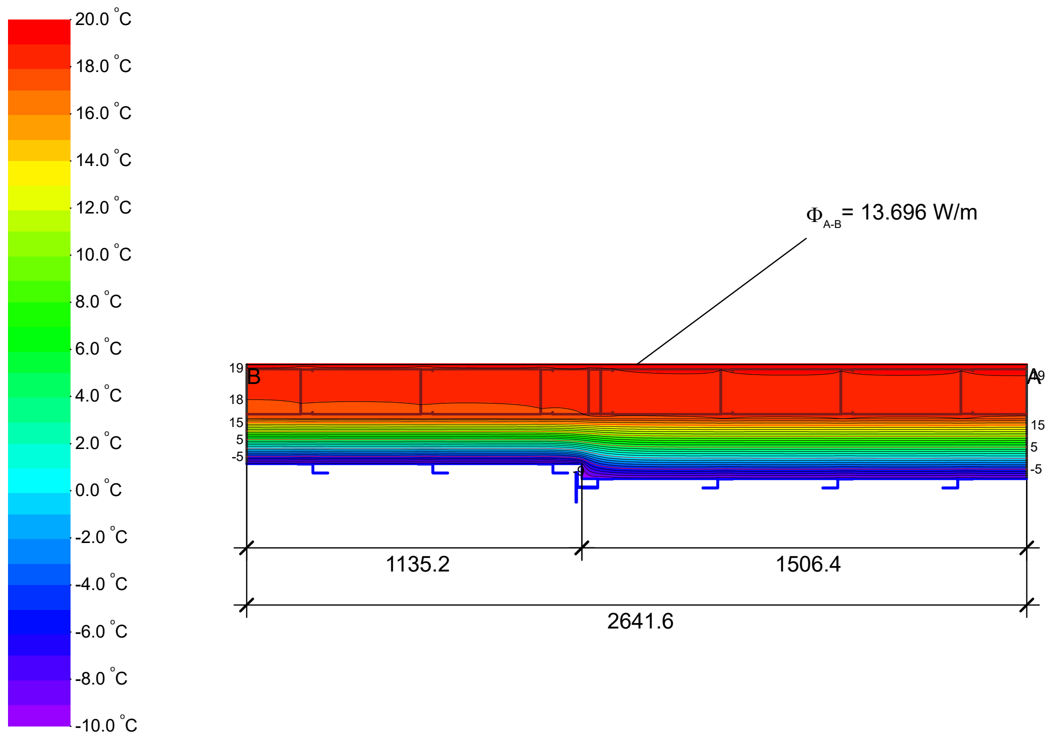
Psi **0.003** **W/mK**

fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***18.8***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor **0.95** **fRsi %**





Material	λ[W/(m·K)]	ε
Gypsum	0.250	0.900
Mineral wool 0.034	0.034	
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.9				0.900
Exterior, ventilated		-10.000	0.130	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

04/03/2016
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flixo frame 7.0.625.1

Psi Calculation

Client	FX Fowle
Detail	Parapet (rainscreen wall)
Detail No.	**11**

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Psi value

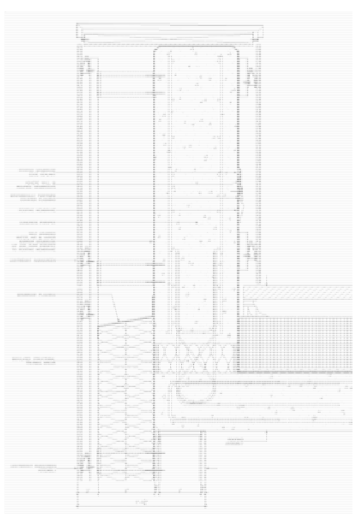
Full model Q-value (W/m)	dT (K)	L2d	
16.889	30	0.563	
Wall U-value (W/m²K)		length in model (mm)	l_w* U'_w
0.152		1658.2	0.252
Roof U-value (W/m²K)		length in model (mm)	l_R*U'_R
0.136		2017.5	0.275

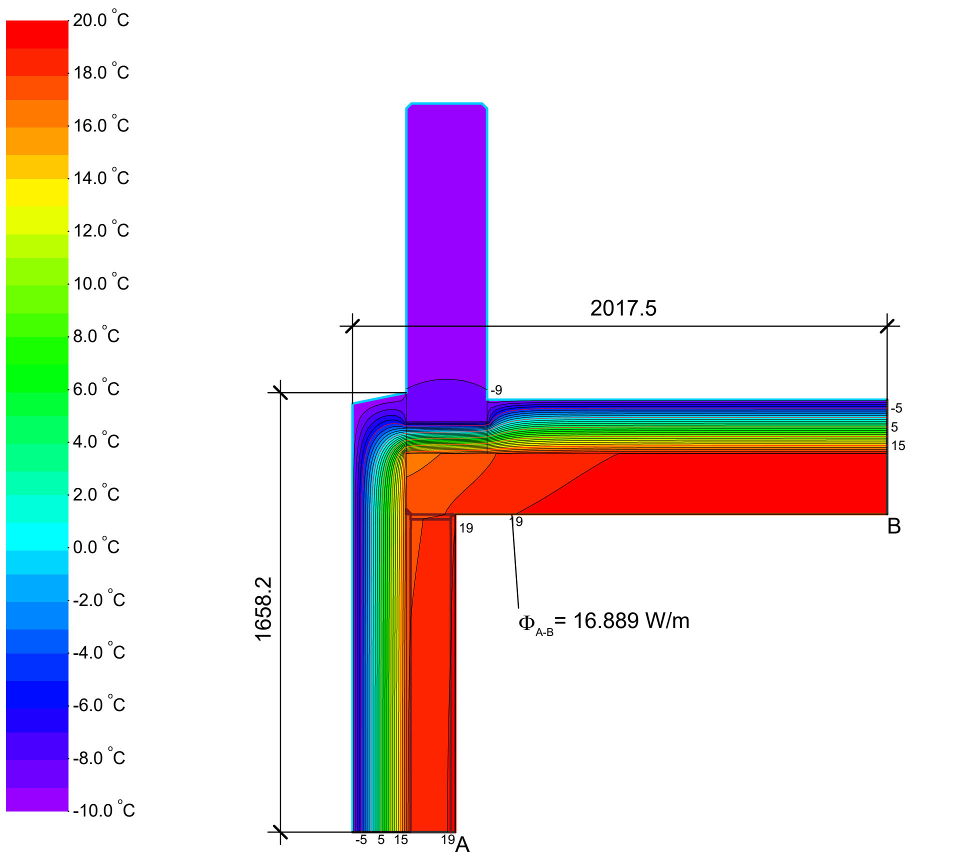
Psi **0.036** **W/mK**

fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***17.6***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor **0.91** **fRsi %**





Material	λ[W/(m·K)]	ε
Concrete, reinforced (with 2% of steel)	2.500	0.900
Gypsum	0.250	0.900
Insulation EPS 0.057	0.057	
Mineral wool 0.034	0.034	0.900
Rigid insulation 0.029	0.029	
Silicone foam	0.120	0.900
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.9				0.900
Exterior, ventilated		-10.000	0.130	
Interior, heat flux, upwards		20.000	0.100	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

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flixo frame 7.0.625.1

Psi Calculation

Client	FX Fowle
Detail	Rainscreen soffit
Detail No.	**12**

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Psi value

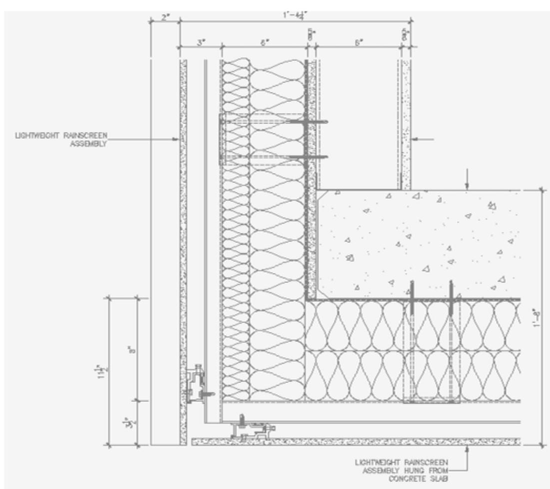
Full model Q-value (W/m)	dT (K)	L2d	
15.125	30	0.504	
Wall U-value (W/m²K)		length in model (mm)	l_w* U'_w
0.197		1519.1	0.299
Floor U-value (W/m²K)		length in model (mm)	l_R*U'_R
0.157		1636.5	0.257

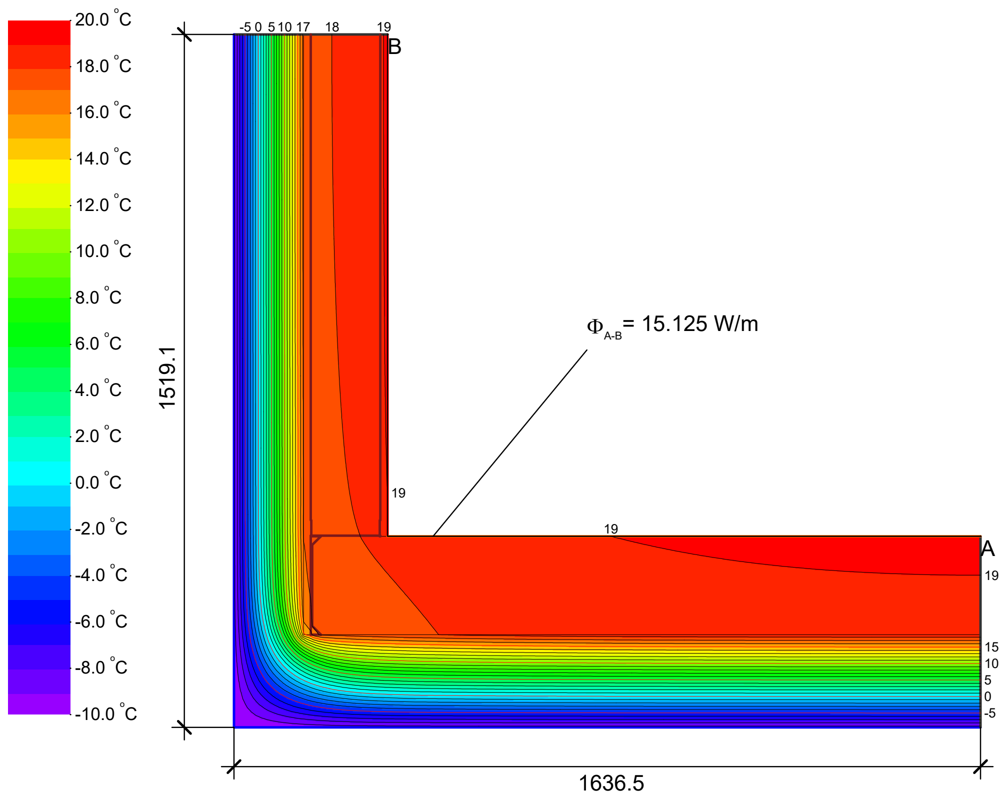
Psi **-0.052** **W/mK**

fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***18.0***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor **0.92** **fRsi %**





Material	λ[W/(m·K)]	ε
Concrete, reinforced (with 2% of steel)	2.500	0.900
Gypsum	0.250	0.900
Mineral wool 0.034	0.034	0.900
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.9				0.900
Exterior, ventilated		-10.000	0.130	
Interior, heat flux, downwards		20.000	0.170	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

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flixo frame 7.0.625.1

Psi Calculation

Client FX Fowle
Detail Rainscreen balcony
Detail No. **13**

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Psi value

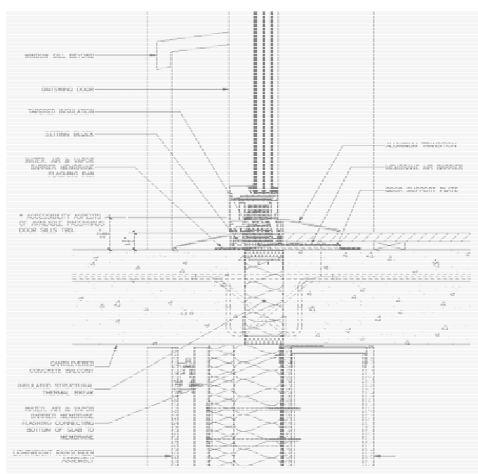
Full model Q-value (W/m)	dT (K)	L2d	
21.099	30	0.703	
Window Q value (W/m)	dT (K)	length in model (mm)	Window U-value
5.418	20	321.3	0.843
Wall model Q-value (W/m)	dT (K)	length in model (mm)	
2.361	30	400	0.197
Wall length in full model		1400	

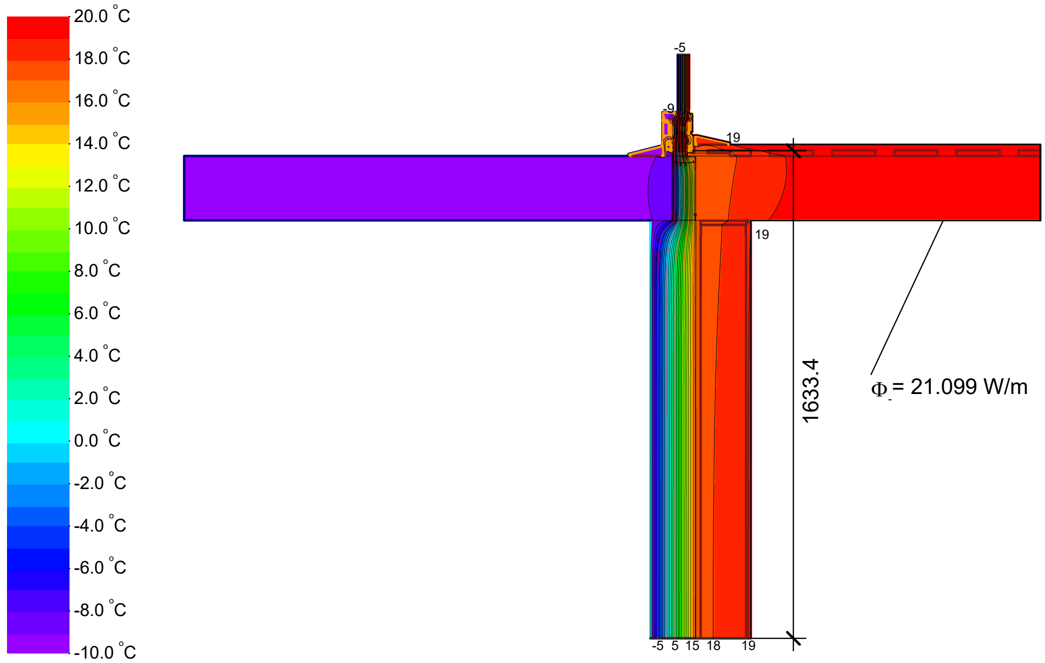
Psi **0.157** **W/mK**

fRsi

Lowest Surface temp @0.25 Rsi	Tsi	***16.9***	°C
Internal Temp	Ti	***20.0***	°C
External Temp	Te	***-5.0***	°C
Critical temperature factor		**0.70**	

Temperature Factor **0.88** **fRsi %**





Material	λ[W/(m·K)]	ε
Aluminum	160.000	0.900
Aluminum	160.000	0.300
Concrete, reinforced (with 2% of steel)	2.500	0.900
EPDM	0.250	0.900
Foam Fill	0.020	0.900
Foam Fill	0.020	0.300
Gypsum	0.250	0.900
Insulation EPS 0.057	0.057	
Mineral wool 0.034	0.034	
PVC	0.170	0.300
PVC	0.170	0.900
PVC flexible 0.14	0.140	0.900
Panel	0.035	0.900
Rigid insulation 0.029	0.030	0.900
Silicone foam	0.120	0.900
Slightly ventilated air cavity	anisotropic	
Stainless steel	30.000	0.900
Unventilated air cavity	anisotropic	
Wood	0.130	0.900

Boundary Condition	$q[W/m^2]$	$\theta[^{\circ}C]$	$R[(m^2 \cdot K)/W]$	ε
Epsilon 0.3				0.300
Epsilon 0.9				0.900
Exterior, normal		-10.000	0.040	
Exterior, ventilated		-10.000	0.130	
Interior, frame, normal		20.000	0.130	
Interior, frame, reduced		20.000	0.200	
Interior, heat flux, downwards		20.000	0.170	
Interior, heat flux, upwards		20.000	0.100	
Interior, normal, horizontal		20.000	0.130	
Symmetry/Model section	0.000			

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flixo frame 7.0.625.1

APPENDIX D

COST ANALYSIS

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PASSIVHAUS TALL RESIDENTIAL BUILDINGS
NYSERDA

INDICTATIVE ECM & LCC REPORT

March 8, 2017

745 ATLANTIC AVENUE
FLOOR 8
BOSTON MA 02111

CONSTRUCTION COST
& RISK CONSULTANTS

PASSIVHAUS TALL RESIDENTIAL BUILDINGS 8-Mar-17
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EXECUTIVE SUMMARY
PASSIVHAUS TALL RESIDENTIAL BUILDINGS
NYSERDA

8-Mar-17

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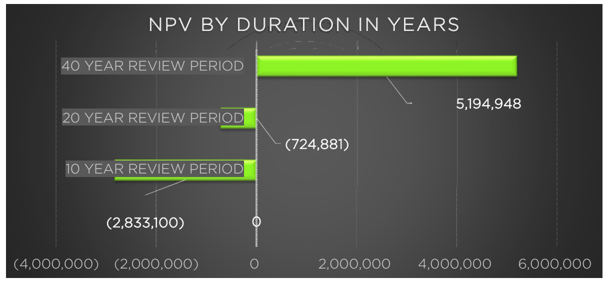
INDICTATIVE ECM & LCC REPORT

The following study reviews the ECM for Passivhaus initiatives on the base case tall residential building. It reviews Passivhaus measures compared to base case design metrics and delivers summary information for PAYBACK PERIODS & NPV over 10, 20 & 40 year durations; reviewing capital costs, annual energy savings & annual maintenance. Based on an initial build cost of $ 375/sf the initial capital required for Passivhaus design of $ 5.3Million equates to 2.4% of the initial estimated building cost. Executive summary results confirm a likely NPV saving of $ 5.2Million over 40 years; this equates to a 2.3% saving on the baseline building investment (Estimated construction cost)

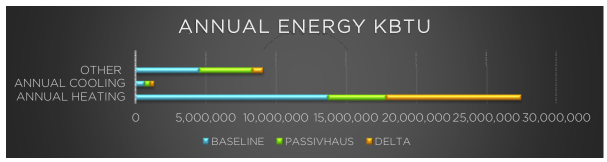
SUMMARY LEVEL RESULTS

PASSIVHAUS TALL RESI BUILDING	SAVINGS ANNUAL	PAYBACK YEARS	NPV NET PRESENT $
10 YEAR REVIEW PERIOD	$ 226,356	No Payback	(2,833,100)
20 YEAR REVIEW PERIOD	$ 226,356	No Payback	(724,881)
40 YEAR REVIEW PERIOD	$ 226,356	24	5,194,948
TYPICAL INITIAL BUILDING	$/SF	($375)	(223,984,875)
INITIAL PASSIVHAUS	$/SF	(9)	(5,266,496)
PERCENTAGE OF BUILD COST			2.4%



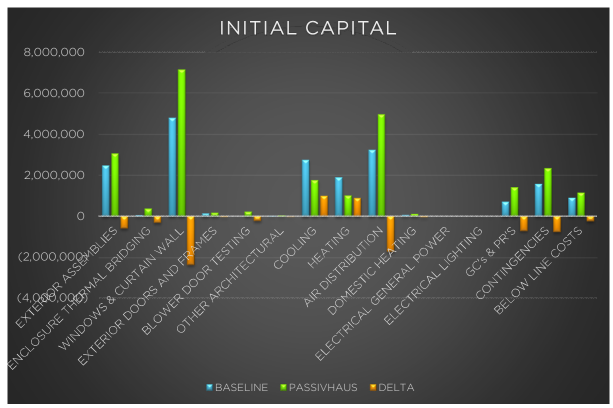
ANNUAL ENERGY TOTALS - KBTU

	BASELINE	PASSIVHAUS	SAVING DELTA
ANNUAL HEATING	13,730,935	4,117,894	9,613,041
ANNUAL COOLING	671,223	387,599	283,624
OTHER	4,546,079	3,766,666	779,413
ANNUAL ENERGY TOTALS - KBTU	18,948,237	8,272,159	10,676,078



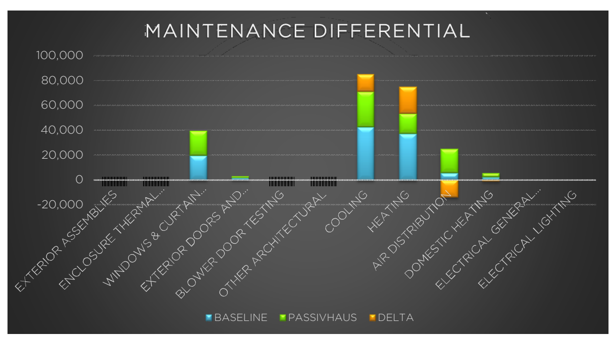
INITIAL CAPITAL COST SUMMARY

COST ELEMENT	BASELINE	PASSIVHAUS	DELTA
EXTERIOR ASSEMBLIES	2,465,721	3,052,169	($586,448)
ENCLOSURE THERMAL BRIDGING	57,710	369,150	($311,440)
WINDOWS & CURTAIN WALL	4,776,695	7,132,887	($2,356,192)
EXTERIOR DOORS AND FRAMES	137,840	167,600	($29,760)
BLOWER DOOR TESTING	0	223,950	($223,950)
OTHER ARCHITECTURAL	25,500	42,500	($17,000)
COOLING	2,747,772	1,752,848	$994,924
HEATING	1,893,605	1,004,624	$888,981
AIR DISTRIBUTION	3,236,877	4,947,547	($1,710,670)
DOMESTIC HEATING	66,000	111,000	($45,000)
ELECTRICAL GENERAL POWER	0	0	$0
ELECTRICAL LIGHTING	0	0	$0
GC's & PR'S	705,000	1,406,000	($701,000)
CONTINGENCIES	1,576,772	2,332,233	($755,461)
BELOW LINE COSTS	907,470	1,145,951	($238,480)
SOFT COSTS	0	175,000	($175,000)
TOTAL CAPITAL COSTS	18,596,963	23,863,459	($5,266,496)



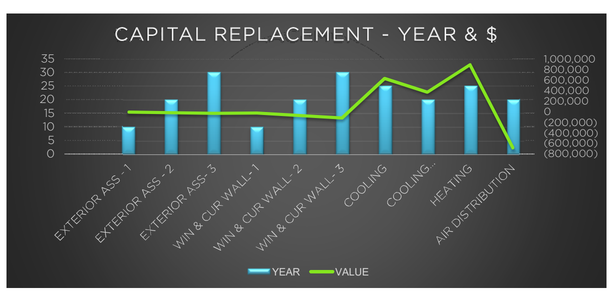
ANNUAL MAINTENANCE COST SUMMARY

	BASELINE	PASSIVHAUS	DELTA
EXTERIOR ASSEMBLIES	0	0	0
ENCLOSURE THERMAL BRIDGING	0	0	0
WINDOWS & CURTAIN WALL	19,500	19,500	0
EXTERIOR DOORS AND FRAMES	1,300	1,300	0
BLOWER DOOR TESTING	0	0	0
OTHER ARCHITECTURAL	0	0	0
COOLING	42,312	28,400	13,912
HEATING	37,200	15,900	21,300
AIR DISTRIBUTION	5,400	18,900	(13,500)
DOMESTIC HEATING	2,000	3,000	(1,000)
ELECTRICAL GENERAL POWER	0	0	0
ELECTRICAL LIGHTING	0	0	0
ANNUAL MAINTENANCE TOTALS	$107,712	$87,000	$20,712



CAPITAL REPLACEMENT SUMMARY

CAPITAL REPLACEMENT SUMMARY	% REPLACED	YEAR	VALUE
EXTERIOR ASS - 1	1.00%	10	(5,864)
EXTERIOR ASS - 2	3.00%	20	(17,593)
EXTERIOR ASS- 3	5.00%	30	(29,322)
WIN & CUR WALL- 1	1.00%	10	(23,562)
WIN & CUR WALL- 2	3.00%	20	(70,686)
WIN & CUR WALL- 3	5.00%	30	(117,810)
COOLING	63.00%	25	626,802
COOLING TOWERS/CONTROLS	37.00%	20	368,122
HEATING	100.00%	25	888,981
AIR DISTRIBUTION	40.00%	20	(684,268)



PASSIVHAUS TALL RESIDENTIAL BUILDINGS 8-Mar-17
NYSERDA
INDICTATIVE ECM & LCC REPORT

EXCLUSIONS & ASSUMPTIONS

1 Man hours for maintenance costs are assumed to be direct employed landlords staff
2 Contractor required to pay prevailing UNION wage
3 All capital and maintenance work to be carried out in regular hours
4 Costs based on the following documents:
5 Project drawings dated June 26, 2015
6 Equipment costs to carry out maintenance are not included
7 Costs include for survey / intrusive inspection work
8 Permit and local code costs are not included
9 All costs assume work to be carried out within a new building design; not within an occupied or existing building
10 See individual summary sheets for qualifications to relevant sections on capital , replacement , maintenance and energy.
11 See INPUTS sheet at the rear of the report for unit costs of energy applied to savings.
12 We have asumed there will be a demand charge credit due to reduced steam usage.
13 All capital costs exclude both design and construction contingency
14 We have assumed some differential of approximately 8 weeks between construction schedules and the cost of GC's
15 Total values for KBTU's are determined by multiplying the SF'S by the reduced KBTU's / sf/ hr
16 Unit costs of electric & natural gas are based on NYSERDA MPP Program Guidelines V6
17 All energy and energy cost numbers are based on standard behavior patterns for resident users.
18 Discount ranges are in line with accepted industry normals
19 Inflation on energy ranges is modelled at 3% low range scenarios and 7% per annum for high range scenarios
20 We have applied a median discount rate of 5%, this discount rate will vary depending on developer/ organisation
21 The efficiencies during installation using the stand-off continous steel shelf angles ILO continous steel shelf angles offsets the cost increase of material.
22 The report includes a demand charge credit on electric of $ 23,153 per annum.

PASSIVHAUS TALL RESIDENTIAL BUILDINGS
NYSERDA
INDICTATIVE ECM & LCC REPORT

BASIS DESCRIPTIONS

LCC "The Life Cycle Cost is the total cost of owning, operating and maintaining (including periodic costs) the building system(s) over a given study period, with all costs adjusted (discounted) to reflect the time-value of money and the discount rate (cost of capital) of the institution funding the project."

INPUTS

• *Initial or First Costs* - Immediate capital expenditure including labor and material

• *Utility (Costs)/Savings* - Includes electricity, steam, gas, water, etc.

• *Operation & Maintenance (Costs)/Savings* - Implications from ongoing upkeep of systems. A variable rate per hour for facilities maintenance personnel has been applied. We advise reviewing these costs for accurate feedback on applicability of these for the owner.

• *Periodic, Replacement (Costs)/Savings* - Non-reoccurring expenses.

• *Other (Costs)/Savings* - Captures productivity gains resulting from implemented sustainable design measures (includes absenteeism, turn-over, etc.)

• *Non-monetary (Costs)/Savings* - Everything else that is difficult to quantify (i.e. reduction in pollution) and other non-economic factors affecting the decision

OUTPUTS

• *Simple Payback* - Commonly associated with LCCA, but is only a simple calculation that does not take into account long-term performance or profitability (ignores the time value of money). As some sustainable/green measures include increased first costs, they would never be implemented if only simple payback were used in the decision making process

• *IRR (Internal Rate of Return)* - Often is used as a comparison metric to an internal "hurdle rate" (the lowest acceptable rate of return). While this does account for time value of money, it does not incorporate the discount rate of the firm or institution and it is not very flexible when dealing with irregular cash flows. It uses an iterative process to determine what rate would return a Present Value of zero, which leads us to the preferred methodology – Net Present Value

• *NPV (Net Present Value)* - The most flexible valuation matrix when dealing with irregular cash flows and also takes into account both the time-value-of-money and the discount rate of a firm. NPV returns the projected (cost)/savings of specific design measures and allows direct comparison between measures. NPV projections can also be summed to provide an overall picture of different design strategies.

Sensitivity analysis is also built into the model (i.e. utility, escalation and discount rate) to provide a 'Most Likely' (baseline) and 'Low and High' boundaries. These are adjusted on a project specific basis.

PASSIVHAUS TALL RESIDENTIAL BUILDINGS 08-Mar-17
NYSERDA
INDICTATIVE ECM & LCC REPORT

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ECM REF	Description	Capital Cost (Initial cost)	Yearly Utility Saving	Demand Charge Credits	Annual Tariff Savings	Yearly O & M	Periodic >= 40 YEARS	Payback @ 10 YRS	NPV @ 10 YRS	Payback @ 40 YRS	NPV @ 40 YRS
		(COST) / SAVINGS						STUDY DURATION = 10 Years		STUDY DURATION = 40 Years	
ECM1	FULL PASSIVHAUS REVIEW	($5,266,496)	$ 226,356	$ 23,153	$ 203,203	$20,712	$934,800	No Payback	($2,833,100)	24.00	$5,194,948
ECM2	Project ECM 2										
ECM3	Project ECM 3										
ECM4	Project ECM 4										

NPV = Net Present Value

PASSIVHAUS TALL RESIDENTIAL BUILDINGS
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08-Mar-17

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NPV MATRIX - DISCOUNT RATES & ENERGY INFLATION

NPV VALUES $ BY ENERGY INFLATION & DISCOUNT RATE

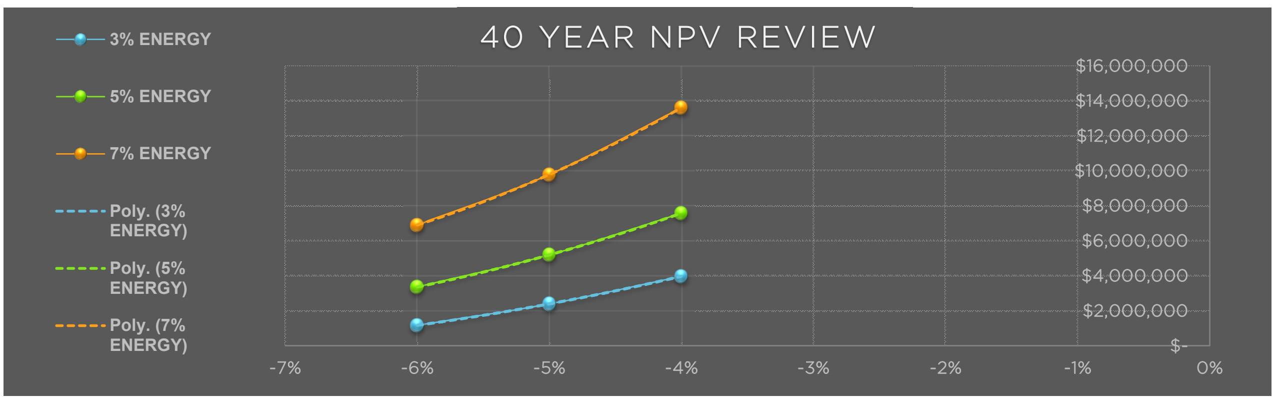
40 YEAR REVIEW PERIOD

DISCOUNT RATE %	3% ENERGY	5% ENERGY	7% ENERGY
-4%	$3,970,386	$7,580,769	$13,604,371
-5%	$2,396,520	$5,194,948	$9,789,418
-6%	$1,172,477	$3,365,570	$6,906,325

ENERGY INFLATION % ANNUAL

DISCOUNT RATE

RELATIONSHIPS



PASSIVHAUS TALL RESIDENTIAL BUILDINGS
NYSERDA
INDICTATIVE ECM & LCC REPORT

8-Mar-17

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Description:

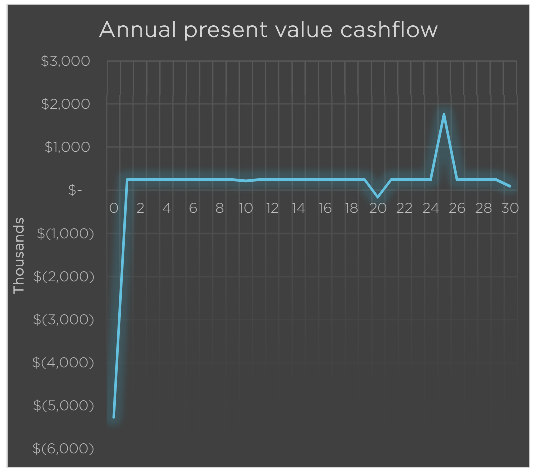
ECM CODE	ECM 1	
Costs/Savings:	Initial Capital	($5,266,496)
non-discounted	Utility	$ 226,356
($) = Cost	O & M	$20,712
$ = Savings	Periodic	$934,800
	Other	$0

BASELINE REVIEW PERIOD:	40 YEARS
Payback:	24
IRR:	N/A
Net Present Value:	5,194,948

INPUT DATA	QTY	UNIT	RATE	TOTAL

Initial Capital (COSTS)/SAVINGS

	QTY	UNIT	RATE	TOTAL
Difference in first costs from base scheme- See Appendix A	1	EA	($5,266,496)	($5,266,496)
			Sub-total	($5,266,496)

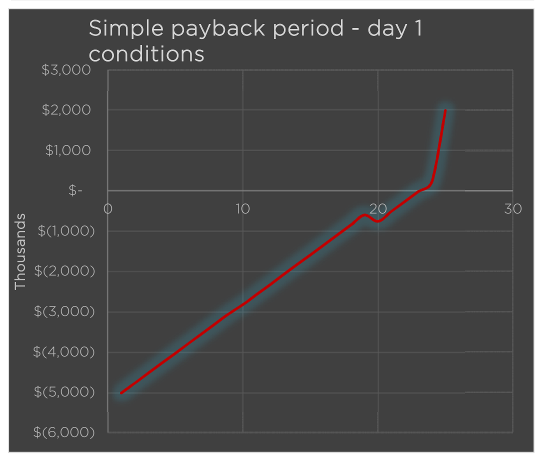


UTILITY (COSTS)/SAVINGS - ANNUAL

	Quantity	Unit	Rate	Total	Year
Electric	$83,506	KBTU	$ 0.0568	$ 83,506	
Gas	$142,850	KBTU	$ 0.0149	$ 142,850	
Water	$ -			$ -	
Steam + credit	$0		$ 0.0293	$ -	
			Sub-total	$ 226,356	

O &M (COSTS)/SAVINGS - ANNUAL

	Quantity	Unit	Rate	Total	Year
Summary of O&M	1	EA	$ 20,712	$20,712	
SEE O& M COST			Sub-total	$20,712	

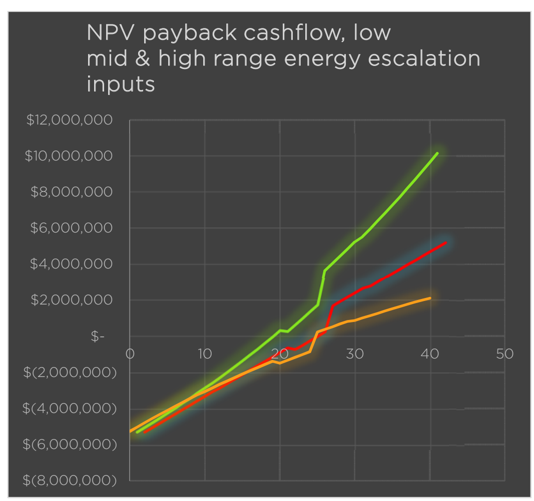


PERIODIC (COSTS)/SAVINGS

	Quantity	Unit	Rate	Total	Year
EXTERIOR ASS - 1	1	EA	($5,864)	($5,864)	10
EXTERIOR ASS - 2	1	EA	($17,593)	($17,593)	20
EXTERIOR ASS- 3	1	EA	($29,322)	($29,322)	30
WIN & CUR WALL- 1	1	EA	($23,562)	($23,562)	10
WIN & CUR WALL- 2	1	EA	($70,686)	($70,686)	20
WIN & CUR WALL- 3	1	EA	($117,810)	($117,810)	30
COOLING	1	EA	$626,802	$626,802	25
COOLING	1	EA	$368,122	$368,122	20
HEATING	1	EA	$888,981	$888,981	25
AIR DISTRIBUTION	1	EA	($684,268)	($684,268)	20
SEE PERIODIC SUMMARY			Sub-total	$934,800	

OTHER (COSTS)/SAVINGS

	Quantity	Unit	Rate	Total	Year
			Sub-total	$0	



ENERGY ESCALATION REVIEW / RANGES WITH 5% DISCOUNT

	Most Likely	low	high
Electricity	5%	3%	7%
Gas	5%	3%	7%
Water	5%	3%	7%
Other	4%	3%	5%
NPV	$ 5,194,948	$ 2,116,742	$ 10,145,503

DISCOUNTING RATES/ RANGES WITH 5% ENERGY INFLATION

Base	Mid	Boundary Range low	Boundary Range high
Discount Rate	5.0%	4.0%	6.0%
NPV	$ 5,194,948	$ 7,580,769	$ 3,365,570

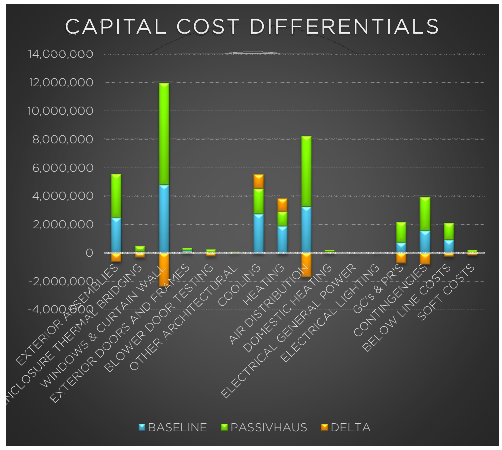
PASSIVHAUS TALL RESIDENTIAL BUILDINGS
NYSERDA
INDICTATIVE ECM & LCC REPORT

DHARAM CONSULTING

CAPITAL COST SUMMARY

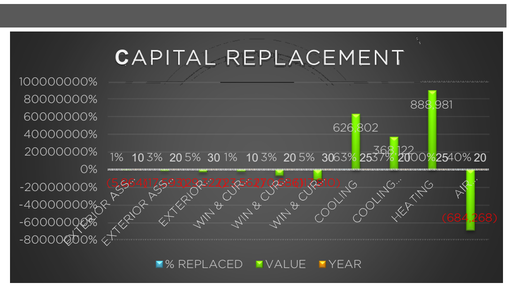
INITIAL CAPITAL COST SUMMARY

	BASELINE	PASSIVHAUS	DELTA
EXTERIOR ASSEMBLIES	2,465,721	3,052,169	(586,448)
ENCLOSURE THERMAL BRIDGIN(	57,710	369,150	(311,440)
WINDOWS & CURTAIN WALL	4,776,695	7,132,887	(2,356,192)
EXTERIOR DOORS AND FRAMES	137,840	167,600	(29,760)
BLOWER DOOR TESTING	0	223,950	(223,950)
OTHER ARCHITECTURAL	25,500	42,500	(17,000)
COOLING	2,747,772	1,752,848	994,924
HEATING	1,893,605	1,004,624	888,981
AIR DISTRIBUTION	3,236,877	4,947,547	(1,710,670)
DOMESTIC HEATING	66,000	111,000	(45,000)
ELECTRICAL GENERAL POWER	0	0	0
ELECTRICAL LIGHTING	0	0	0
GC's & PR'S	705,000	1,406,000	(701,000)
CONTINGENCIES	1,576,772	2,332,233	(755,461)
BELOW LINE COSTS	907,470	1,145,951	(238,480)
SOFT COSTS	0	175,000	(175,000)
INITIAL CAPITAL COST TOTALS	18,596,963	23,863,459	(5,266,496)



CAPITAL REPLACEMENT SUMMARY

% REPLACEMENT	% REPLACED	VALUE	YEAR
EXTERIOR ASS - 1	1%	(5,864)	10
EXTERIOR ASS - 2	3%	(17,593)	20
EXTERIOR ASS- 3	5%	(29,322)	30
WIN & CUR WALL- 1	1%	(23,562)	10
WIN & CUR WALL- 2	3%	(70,686)	20
WIN & CUR WALL- 3	5%	(117,810)	30
COOLING	63%	626,802	25
COOLING TOWERS/CONTROLS	37%	368,122	20
HEATING	100%	888,981	25
AIR DISTRIBUTION	40%	(684,268)	20



CONTINGENCY & ESCALATION SUMMARY

Design contingency	0%
Construction contingency	0%
Owners contingency	0%
Escalation (annual):first 2 years	SEE ECM
Escalation following	SEE ECM

QUALIFICATIONS

We presently do not carry either design or construction contingency on the capital cost differentials.
Per note provided in documentation we have assumed no day one cost differential for lighting
Costs presented are assumed to have some differential in design. If the cost is not shown it assumed to be no differential.

BASELINE DESIGN CAPITAL COSTS 8-Mar-17
PASSIVHAUS TALL RESIDENTIAL BUILDINGS
INDICTATIVE ECM & LCC REPORT

DHARAM CONSULTING

TRADE	QTY	UNIT	RATE	TOTAL
EXTERIOR ASSEMBLIES	300,000			$ 2,465,721
Roof				
6" of XPS	24,555	SF	3.50	$ 85,943
Ground floor slab				
4" of mineral wool insulation	33,558	SF	2.75	$ 92,285
Basement slab				
No insulation	0	SF	0.00	$ -
Lightweight Rainscreen				
Average 4" mineral wool insulation Liquid applied AVB	1	LS	1,106,388.75	$ 1,106,389
4" and 6" deep metal clips	157,071	SF	0.75	$ 117,803
Batt insulation between studs	157,072	SF	1.50	$ 235,608
Rainscreen back up wall framing at windows	850	EA	15.00	$ 12,750
Brick Cavity				
3" mineral wool insulation in cavity No mineral wool insulation inboard	1	LS	287,997.55	$ 287,998
Continuous steel shelf angels	2,000	LF	22.50	$ 45,000
Galavnized wire brick ties	19,749	SF	0.25	$ 4,937
Party Wall				
CMU 3" mineral wool insulation inboard	16,619	SF	27.50	$ 457,023
Foundation wall				
2" XPS, 3' deep (only at conditioned space)	8,883	SF	2.25	$ 19,987
ENCLOSURE THERMAL BRIDGING	300,000			$ 57,710
Lightweight Rainscreen				
No scope in base scope				no baseline scope
Brick Cavity				
Brick base course, solid grout first +/- 6", galvanized cavity flashing, CMU base course at back side of parapet	1	LS	44,200.00	$ 44,200
General				

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TRADE	QTY	UNIT	RATE	TOTAL
Insulation up and over parapets to roof, steel penetration at entrance canopies, dunnage & structural penetrations	1	LS	13,510.00	$ 13,510
WINDOWS & CURTAIN WALL	300,000			$ 4,776,695
General				
Double glazing	77,749	SF	60.00	$ 4,664,940
Minimally thermally broken non-insulated frames	44,702	LF	1.75	$ 78,229
Caulk air barrier	44,702	LF	0.75	$ 33,527
Windows				
N/A				
Curtainwall				
N/A				
EXTERIOR DOORS AND FRAMES	300,000			$ 137,840
General				
Minimally thermally broken non-insulated frames, caulk air barrier	480	LF	1.75	$ 840
Airtight measured				
Light gasketing, normal locks	1	LS	2,000.00	$ 2,000
Glazed				
Double glazing	1,500	SF	85.00	$ 127,500
Solid				
Minimally insulated	1	LS	7,500.00	$ 7,500
BLOWER DOOR TESTING	300,000			$ -
Not for baseline				
OTHER ARCHITECTURAL	300,000			$ 25,500
Retail entries as per drawings	300	SF	85.00	$ 25,500
COOLING	300,000			$ 2,747,772
Equipment				
Water cooled chillers; 350 Tons each	1,050	Tons	650.00	$ 682,500
Cooling Towers	2,400	Tons	250.00	$ 600,000
Heat exchangers; HX-3 thru 6, 150PSIG, 43GPM	3	EA	30,000.00	$ 90,000
Condenser water pumps; CWP-1 thru 3,	3	EA	55,000.00	$ 165,000

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PASSIVHAUS TALL RESIDENTIAL BUILDINGS
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DHARAM CONSULTING

TRADE	QTY	UNIT	RATE		TOTAL
Chilled water pumps; CHWP-1 thru 3, 1000GPM	3	EA	55,000.00	$	165,000
CHW circulation pumps	2	EA	5,000.00	$	10,000
VFD's for CHW Pumps	6	EA	10,000.00	$	60,000
Expansion tanks and air separators	1	LS	10,000.00	$	10,000
Chemical Treatment; Allow	1	LS	15,000.00	$	15,000
Dual Temperature Pumps; DTP-1 & 2, 2800GPM	2	EA	35,000.00	$	70,000
Condenser Water System Piping					
CW Piping; 14" including fittings	230	LF	415.00	$	95,450
CW Piping; 12" including fittings	150	LF	350.00	$	52,500
CW Piping; 10" including fittings	80	LF	325.00	$	26,000
CW Piping; 8" including fittings	250	LF	220.00	$	55,000
CW Piping; 6" including fittings	150	LF	165.00	$	24,750
CW Piping; <4" including fittings	300	LF	90.00	$	27,000
CW Piping; <2-1/2" including fittings	300	LF	50.00	$	15,000
Insulation for CHW Piping	1,460	LF	25.00	$	36,500
Valves & Specialties	1	LS	49,830.00	$	49,830
Chilled Water System Piping					
CHW Piping; 8" including fittings	250	LF	220.00	$	55,000
CHW Piping; 6" including fittings	150	LF	165.00	$	24,750
CHW Piping; <4" including fittings	300	LF	90.00	$	27,000
` CHW Piping; 2-1/2" including fittings	400	LF	55.00	$	22,000
CHW Piping; <2-1/2" including fittings	200	LF	50.00	$	10,000
Insulation for CHW Piping	1,300	LF	20.00	$	26,000
Valves & Specialties	1	LS	24,712.50	$	24,713
Final connections					
Piping Connections; Chillers	3	EA	15,000.00	$	45,000
Piping Connections; Cooling Towers	3	EA	13,500.00	$	40,500
Piping Connections; CHW Pumps	2	EA	12,500.00	$	25,000
Piping Connections; CW Pumps	2	EA	12,500.00	$	25,000
Building Management System					
Primary					
Cooling Plant	70	PTS	1,500.00	$	105,000
Test & commission	1	LS	28,279.70	$	28,280
Rigging & Vibration Isolation allowance	1	LS	40,000.00	$	40,000
HEATING	300,000			$	1,893,605
Equipment					
Gas fired boilers; B-1 thru 8, 2,550 MBH ea	20,400	MBH	40.00	$	816,000
Heat exchangers; HX-1 thru 3, 150PSIG, 43GPM	3	EA	30,000.00	$	90,000
Primary heating water pumps; HWP-1 & HWP-2, 1,200GPM ea	2	EA	65,000.00	$	130,000
Boiler Circulation Pumps; 130GPM each	8	EA	3,500.00	$	28,000
VFD's for HW Pumps	2	EA	10,000.00	$	20,000

BASELINE DESIGN CAPITAL COSTS 8-Mar-17
PASSIVHAUS TALL RESIDENTIAL BUILDINGS
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TRADE	QTY	UNIT	RATE		TOTAL
Expansion tanks and air separators	1	LS	10,000.00	$	10,000
Glycol Feed System; including piping, valves pumps and tanks	1	LS	25,000.00	$	25,000
Chemical Treatment; Allow	1	LS	15,000.00	$	15,000
Heating circulation pumps for FTR s; allow	4	EA	5,000.00	$	20,000
Hot Water System, Erv PIPING					
HW Piping; 8" including fittings	200	LF	220.00	$	44,000
HW Piping; 6" including fittings	150	LF	165.00	$	24,750
HW Piping; <4" including fittings	300	LF	90.00	$	27,000
HW Piping; 2-1/2" including fittings	400	LF	55.00	$	22,000
HW Piping; <2-1/2" including fittings	2,540	LF	50.00	$	127,000
Insulation for HW Piping	3,590	LF	15.00	$	53,850
Valves & Specialties	1	LS	36,712.50	$	36,713
Piping connections					
Piping Connections; Boilers	8	EA	15,000.00	$	120,000
Piping Connections; HW Pumps	2	EA	13,500.00	$	27,000
Piping Connections; DTP Pumps	2	EA	12,500.00	$	25,000
Piping Connections; Heat Exchangers	4	EA	12,500.00	$	50,000
Building Management System					
Heating Plant	80	PTS	1,500.00	$	120,000
Test & commission	1	LS	22,292.50	$	22,293
Rigging & Vibration Isolation allowance	1	LS	40,000.00	$	40,000
AIR DISTRIBUTION	300,000			$	3,236,877
Air handling equipment					
ERV-1; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters (25 Tons)	10,000	CFM	11.00	$	110,000
ERV-1; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters (25 Tons)	8,000	CFM	11.00	$	88,000
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - Allow for Cellar, Lobby and MER's	8,000	CFM	11.00	$	88,000
VFD for ERV's	6	EA	15,000.00	$	90,000
Air distribution					

BASELINE DESIGN CAPITAL COSTS 8-Mar-17
PASSIVHAUS TALL RESIDENTIAL BUILDINGS
INDICTATIVE ECM & LCC REPORT

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TRADE	QTY	UNIT	RATE	TOTAL
Galvanized sheet steel ductwork; including insulation, acoustical lining, volume dampers and registers, grilles & diffusers - RISERS & DUCT SERVING RESIDENTIAL SPACES	73,500	LBS	13.00	$ 955,500
Ductwork insulation and acoustical lining	51,450	SF	4.50	$ 231,525
Volume dampers, balancing dampers, etc.	1	LS	67,000.00	$ 67,000
Specialty dampers; fire, fire/smoke, motorized,	1	LS	96,000.00	$ 96,000
Diffusers, registers & grilles - ceiling & wall	690	EA	225.00	$ 155,250
Galvanized sheet steel ductwork; including insulation, acoustical lining, volume dampers and registers, grilles & diffusers - SERVING NON RESIDENTIAL SPACES - Allow	20,000	LBS	18.50	$ 370,000
Plenums; double wall - Allow	3,000	SF	75.00	$ 225,000
Electric Duct heater; EDH-1 serving Trash Room	1	EA	3,500.00	$ 3,500
Sound Attenuators; Allow	1	LS	20,000.00	$ 20,000
Duct Silencer; DS-1-1 serving Mech. Rm	1	EA	5,000.00	$ 5,000
Boiler Flue; 12"	50	LF	225.00	$ 11,250
Boiler Flue; 10"	2,288	LF	185.00	$ 423,280
Building Management System				
ERV's; 25 pts each	100	PTS	1,500.00	$ 150,000
Test & commission	1	LS	117,572.20	$ 117,572
Rigging & Vibration Isolation allowance	1	LS	30,000.00	$ 30,000
DOMESTIC HEATING	300,000			$ 66,000
Instantaneous water heat exchangers	4	EA	15,000.00	$ 60,000
Storage tanks	2	EA	3,000.00	$ 6,000
Pumps				No change
Controls				No change
ELECTRICAL GENERAL POWER	300,000			$ -
NO DIFFERENTIAL				
ELECTRICAL LIGHTING	300,000			$ -
NO DIFFERENTIAL				
SOFT COSTS	300,000			$ -

BASELINE DESIGN CAPITAL COSTS 8-Mar-17
PASSIVHAUS TALL RESIDENTIAL BUILDINGS
INDICTATIVE ECM & LCC REPORT

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TRADE	QTY	UNIT	RATE	TOTAL
ENERGY MODELLING COSTS				No baseline cost
ADDITIONAL DESIGN FEE CO-ORDINATION				No baseline cost
PROJECT REQUIREMENTS	300,000			$ 360,000
General project requirements	30.0	wks	12000.00	$ 360,000
TOTAL DIRECT COSTS				$ 15,767,720
ALLOCATIONS				$ 2,829,242
General Conditions	30.0	wks	11,500	$ 345,000
Permits	1.2 %			$ 189,213
GL Insurance	1.12%			$ 176,598
Design Contingency	10.0 %			$ 1,576,772
Construction Contingency	0.0 %			$ -
Fee	3.0 %			$ 541,659
Escalation - 0%	0.0 %			$ -
TOTAL CONSTRUCTION COST				$ 18,596,963

PASSIVHAUS DESIGN CAPITAL COSTS 8-Mar-17
PASSIVHAUS TALL RESIDENTIAL BUILDINGS
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TRADE	QTY	UNIT	RATE	TOTAL
EXTERIOR ASSEMBLIES	300,000			$ 3,052,169
Roof				
8" of XPS	24,555	SF	4.75	$ 116,636
Ground floor slab				
4" of mineral wool insulation	33,558	SF	2.75	$ 92,285
Basement slab				
3" XPS	16,118	SF	1.25	$ 20,148
Lightweight Rainscreen				
Average 7" mineral wool insulation Membrance applied AVB	1	LS	1,504,659.00	$ 1,504,659
6" and 8" deep fiberglass clips	157,072	SF	1.50	$ 235,608
No Batt insulation between studs				not required
Rainscreen back up wall framing at windows	850	EA	50.00	$ 42,500
Brick Cavity				
5" mineral wool insulation in cavity 2" mineral wool insulation inboard	1	LS	470,188.25	$ 470,188
Stand-off steel shelf angels	2,000	LF	25.00	$ 50,000
Stainless Steel Brick ties	19,749	SF	0.75	$ 14,812
Lot Line Wall				
Insulated CMU 1" mineral wool insulation inboard	16,619	SF	28.75	$ 477,796
Foundation wall				
3" XPS, Full height (16' high) (only at conditioned space)	8,883	SF	3.10	$ 27,537
ENCLOSURE THERMAL BRIDGING	300,000			$ 369,150
Lightweight Rainscreen				
Plastic sill pans, sheet membrane materials with metal flashing at window head	850	EA	65.00	$ 55,250
Brick Cavity				
Cellular glass base course, XPS insulation first 18", discontinous stainless steel cavity flashing with membrane bridge, shelf angle at back side of parapet	1	LS	57,900.00	$ 57,900

PASSIVHAUS DESIGN CAPITAL COSTS 8-Mar-17
PASSIVHAUS TALL RESIDENTIAL BUILDINGS
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TRADE	QTY	UNIT	RATE	TOTAL
General				
Thermal breaks to balconies & parapet	1,500	LF	95.00	$ 142,500
No insulation up and over parapets to roof, insulated connections with stainless steel bolts at entrance canopies, structural roof penetrations, enclosure MEP pipe penetrations to be thermally broken	1	LS	83,500.00	$ 83,500
Dunnage	1	LS	30,000.00	$ 30,000
WINDOWS & CURTAIN WALL	300,000			$ 7,132,887
General				
Triple glazing	77,749	SF	85.00	$ 6,608,665
Heavily thermally broken insulated frames	44,702	LF	8.00	$ 357,616
Membrane air barrier	44,702	LF	3.00	$ 134,106
Windows				
Dead load support angles	1	LS	10,000.00	$ 10,000
Curtainwall				
Mineral wool insulation around frame	7,500	LF	3.00	$ 22,500
EXTERIOR DOORS AND FRAMES	300,000			$ 167,600
General				
Heavily thermally broken insulated frames, passive house certified, membrane air barrier	640	LF	2.50	$ 1,600
Airtight measured				
Gasketing upgrade, Multi-point locks for better seal	20	EA	175.00	$ 3,500
Glazed				
Tripple glazing to glazed door areas	1,500	SF	100.00	$ 150,000
Solid				
Heavily insulated	1	LS	12,500.00	$ 12,500
BLOWER DOOR TESTING	300,000			$ 223,950
Exterior blower door testing				

PASSIVHAUS DESIGN CAPITAL COSTS 8-Mar-17
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TRADE	QTY	UNIT	RATE	TOTAL
Allow to 4 areas per level and allow to 10 levels	40	EA	1,450.00	$ 58,000
Allow to multiple levels at one time	10	EA	1,450.00	$ 14,500
Allow for whole building tesr	1	EA	1,450.00	$ 1,450
Allow for mock up	1	EA	50,000.00	$ 50,000
Allow for third party commissioning	25	DAY	2,000.00	$ 50,000
Allow for construction administration oversignt	25	DAY	2,000.00	$ 50,000
Blower door frame $400, Pressure hose $100, Fan $450, Fan Seal $75, Gauges $100, Gauge Clamp $100, Smoke puffer $25, Protection $200				
OTHER ARCHITECTURAL	300,000			$ 42,500
Retail vestibules	300	SF	135.00	$ 40,500
Elevator shafts thermally insulated emergency smoke vent at top	8	EA	250.00	$ 2,000
COOLING	300,000			$ 1,752,848
Equipment				
Chillers; 200 Tons each	400	Tons	800.00	$ 320,000
Cooling Towers	800	Tons	250.00	$ 200,000
Heat exchangers; 150PSIG, 43GPM	2	EA	30,000.00	$ 60,000
Condenser water pumps; 10HP each	4	EA	35,000.00	$ 140,000
Chilled water pumps; 7.5HP each	2	EA	30,000.00	$ 60,000
CHW circulation pumps;	2	EA	7,500.00	$ 15,000
VFD's for CHW Pumps	6	EA	10,000.00	$ 60,000
Expansion tanks and air separators	1	LS	10,000.00	$ 10,000
Chemical Treatment; Allow	1	LS	15,000.00	$ 15,000
Dual Temperature Pumps; 15HP each	2	EA	35,000.00	$ 70,000
Condenser Water System Piping				
CW Piping; 14" including fittings	230	LF	415.00	$ 95,450
CW Piping; 12" including fittings	150	LF	350.00	$ 52,500
CW Piping; 10" including fittings	80	LF	325.00	$ 26,000
CW Piping; 8" including fittings	250	LF	220.00	$ 55,000
CW Piping; 6" including fittings	150	LF	165.00	$ 24,750
CW Piping; <4" including fittings	300	LF	90.00	$ 27,000
CW Piping; <2-1/2" including fittings	300	LF	50.00	$ 15,000
Insulation for CHW Piping	1,460	LF	25.00	$ 36,500
Valves & Specialties	1	LS	44,355.00	$ 44,355
Chilled Water System Piping				
CHW Piping; 8" including fittings	150	LF	220.00	$ 33,000
CHW Piping; 6" including fittings	100	LF	165.00	$ 16,500
CHW Piping; <4" including fittings	600	LF	90.00	$ 54,000
` CHW Piping; 2-1/2" including fittings	250	LF	55.00	$ 13,750

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DHARAM
CONSULTING

TRADE	QTY	UNIT	RATE	TOTAL
CHW Piping; <2-1/2" including fittings	200	LF	50.00	$ 10,000
Insulation for CHW Piping	1,300	LF	20.00	$ 26,000
Valves & Specialties	1	LS	19,087.50	$ 19,088
Final connections				
Piping Connections; Chillers	2	EA	15,000.00	$ 30,000
Piping Connections; Cooling Towers	2	EA	13,500.00	$ 27,000
Piping Connections; CHW Pumps	2	EA	12,500.00	$ 25,000
Piping Connections; CW Pumps	2	EA	12,500.00	$ 25,000
Building Management System				
Primary				
Cooling Plant	60	PTS	1,500.00	$ 90,000
Test & commission	1	LS	21,955.70	$ 21,956
Rigging & Vibration Isolation allowance	1	LS	35,000.00	$ 35,000
HEATING	300,000			$ 1,004,624
Equipment				
Gas fired boilers; 2000 MBH ea	4,000	MBH	40.00	$ 160,000
Heat exchangers; Allow	2	EA	40,000.00	$ 80,000
Primary heating water pumps; 10HP each	2	EA	50,000.00	$ 100,000
Boiler Circulation Pumps; 3HP each	2	EA	3,500.00	$ 7,000
VFD's for HW Pumps	2	EA	10,000.00	$ 20,000
Expansion tanks and air separators	1	LS	10,000.00	$ 10,000
Glycol Feed System; including pumps, tanks	1	LS	15,000.00	$ 15,000
Chemical Treatment; Allow	1	LS	15,000.00	$ 15,000
Heating circulation pumps for FTR s; allow	3	EA	5,000.00	$ 15,000
Hot Water System, Erv PIPING				
HW Piping; 8" including fittings	100	LF	220.00	$ 22,000
HW Piping; 6" including fittings	150	LF	165.00	$ 24,750
HW Piping; <4" including fittings	550	LF	90.00	$ 49,500
HW Piping; 2-1/2" including fittings	250	LF	55.00	$ 13,750
HW Piping; <2-1/2" including fittings	2,540	LF	50.00	$ 127,000
Insulation for HW Piping	3,590	LF	20.00	$ 71,800
Valves & Specialties	1	LS	35,550.00	$ 35,550
Piping connections				
Piping Connections; Boilers	2	EA	15,000.00	$ 30,000
Piping Connections; HW Pumps	2	EA	13,500.00	$ 27,000
Piping Connections; DTP Pumps	2	EA	12,500.00	$ 25,000
Piping Connections; Heat Exchangers	2	EA	12,500.00	$ 25,000
Building Management System				

PASSIVHAUS DESIGN CAPITAL COSTS 8-Mar-17
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DHARAM CONSULTING

TRADE	QTY	UNIT	RATE	TOTAL
Heating Plant	55	PTS	1,500.00	$ 82,500
Test & commission	1	LS	13,774.00	$ 13,774
Rigging & Vibration Isolation allowance	1	LS	35,000.00	$ 35,000
AIR DISTRIBUTION	300,000			$ 4,947,547
Air handling equipment				
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - 2800CFM each	8,400	CFM	12.50	$ 105,000
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - 3000CFM each	3,000	CFM	12.50	$ 37,500
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - 3300CFM each	6,600	CFM	12.50	$ 82,500
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - 3600CFM each	3,600	CFM	12.50	$ 45,000
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - 3600CFM each	3,600	CFM	12.50	$ 45,000
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - 1000CFM each - serving 4th Fl Amenity	1,000	CFM	12.50	$ 12,500
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - 500CFM each - serving Lobby	500	CFM	12.50	$ 6,250
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - 125CFM each - serving Cellar Storage	125	CFM	12.50	$ 1,563
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - 3600CFM each - serving Cellar MER's	7,200	CFM	12.50	$ 90,000
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - 300CFM each - serving Cellar Bike Rms	300	CFM	12.50	$ 3,750
ERV; supply & return fans, cooling & heating (glycol) coils, filters, pre-filters, final filters - 4000CFM each	4,000	CFM	12.50	$ 50,000
VFD for ERV's	22	EA	15,000.00	$ 330,000
Air distribution				

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TRADE	QTY	UNIT	RATE	TOTAL
Galvanized sheet steel ductwork; including insulation, acoustical lining, volume dampers and registers, grilles & diffusers - RISERS & DUCT SERVING RESIDENTIAL SPACES	117,500	LBS	13.00	$ 1,527,500
Ductwork insulation and acoustical lining	82,250	SF	4.50	$ 370,125
Volume dampers, balancing dampers, etc.	1	LS	107,000.00	$ 107,000
Specialty dampers; fire, fire/smoke, motorized,	1	LS	153,000.00	$ 153,000
Diffusers, registers & grilles - ceiling & wall	1,610	EA	225.00	$ 362,250
Galvanized sheet steel ductwork; including	30,000	LBS	18.50	$ 555,000
Plenums; double wall - Allow	3,500	SF	75.00	$ 262,500
Electric Duct heater; EDH-1 serving Trash	1	EA	3,500.00	$ 3,500
Sound Attenuators; Allow	1	LS	25,000.00	$ 25,000
Duct Silencer; DS-1-1 serving Mech. Rm	1	EA	5,000.00	$ 5,000
Boiler Flue; 12"	50	LF	225.00	$ 11,250
Boiler Flue; 10"	630	LF	185.00	$ 116,550
Aeroseal	1	LS	10,000.00	$ 10,000
Building Management System				
ERV's; 25 pts each	275	PTS	1,500.00	$ 412,500
Test & commission	1	LS	172,309.50	$ 172,310
Rigging & Vibration Isolation allowance	1	LS	45,000.00	$ 45,000
DOMESTIC HEATING	300,000			$ 111,000
Gas fired condensing units, 750 MBH each	4	EA	26,250.00	$ 105,000
Storage tanks	2	EA	3,000.00	$ 6,000
Pumps				No change
Controls				No change
ELECTRICAL GENERAL POWER	300,000			$ -
NO DIFFERENTIAL				
ELECTRICAL LIGHTING	300,000			$ -
NO DIFFERENTIAL				
SOFT COSTS	300,000			$ 175,000
ENERGY MODELLING COSTS	1	LS	75,000.00	$ 75,000
ADDITIONAL DESIGN FEE CO-ORDINATION	1	LS	100,000.00	$ 100,000
PROJECT REQUIREMENTS	300,000			$ 456,000

PASSIVHAUS DESIGN CAPITAL COSTS 8-Mar-17
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TRADE	QTY	UNIT	RATE	TOTAL
General project requirements	38.0	wks	12000.00	$ 456,000
				$ -
TOTAL DIRECT COSTS				$ 19,435,275
ALLOCATIONS				$ 4,428,184
General Conditions	38.0	wks	25,000	$ 950,000
Permits	1.2 %			$ 233,223
GL Insurance	1.12%			$ 217,675
Design Contingency	12.0 %			$ 2,332,233
Construction Contingency	0.0 %			$ -
Fee	3.0 %			$ 695,052
Escalation - 0%	0.0 %			$ -
TOTAL CONSTRUCTION COST				$ 23,863,459

PASSIVHAUS TALL RESIDENTIAL BUILDINGS
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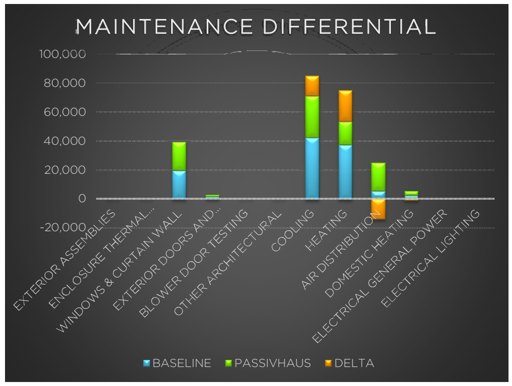
ANNUAL MAINTENANCE

ANNUAL MAINTENANCE COST SUMMARY	BASELINE	PASSIVHAUS	DELTA
EXTERIOR ASSEMBLIES	0	0	0
ENCLOSURE THERMAL BRIDGING	0	0	0
WINDOWS & CURTAIN WALL	19,500	19,500	0
EXTERIOR DOORS AND FRAMES	1,300	1,300	0
BLOWER DOOR TESTING	0	0	0
OTHER ARCHITECTURAL	0	0	0
COOLING	42,312	28,400	13,912
HEATING	37,200	15,900	21,300
AIR DISTRIBUTION	5,400	18,900	(13,500)
DOMESTIC HEATING	2,000	3,000	(1,000)
ELECTRICAL GENERAL POWER			
ELECTRICAL LIGHTING			
ANNUAL MAINTENANCE TOTALS	107,712	87,000	20,712



MAINTENANCE METRICS

Cooling tower, minimal checks , $ 300/ year
Chiller , $ 4,900 per annum for electric, $ 1800 per annum for absorption
VFD drives, calibration $ 1200/ annum
Boilers, $ 750/ annum
Pumps, $ 600/ annum

QUALIFICATIONS

We assume the maintenance for exterior assemblies and windows is the same for both baseline design and PH; therefore is zero.

ANNUAL MAINTENANCE DETAIL 8-Mar-17
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TRADE	QTY	UNIT	RATE	TOTAL
EXTERIOR ASSEMBLIES	300,000			$ -
NONE ASSUMED				
ENCLOSURE THERMAL BRIDGING	300,000			$ -
NONE ASSUMED				
WINDOWS & CURTAIN WALL	300,000			$ -
BASELINE				$ 19,500
ANNUAL WINDOW CLEAN - 300 M/HOURS	300	HRS	65.00	$ 19,500
PASSIVHAUS				$ 19,500
ANNUAL WINDOW CLEAN - 300 M/HOURS	300	HRS	65.00	$ 19,500
EXTERIOR DOORS AND FRAMES	300,000			$ -
BASELINE				$ 1,300
ANNUAL WINDOW CLEAN - 20 M/HOURS	20	HRS	65.00	$ 1,300
PASSIVHAUS				$ 1,300
ANNUAL WINDOW CLEAN - 20 M/HOURS	20	HRS	65.00	$ 1,300
BLOWER DOOR TESTING	300,000			$ -
NONE ASSUMED				
OTHER ARCHITECTURAL	300,000			$ -
NONE ASSUMED				
COOLING	300,000			$ 13,912
BASELINE				$ 42,312
ABSORBPTION CHILLERS	3	EA	1,804.12	$ 5,412
COOLING TOWERS	3	EA	300.00	$ 900
CONDENSER CHILLED WATER PUMPS	24	EA	600.00	$ 14,400
VFD DRIVES, PUMPS	18	EA	1,200.00	$ 21,600
PASSIVHAUS				$ 28,400
ELECTRIC CHILLERS	2	EA	4,900.00	$ 9,800

ANNUAL MAINTENANCE DETAIL	8-Mar-17				DHARAM CONSULTING
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TRADE	QTY	UNIT	RATE		TOTAL
COOLING TOWERS	2	EA	300.00	$	600
CONDENSER & CHILLED WATER PUMPS	10	EA	600.00	$	6,000
VFD DRIVES, PUMPS	10	EA	1,200.00	$	12,000
HEATING	300,000			$	21,300
BASELINE				$	37,200
CONDENSING BOILERS	8	EA	750.00	$	6,000
PUMPS	16	EA	600.00	$	9,600
VFD DRIVES, PUMPS	18	EA	1,200.00	$	21,600
PASSIVHAUS				$	15,900
CONDENSING BOILERS	2	EA	750.00	$	1,500
PUMPS	4	EA	600.00	$	2,400
VFD DRIVES, PUMPS	10	EA	1,200.00	$	12,000
AIR DISTRIBUTION	300,000				(13,500)
BASELINE				$	5,400
ERV UNITS, 1 HOUR PER MONTH	2	EA	1,500.00	$	3,000
VFD DRIVES, (ASSUME 2 PER AHU)	2	EA	1,200.00	$	2,400
PASSIVHAUS				$	18,900
ERV UNITS 1 HOUR PER MONTH	7	EA	1,500.00	$	10,500
VFD DRIVES, (ASSUME 2 PER AHU)	7	EA	1,200.00	$	8,400
DOMESTIC HEATING	300,000				(1,000)
BASELINE				$	2,000
4 HEAT EXCHANGERS	4	EA	500.00	$	2,000
PASSIVHAUS				$	3,000
4 GAS FIRED CONDENSING UNITS	4	EA	750.00	$	3,000
ELECTRICAL GENERAL POWER	300,000			$	-
NO DIFFERENTIAL					
ELECTRICAL LIGHTING	300,000			$	-
NO DIFFERENTIAL					
TOTAL DIRECT COSTS				$	21,712.36

PASSIVHAUS TALL RESIDENTIAL BUILDINGS
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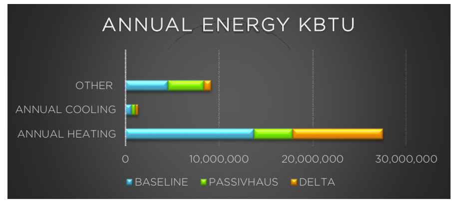
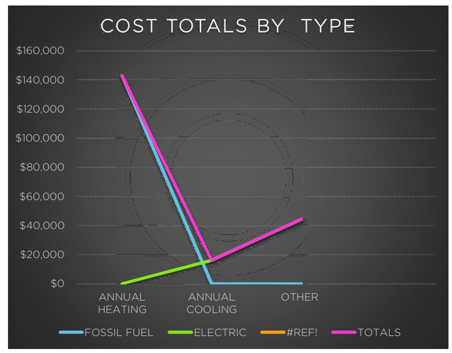
ENERGY MODEL SUMMARY

ANNUAL ENERGY TOTALS - KBTU	BASELINE	PASSIVHAUS	DELTA
ANNUAL HEATING	13,730,935	4,117,894	9,613,041
ANNUAL COOLING	671,223	387,599	283,624
OTHER	4,546,079	3,766,666	779,413
ANNUAL ENERGY TOTALS - KBTU	18,948,237	8,272,159	10,676,078



ANNUAL ENERGY COST DIFFERENTIALS $	FOSSIL FUEL	ELECTRIC	TOTALS
ANNUAL HEATING	$142,850	$0	$142,850
ANNUAL COOLING	$0	$16,103	$16,103
OTHER	$0	$44,251	$44,251
ANNUAL ENERGY TOTALS $	$ 142,850	$ 60,353	$ 203,203



INPUT DATA	$ / UNIT	UNIT	$ /UNIT	UNIT
Electrical:	$0.19	kW/H	$0.06	KBTU
Gas:	$1.49	Therm	$0.01	KBTU

QUALIFICATIONS

PASSIVHAUS TALL RESIDENTIAL BUILDINGS
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ENERGY MODEL

ECM	MEASURE	BASELINE				PASSIVHAUS				DELTA TOTALS				
	BUILDING SQUARE FOOTAGE METRICS	GFA	593,430	SF		597,293	SF							
ECM	MEASURE	KBTU/SF/Yr	Fossil KBTU	Electric KBTU	TOTAL KBTU	KBTU/SF/Yr	Fossil KBTU	Electric KBTU	TOTAL KBTU	Fossil KBTU	$ TOTAL	Electric KBTU	$ TOTAL	$ TOTAL
ECM 1	% ALLOCATION		100%	0%			100%	100%						
	ANNUAL HEATING	23	13,730,935	0	13,730,935	6.89	4,117,894		4,117,894	9,613,041	$142,850	0	$0.00	$142,849.79
	ANNUAL COOLING	1.13		671,223	671,223	0.65		387,599	387,599	0	$0	283,624	$16,102.52	$16,102.52
	OTHER	7.66		4,546,079	4,546,079	6.31		3,766,666	3,766,666	0	$0	779,413	$44,250.54	$44,250.54
TOTALS		31.93	13,730,935	5,217,302	18,948,237	13.85	4,117,894	4,154,265	8,272,159	9,613,041	$142,850	1,063,037	$60,353	$203,203
KWH CONERT FOR STEAM														
INPUT RATE - $ / UNIT KBTU			$0.015	$0.057			$0.015	$0.057		$0.015		$0.057		
TOTALS														
DEMAND CREDITS IF APPLICABLE													$ 23,153	$ 23,153
TOTALS - ENERGY COST $			$204,041.69	$296,208.11	$500,249.81		$61,191.90	$235,855.05	$297,046.95		$142,850		$83,506	$226,356

SUB TOTAL ANNUAL ENERGY SAVING	$ 226,356

PASSIVHAUS TALL RESIDENTIAL BUILDINGS
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INPUT DATA

ENERGY EFFICIENCY MEASURE 1:		UNIT 1			UNIT 2		
Water:	Building rate	$	3.810	100 / cf			
Water:	Industrial rate	$	2.370	100 / cf			
Electrical:		$	0.1936	kW/H	$	0.057	KBTU
Gas:		$	1.4860	Therm	$	0.015	KBTU
Steam:		$	0.1000	kW/H	$	0.029	KBTU

ENERGY MODEL ASSUMPTIONS		BASE	LOW	HIGH
Utility rate increases:	Electricity	5.00%	3.00%	7.00%
	Gas	5.00%	3.00%	7.00%
	Water	5.00%	3.00%	7.00%

ESCALATION		BASE	LOW	HIGH
ESCALATION	CONSTRUCTION	4.00%	3.00%	5.00%

DISCOUNTING	BASE	LOW	HIGH
Duration for Study:	40 years		
Cost of Capital (Discount Rate):	5.00%	4.00%	6.00%

QUALIFICATIONS

Escalation for other refers to balance and cost of construction
Escalation for energy on the high range is thought to be potentially +7% per annum
Unit costs of electric & natural gas are based on NYSERDA MPP Program Guidelines V6