Achieving EnerPHit For a Mid-Rise Multi-Unit Residential Building | Project 7814.038

Extension to *Multi-Unit Residential Building Deep Retrofit Energy Study*

To
Micah Lang, City of Vancouver
Bojan Andjelkovic, BC Hydro
Norm Connolly, City of New Westminster

Submitted January 28, 2016 by
RDH Building Science Inc.
244 West 8th Avenue
Vancouver BC V5Y 1N5

Abstract

This project was completed as an extension to an energy efficiency research and demonstration project for a multi-unit residential building that started in 2012. The research aims to understand how the deep energy retrofit that is currently in progress at the "Belmont" building compares to the energy performance under the Passive House "EnerPHit" standard, more specifically its heating demand standard; essentially the heat loss of the building. In addition, the research highlights what additional measures (if any) would need to be incorporated to achieve the standard.

This project seeks to answer the following guiding research questions:

- → What are the options available to reach an EnerPHit heating demand of 25 kWh/m^2?
- → What are ballpark incremental costs associated with these options?
- → Are the options feasible given availability of equipment/technology and experience/skills of contractors?

Additional EnerPHit requirements, including the primary energy requirement (120 kWh/m^2 primary energy), are beyond the scope of this study.

Achieving EnerPHit for Mid- and High-Rise Multifamily Retrofits

Overall, this work showed that going the extra step to meet the EnerPHit heating demand requires careful attention to detail, but could be achieved at the Belmont and other multifamily buildings with little to no added cost beyond the deep energy retrofit that was already completed.

The deep energy retrofit that is in progress at the Belmont will come close to achieving the EnerPHit heating demand standard. Additional Energy Conservation Measures (ECMs) required for EnerPHit would have added approximately 0.3% to 1.4% to the construction budget for the Belmont. With these measures, the building's heating demand would achieve 25 kWh/m^2, assessed using Passive House software (PHPP).

Considering EnerPHit retrofits for other multifamily buildings, the Belmont deep energy retrofit added approximately 3% to 5% to the construction budget. By extension, an EnerPHit retrofit is projected to add approximately 3.5% to 5.5% in capital cost to a standard building enclosure retrofit, a small increment of 0.5% compared to the current Belmont project. For further details on the overall economics of deep energy retrofits for multifamily buildings refer to the research reports for *Multi-Unit Residential Building Deep Retrofit Energy Study* (in progress at the time of writing).

Challenges and Limitations to Achieving EnerPHit

Buildings with certain features may see challenges that require alternative solutions to those used for this study of the Belmont building, and potentially additional costs, to achieve the EnerPHit heating demand standard. This includes the following conditions:

- → Buildings with exterior balconies

- → Buildings with high window to wall ratios and/or combustible exterior insulation or cladding (due to fire code requirements for combustibility of window frame materials)

Recommendations for Additional Research

Additional research and guidelines are needed in the following areas:

- → Window combustibility requirements for fire codes, enabling use of low-conductivity windows under certain conditions
- → High solar heat gain glazing in multifamily retrofits and associated summer heating and occupant comfort
- → Guidelines on heat recovery ventilation strategies to address kitchen and bathroom exhaust in an EnerPHit retrofit
- → Heating set point temperatures and the impact of internal gains from lighting and plug loads
- → Economics and guidelines on retrofit options for balconies

Contents

Appendices

1 Introduction

Passive House construction is growing in popularity in North America, following the extensive momentum established in Europe. The Passive House standard includes an ultra-low energy consumption target that is achieved through passive measures such as a well-insulated, airtight building enclosure with minimal thermal bridging, passive solar heating, heat recovery ventilation, and shading. The standard is frequently applied to new buildings. Recognizing the challenges of achieving passive design in existing buildings, the Passive House Institute (PHI) has a less-stringent standard for retrofits called EnerPHit.

The Belmont deep energy retrofit project, completed in late 2012, used passive design principles to yield significant, measured energy savings. Though the Passive House standard was not used at the time of design, many of the same principles were followed. It was theorized, but not tested, that the project was likely close to the EnerPHit standard.

This current study was initiated as an extension to the Belmont demonstration project and research work in order to determine how close the pre-existing project is to the EnerPHit standard, and what additional measures could have been taken to achieve the standard.

1.1 Building Background

Originally constructed in 1986, the Belmont is a 13-storey residential building in Vancouver. After weighing various options on how best to maintain and reinvest in their property, the owners decided to proceed with a building enclosure renewal project in 2012. While the primary objectives of the renewal pertained to durability, aesthetics, and comfort, improving the energy efficiency of the building was also a key objective.

The renewals included replacing windows, overcladding walls with exterior insulation (and rainscreen), and improving the airtightness of the building. Triple-glazed windows with fiberglass frames were used rather than the more typical double-glazed, aluminum-framed windows. Exterior insulation was added to the exposed concrete walls, which was then was overclad with stucco and metal panels attached with fiberglass clips to minimize thermal bridging. Airtightness improvements were made through detailing at windows, doors and penetrations. Design work is currently underway to upgrade the ventilation system through the installation of in-suite heat recovery ventilation (HRV) equipment. The retrofit has so far achieved an overall 19% energy reduction and is aiming to increase that to 30%, with an associated 39% reduction in greenhouse gas (GHG) emissions.

Further details on the Belmont project are provided in Appendix A[1].

1.2 Passive House Standards

The Passive House Institute administers several certification programs to design and recognize ultra-low energy buildings that follow the Passive House approach. The primary standard applied to new Passive House buildings has three requirements:

→ Space heating demand and cooling demand each below 15 kWh/m^2, or 10 W/m^2 peak, calculated using Passive House Planning Package (PHPP) software

[1] Also available at http://rdh.com/wp-content/uploads/2015/09/TB-8-Deep-Energy-Retrofit3.pdf

→ Airtightness of 0.6 air changes per hour (ACH), tested at 50 Pa for pressurization and depressurization

→ Total primary energy demand[2] of 120 kWh/m² per year, calculated using PHPP

While these requirements can be applied to retrofit projects, the Passive House Institute recognizes that it is much more difficult for existing buildings to achieve given inherent design limitations. The EnerPHit[3] standard has the following criteria:

→ Space heating and cooling demand each below 25 kWh/m², calculated using PHPP[4]

→ Airtightness of 1.0 ACH at 50 Pa, tested

→ Total primary energy demand of 120 kWh/m² per year calculated using PHPP, plus an allowance[5] for heating energy greater than 15 kWh/m²

EnerPHit has an alternate compliance path that allows certification based on the performance of individual building components. The primary compliance path (25 kWh/m² heating demand) is the focus of this report; the alternate compliance path is outside scope, and would not have been met by the retrofit measures, as completed.

The focus of this project is on the heating demand requirement of 25 kWh/m² since the Belmont retrofit project is focused on enclosure and ventilation components. The primary energy requirement of 120 kWh/m² incorporates all energy end-uses, including lighting, domestic hot water, and miscellaneous consumption. Achievement of this primary energy target is beyond the scope of this project, though comments are provided on how the existing building's performance compares to this requirement.

1.3 Project Objective

This project was initiated as an extension to The Belmont pilot project to understand how the planned retrofit compares to the Passive House EnerPHit standard, and what additional measures (if any) would need to be incorporated to achieve the standard.

This project seeks to answer the following guiding research questions:

→ What are the options available to reach a heating demand of 25 kWh/m²?

→ What are ballpark incremental costs associated with these options?

→ Are the options feasible given availability of equipment/technology and experience/skills of contractors?

1.4 Project Methodology

1.4.1 Model Building and Planned Retrofit

Previous energy modelling for The Belmont was performed using an hourly energy simulation program (DesignBuilder, an interface for EnergyPlus). For this project, the Belmont was modelled using PHPP for comparison to the EnerPHit standard.

[2] PHPP uses standard multipliers for primary (upstream) energy; in Canada, 3.6 for electricity and 1.1 for gas.

[3] Available online at http://passiv.de/downloads/03_certification_criteria_enerphit_en.pdf

[4] For this study "space heating demand" includes the heating (sensible and ventilation) load for the whole building, both suites and common areas, but excludes the (unheated) parkade.

[5] Primary energy $Q_P \leq 120$ kWh/m² + ((Q_H - 15 kWh/(m²a)) PEF; Q_H is the heating demand and PEF is the primary energy factor for the country.

Three initial model iterations were produced:

- → Pre-retrofit: Original building prior to energy interventions in 2012
- → Phase 1 Enclosure retrofit: Building performance through 2014-2015, with enclosure retrofit (wall, window, and airtightness improvements)
- → Phase 2 Ventilation retrofit: Following planned 2016 retrofit with HRVs

The three stages of the building's renewals cycle (pre-, intermediate, and post-retrofit) show how close the building is to the EnerPHit standard. These results also show how the PHPP simulation compares to and differs from the previous EnergyPlus simulations and the metered energy consumption data.

1.4.2 Model Upgrades

The existing building and planned retrofit is expected to fall short of the EnerPHit standard, as the level of performance was not as high as that recommended by PHI to achieve its standards. Several potential energy upgrades were identified and simulated in PHPP to view the incremental energy savings and performance relative to EnerPHit.

Energy and greenhouse gas conservation measures (ECMs) were identified based on the range of measures that could contribute to achieving the Passive House heating target (i.e. passive design measures that lead to better insulation, less air leakage, and more solar heat gain). The following ECMs were investigated:

- → Additional wall insulation
- → Highly efficient HRVs
- → Windows with reduced thermal conductivity
- → Higher solar heat gain glazing
- → Improved roof insulation
- → Improved ground floor insulation
- → Reduced thermal bridging
- → Reduced air leakage

The results of the ECM simulations were used to develop several potential packages of measures that achieve the EnerPHit requirement of 25 kWh/m^2 space heating demand.

1.4.3 Economics and Market Readiness

The initial Belmont project work included costing and economic analysis of the planned retrofit. This work has been extended to the additional ECMs that could achieve EnerPHit, assuming the work is performed at the time of major building enclosure renewals. A range of "best case" and "worst case" cost estimates are provided to reach the EnerPHit standard. Additional commentary is provided on the availability of equipment and materials, along with the capacity to implement the ECMs in the current marketplace.

2 Existing Building with Planned Retrofit

This section identifies the primary PHPP inputs that align with the Belmont deep energy retrofit as designed and constructed. PHPP results are shown, and are compared to the previous EnergyPlus simulations that were completed.

2.1 Key PHPP Model Inputs

The Passive House simulation program (PHPP) is very different from traditional North American hourly building energy simulation programs. PHPP requires the building be defined and input in different ways, and it uses different algorithms than hourly simulation programs. This section provides key PHPP model inputs, with comments on how these inputs compare to previous energy simulation work for The Belmont.

2.1.1 Building Geometry

Energy Use Intensity (EUI) values reported in North America typically use Gross Floor Area (GFA), measured to the exterior building enclosure surface and including all interior conditioned space (e.g. wall partition area, stairwells, elevator shafts, etc.). Passive House uses the Treated Floor Area (TFA), which includes only the areas of rooms measured to inside walls. Areas like elevator shafts and stairwells are excluded, and functional areas like corridors and equipment rooms are accounted for at 60% of their actual area.

The calculated floor areas for the Belmont are as follows:

→ TFA calculated for PHPP: 4,139 m^2

→ GFA calculated for previous study work: 5,026 m^2

2.1.2 Building Enclosure

The opaque building enclosure assemblies were modelled in PHPP using the same R-values used in the previous modelling of the Belmont following the 2013 building enclosure retrofit (see Table 2.1). None of these values meet the alternate EnerPHit component certification requirement of 0.15 W/m^2-K for each assembly.

TABLE 2.1 OPAQUE BUILDING ENCLOSURE THERMAL PERFORMANCE VALUES (POST-RETROFIT)

	U_{SI}-Value, W/m^2-K (R-value, hr-ft^2-F/Btu)	**Description**
Exterior walls – post-retrofit	U-0.35 (R-16.1)	3.5” mineral wool insulation with fibreglass clips over concrete wall with 1.5” interior XPS insulation
Exterior walls – pre-retrofit	U-1.42 (R-4.0)	Exposed concrete wall with 1.5” interior XPS insulation
Roof	U-0.59 (R-9.5)	1.5” polyiso insulation over concrete deck
Floor above parkade	U-0.47 (R-12.2)	2” spray fibreglass insulation below concrete floor
Soffit	U-2.15 (R-2.6)	Uninsulated concrete with interior flooring

The above values do account for major thermal bridges based on thermal analysis (e.g. the exterior wall assembly includes cladding attachment and concrete slab edge thermal bridging). However, PHPP includes even more detailed thermal analysis using linear transmittance values for locations where additional heat transfer occurs as a result of penetrations, corners, joints, and transitions. Linear thermal transmittance values for The Belmont were calculated using the three-dimensional heat transfer simulation program Heat3. Table 2.2 summarizes these values; Appendix B provides additional details on the linear transmittance calculations.

TABLE 2.2 OPAQUE BUILDING ENCLOSURE LINEAR TRANSMITTANCE VALUES

	Linear Transmittance, ψ (W/m-K)	Description
Exterior corner	-0.105	Exterior wall corners in the building enclosure
Interior corner	0.094	Interior wall corners in the building enclosure
Parapet	0.350	Concrete thermal bridge around the roof and deck perimeter
Ground floor perimeter	0.824	Where the first floor meets the parkade
Soffit corner	-0.125	Corner at uninsulated soffits

Values that are negative indicate less heat transfer compared to the assembly value and provide a net benefit to reduce the heating demand. These values are calculated using exterior dimensions, as required by PHPP, which is different from the Building Envelope Thermal Bridging Guide[6] values which use interior dimensions.

Glazed components are defined differently in PHPP than in North American hourly energy simulation programs (e.g. EnergyPlus). In PHPP, values are entered for individual components (glazing, window frame, linear transmittance at the edge of glass, and installation linear transmittance). Further, PHI references ISO test standards for determining glazing U-values, whereas North American products are simulated using NFRC ratings[7]. The components for the windows installed at The Belmont were simulated using the ISO methodology for input into PHPP. The original windows and aluminum skylights at the penthouse were not available with ISO ratings, and so NFRC equivalents were used in their place. The skylights represent a very small area at the building and so this simplification is anticipated to have a very minor impact on the overall model. PHPP also uses the actual fenestration dimensions, including specific framing sizes, whereas the previous simulations used overall window U-values for standard NFRC sizes[8].

The following fenestration properties were used in the Belmont post-retrofit modelling:

→ PHPP U-value: 1.18 W/m^2-K (calculated from component U-values and actual sizes)
PHPP g-value[9]: 0.26 (applied to glazing only)

[6] https://www.bchydro.com/powersmart/business/programs/new-construction.html#thermal

[7] See International Window Standard: Final Report, available online at https://hpo.bc.ca/files/download/Report/International-Window-Standards.pdf

[8] NFRC standard sizes are 1200 x 1500 mm for fixed windows and 600 x 1500 mm for casement windows.

[9] The primary difference between g-value and product SHGC is that the g-value is for only the glazing area, while the product SHGC is for the whole fenestration product at a standard NFRC size. However, there are additional differences in the calculation of the two values, and g-value is not the same as centre of glass SHGC.

→ EnergyPlus U-value: 1.14 W/m^2-K (NFRC certified value, using standard sizes)
EnergyPlus SHGC: 0.2 (applied to whole product including frame)

The linear transmittance of fenestration installation is also considered in PHPP (and not in EnergyPlus); these values were simulated for the Belmont using two-dimensional heat transfer software THERM and WINDOW:

→ Head: -0.016 W/m-K

→ Sill: 0.07 W/m-K

→ Jamb: 0.055 W/m-K

Linear transmittance values and actual sizes for the window installation were not used in the original analysis of the Belmont because this practice is not currently industry standard. References including ASHRAE 90.1 indicate that the NFRC certified U-value is to be applied to the size of the rough opening.

2.1.3 Airtightness and Ventilation

Airtightness testing was performed at The Belmont before and after the enclosure retrofit. PHPP requires the value to be converted to air changes per hour (ACH) at a test pressure of 50 Pa. The following values were calculated for PHPP:

→ Pre-retrofit: 3.00 ACH_{50}

→ Post-retrofit: 1.35 ACH_{50}

The pre-retrofit air leakage rate measured at the Belmont is typical of high-rise multifamily buildings of similar vintage in southwestern British Columbia that have not been retrofitted[10]. Airtightness rates for these and other large buildings are typically reported in units of l/s per m^2 of enclosure area (or cfm per sf of enclosure area) at a tested rate of 50 or 75 Pa. Air leakage rates were converted to ACH_{50} for this study using the building volume.

The post-retrofit tested airtightness is still higher than the EnerPHit requirement of 1.0 ACH_{50}, and significantly higher than the standard Passive House requirement of 0.6 ACH_{50}. However, it is important to note that this testing was not performed following the Passive House procedure; in particular, bathroom, kitchen, and dryer exhaust vents were not sealed for the test. These values were used in the PHPP model to be conservative, however it is highly likely that the building would achieve the 1.0 ACH_{50} requirement if correctly sealed for the Passive House test. Rough calculations from the test results indicate that excluding bathroom duct leakage gives a rate of 0.84 ACH_{50}, and excluding bathroom, dryer, and kitchen duct leakage gives a rate of 0.34 ACH_{50}.[11] Further airtightness testing is planned for the ventilation retrofit phase of the project, and the Passive House airtightness should be tested at that time.

[10] See *Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia*, available online at https://hpo.bc.ca/sites/www.hpo.bc.ca/files/download/Report/MURB-EnergyStudy-Report.pdf and *Building Enclosure Airtightness Testing in Washington State – Lessons Learned about Air Barrier Systems and Large Building Testing Procedures*, available online at http://rdh.com/wp-content/uploads/2014/10/ASHRAE-2014-Annual-Conference-Building-Enclosure-Airtightness-in-WA-Final.pdf

[11] The Passive House test allows HRV vents to be sealed. Though still in design, the HRV retrofit for the Belmont will likely use the bathroom exhaust, but exclude the kitchen and dryer exhaust. As such, the likely airtightness test result would be approximately 0.84 ACH50. Air leakage can still occur through the kitchen and dryer vents, though the overall building airtightness would likely fall within the EnerPHit criteria of 1.0 ACH50.

The building's current ventilation system is a rooftop make-up air unit that delivers outdoor air to corridors. Suites have intermittent, occupant-controlled bathroom and kitchen exhaust fans, and dryer exhaust. A planned HRV retrofit is currently in design, however the HRV unit has not yet been selected and the design has not been completed. A mid-level efficiency unit is anticipated, and so a unit with an effective efficiency of 82% was used in PHPP.

Following the HRV retrofit, the make-up air unit airflow rate will be lowered to provide the minimum outdoor air rate necessary for corridor pressurization. The reduced rate was assumed to meet ASHRAE 62.1-2001 outdoor air for corridors, 0.25 $l/s\text{-}m^2$ (26 cfm per floor). However, this outdoor air will not have heat recovery since there is no ducted return.

Passive House principles recommend heat recover on all exhaust air. This can present a challenge for kitchen range hoods and dryer exhaust, which can have high airflow rates, and existing floor plans (limiting retrofit ducting configurations). At the Belmont, it is likely that the bathroom exhaust will pass through the HRV, but the kitchen and dryer exhaust will not; the PHPP model has been prepared assuming this configuration. Various approaches to provide make-up air to suites are still being considered.

2.1.4 Other Inputs

The above inputs are sufficient to determine the heating demand, and whether the EnerPHit standard of 25 kWh/m^2 is met. However, additional inputs related to the heating system, hot water, lighting, and miscellaneous electricity are required to assess the primary energy requirement.

Heating

Residential suites are heated by electric baseboards (100% efficient).

Suites also have gas fireplaces, however the fireplaces are intended for aesthetics and have a low space heating efficiency. The fireplaces were omitted from the PHPP model as they do not impact the heating demand target of 25 kWh/m^2. If the building were to pursue certification, fireplaces would need to be changed to highly efficient units or removed to meet the primary energy target. Interestingly, high efficiency fireplaces would likely be better than electric baseboard heating to achieve the Passive House primary energy target since PHPP uses country-wide primarily energy factors of 2.6 for electricity and 1.1 for gas, even though this is not representative of the fuel mix in British Columbia.

The Belmont's corridor ventilation is supplied by an 80% efficient gas-fired make-up air unit in both the pre- and post-retrofit conditions[12]. In either case, the make-up air unit fuel and efficiency is not straightforward to model in PHPP because the make-up air heating cannot be directly modelled with a separate space heating system (the percent of total heating needs to be estimated and then assigned to a gas-fired heater). This only affects the primary energy value and not the heating demand, and so the make-up air unit was omitted from PHPP for this study; the correct outdoor air rates and HRVs are modelled as designed and constructed.

[12] The existing building was ventilated using a pressurized corridor strategy, with a make-up air unit delivering a high volume of outdoor air to the corridors and no direct ventilation to suites. Following the planned Phase 2 HRV retrofit the make-up air unit airflow rate will be lowered significantly and ventilation provided through in-suite HRVs.

Passive House certification is assessed at a heating temperature set point of 20°C. Suite reviews and consumption data suggested that some occupants maintained higher temperature set points; the final calibrated model used an average set point of 23°C. However, the PHPP model was left at 20°C to assess how the building would compare to the certification standard.

Domestic Hot Water

The building's domestic hot water (DHW) is provided by a central gas-fired boiler with an efficiency of 82%. This was modelled in PHPP. If the building pursued certification, a higher efficiency unit would need to be installed to meet the primary energy requirement.

DHW use was calibrated in the EnergyPlus model to align with metered data. PHPP includes standard values for design and certification.

→ PHPP DHW based on assumptions: 76,572 kWh (19 kWh/m^2 based on TFA)

→ EnergyPlus calibrated: 130,197 kWh (26 kWh/m^2 based on GFA)

The PHPP energy consumption is much lower because the PHPP standard DHW consumption is less hot water use than is currently consumed at the Belmont.

Lighting and Miscellaneous Electrical

The EnergyPlus model used miscellaneous electrical loads calibrated to align with metered utility consumption data. PHPP includes standard default values for lighting and miscellaneous electricity based on the assume occupant density of the space.

→ PHPP Lighting and Plug Load Assumptions: 95,734 kWh (23 kWh/m^2 based on TFA)

→ EnergyPlus Lighting and Plug Loads: 295,890 kWh (59 kWh/m^2 based on GFA)

The PHPP lighting and plug load consumption is much lower than the EnergyPlus (calibrated model) consumption. This is because the PHPP standard inputs for lighting, appliances, and other electrical loads are significantly lower than the metered electricity consumption for these end-uses at the Belmont. These values were not calibrated in PHPP as measures related to the primary energy target were beyond the scope of the retrofit project, and since the goal of this study is to assess compliance with EnerPHit using standard conditions.

2.2 Simulation Results

Table 2.3 summarizes the Passive House certification criteria produced by PHPP for the three phases of the building retrofit. The heating demand (kWh/m^2) is the primary focus of this study, and must be below 25 kWh/m^2 for EnerPHit certification. As designed, the phase 2 heating demand of 42 kWh/m^2 is 68% higher than the EnerPHit requirement.

TABLE 2.3 PHPP SIMULATION RESULTS FOR THE BELMONT

	Space Heating Demand, kWh/m^2	Space Heating Load*, W/m^2	Primary Energy**, kWh/m^2
Pre-Retrofit	213	85	641
Phase 1 Post-Retrofit	69	30	267
Phase 2 Post-Retrofit	42	22	193

*Not a requirement for EnerPHit certification.

**Primary energy based on default PHPP assumptions for DHW, lighting, miscellaneous electrical use, and temperature set point.

2.3 Comparison to Previous Modelling

It is difficult to compare the PHPP results to the EnergyPlus simulations from the previous study work. This is due to several factors:

→ Different reference areas: PHPP references TFA (useable interior space) while the previous work referenced GFA

→ Heating demand: PHPP indicates the heating demand before applying mechanical equipment and efficiencies, whereas the past modelling presented heating energy including equipment efficiencies

Table 2.4 shows the approximate heating demand simulated in EnergyPlus compared to the PHPP demand, normalized by TFA and by GFA. The EnergyPlus demand is different from previous study results as it has been calculated as electric baseboard heating plus make-up air ventilation divided by an efficiency of 80%.

Though the comparison is approximate, the results indicate that PHPP and EnergyPlus yield similar heating demand for ultra-low heating energy buildings (i.e. Passive House-level performance). In this study, the Phase 2 post-retrofit heating demand values are close. However, for typical existing or code minimum buildings, the tool does not align well with hourly energy simulation programs.

The PHPP space heating demand values shown in the table below (and throughout this report) were not calibrated to align with metered data in the same way that the EnergyPlus model was. This was done because the PHPP model would have to use standard values for EnerPHit certification, and the goal of the study was to compare the building to the EnerPHit standard. The key calibration related to heating energy was the higher set point temperature of 23°C; this would change the PHPP heating demand values significantly[13].

TABLE 2.4 COMPARING PHPP TO ENERGYPLUS

	EnergyPlus Approx. Space Heating Demand, kWh/m²		**PHPP Space Heating Demand, kWh/m²**	
	Per TFA	**per GFA**	**per TFA**	**per GFA**
Pre-Retrofit	149	122	213	175
Phase 1 Post-Retrofit	100	82	69	57
Phase 2 Post-Retrofit	45	37	42	35

[13] Detailed information on post-retrofit setpoint temperatures was not collected during the project. Although the residents may have lowered their thermostat setopint temperatures as a result of a more comfortable enclosure, the "EnergyPlus" model results have been calibrated to metered utility data and are therefore representative of actual heating energy used at the building.

3 ECM Upgrades for EnerPHit

Several ECMs were investigated to view the impact on space heating demand and the contribution towards achieving the EnerPHit target of 25 kWh/m². ECMs were first simulated individually to view the measures with the greatest impact. Packages of ECMs that meet EnerPHit were developed from these findings.

3.1 Individual ECM Results

The following energy conservation measures (ECMs) were simulated in PHPP using the final post-retrofit model of The Belmont (phase 2, including HRVs):

- → Additional wall insulation (Effective R20, R25, R30)
- → Window frames with reduced thermal conductivity (Passive House frames, ISO calculated U_{frame} < 0.8 W/m²-K[14])
- → Higher solar heat gain glazing (g-value 0.56)
- → Improved roof insulation (Effective R20, R30)
- → Improved ground floor insulation (Effective R20, R30)
- → Improved soffit insulation (Effective R10, R20, R30)
- → Reduced thermal bridging (includes several details improved, see Table 3.1 and Appendix B)
- → Reduced air leakage (1.0 ACH_{50}, 0.6 ACH_{50})
- → High efficiency HRVs (effective 92%)
- → Heat recovery on corridor make-up air (would require ducted return and rooftop HRV, or one HRV per floor ducted through suites)

TABLE 3.1 DETAIL PSI VALUES INCLUDED IN ECM "REDUCED THERMAL BRIDGING"

Detail Type	Detail Psi Value (W/m-K)	ECM Psi Value (W/m-K)	Percent Improvement (%)
Base of Wall - Ground Floor	0.824	0.130	84%
Parapet	0.371	0.123	67%
Window Sill	0.070	0.025	64%
Window Head	-0.016	-0.017	9%
Window Jamb	0.055	-0.007	113%

Table 3.2 shows the PHPP simulation results for each individual ECM compared to the post-retrofit scenario. The measures with the greatest individual heating demand savings are both related to windows: high solar heat gain glass, and Passive House-level window frames (U_{frame} < 0.8 W/m²-K). In fact, the change to high solar gain glass alone brings the building very close to the EnerPHit standard of 29 kWh/m².

While the high solar gain glass provides significant energy benefit, this also comes at a risk of overheating as the suites do not have air conditioning, and the building has a

[14] By comparison, the installed fiberglass frames had ISO calculated U-values of 1.3 to 1.6 W/m²-K.

reasonably high window to wall ratio of 50%. The original windows with clear glass had high solar gain (even higher than a g-value of 0.56, an ECM for this study) and so replacing like for like should not make the condition worse. Also, the PHPP model indicates that overheating is not a concern with high solar gain glass as long as windows are opened at night to provide cooling. However, the PHPP model is a simple, single-zone calculation that does not accurately simulate zones by orientation, and so additional investigation is warranted to verify this result. If high solar gain glass were proposed, it would be prudent to investigate overheating further and consider incorporating exterior shading to prevent discomfort. Overheating in the existing building was not investigated prior to the retrofit.

TABLE 3.2 PHPP RESULTS FOR INDIVIDUAL ECMS

	Heating Demand, kWh/m^2	**Heating Load, W/m^2**	**Primary Energy, kWh/m^2**
Phase 2 post-retrofit	*42*	*22*	*193*
Wall insulation: R20 (4" MW)	41	21	189
Wall insulation: R25 (6" MW)	39	21	185
Wall insulation: R31 (8" MW)	38	21	183
Passive House window frame	33	19	168
High SHGC glass (g-value 0.56)	29	21	160
Roof insulation: R20	42	22	193
Roof insulation: R30	39	21	185
Ground floor insulation: R20	40	21	192
Ground floor insulation: R30	41	22	190
Soffit insulation: R10	40	21	188
Soffit insulation: R20	40	21	187
Soffit insulation: R30	40	21	187
Reduced thermal bridging	39	21	184
Reduced air leakage: 1.0 ACH_{50}	40	20	188
Reduced air leakage: 0.6 ACH_{50}	38	19	183
High efficiency HRVs (92%)	40	21	186
Heat recovery for corridor ventilation (82%)	40	21	187
Heat recovery for corridor ventilation (92%)	40	21	186

3.2 EnerPHit Packages

One of the requirements for EnerPHit is that the building must achieve an airtightness of 1.0 ACH_{50}. As noted previously, the building was not tested using the Passive House procedure with exhaust vents sealed, and so the true airtightness rate may in fact meet this requirement.

In developing the lowest cost EnerPHit packages, the measures with the greatest savings and least cost were considered. The following ECMs appear to make the most sense for an EnerPHit package:

- → Reduced air leakage to 1.0 ACH_{50}: likely achieved (or very close)
- → Soffit insulation R10 (approx. 2" mineral wool insulation): the soffits were the only uninsulated enclosure component that remained following the retrofit; adding minimal insulation provides a significant improvement over the uninsulated condition.
- → High solar heat gain glazing: The installed triple glazed units had low solar gain glass; changing to a high solar gain glass yields significant savings[15]. This configuration would still have lower solar gain than the original glazing units, however further analysis would be recommended to assess the risk of overheating.
- → Reduced thermal bridging: Several details were identified that could be improved to reduce the linear transmittance or thermal bridging. Additional details on the improvements made are discussed in Appendix A.

Other combinations of ECMs would be possible, though would have a higher capital cost than the above measures. For example, the "Passive House window frame" ECM yields significant savings but would have a high incremental cost due to the limited number of products available in Vancouver.

These measures were simulated in combination using PHPP to view the impact on heating demand and to assess whether the project meets EnerPHit. Table 3.3 shows the results of two groups of low/no-cost ECMs that achieve the EnerPHit requirement of 25 kWh/m^2.

TABLE 3.3 PHPP RESULTS FOR ENERPHIT PACKAGES

Low/No Cost ECMs	**Heating Demand, kWh/m^2**	**Heating Load, W/m^2**	**Primary Energy, kWh/m^2**
Phase 2 post-retrofit	*42*	*22*	*193*
EnerPHit package 1 → Reduced air leakage Soffit insulation High solar gain glazing	26	19	150
EnerPHit package 2 → Reduced air leakage Reduced thermal bridging High solar gain glazing	24	18	147
EnerPHit package 3 → Reduced air leakage Reduced thermal bridging Soffit insulation High solar gain glazing	23	18	143

[15] Several glazing manufacturers and low-emissivity products are available with a range of low to high solar gain. The Belmont retrofit used Cardinal LoE 366 on surface 2 and LoE 180 on surface 5, a low solar gain combination. The ECM simulated in this study assumes a high solar gain product with Cardinal LoE 180 on surfaces 2 and 5. Other manufacturers and products are available with similar performance characteristics.

4 Economics and Market Readiness

Barriers to Passive House and near-passive construction often include high capital costs and lack of market readiness (product availability, training for professionals and trades). This section provides comments on these factors in achieving EnerPHit at the Belmont.

4.1 Economics

Some of the ECMs investigated here would add significant costs to the retrofit project, such as Passive House window frames, high efficiency HRVs, and make-up air heat recovery. However, a few low- or no-cost measures were identified that, together, reach the EnerPHit standard for heating demand at the Belmont.

→ Reduced air leakage to 1.0 ACH_{50}
This would likely be achieved (or very close) if the building were tested with vents sealed per the Passive House testing standard. If additional air sealing is required to meet this standard, this could have been achieved through targeted investigation (such as smoke testing) performed at the time of the airtightness test and sealing during construction with no added cost to the project.

→ Soffit insulation R10: Estimated cost of $20,000 to $30,000 for insulation, low-conductivity cladding attachment, and metal panel cover.

→ High solar heat gain glazing: No additional cost for high solar gain glazing.

→ Reduced thermal bridging: Est. $5,000 to $10,000 to improve ground, parapet, and window installation details.

A true cost-payback analysis would require simulating these measures in EnergyPlus to provide a fair comparison to the previous financial analysis. However, it is significant that these measures are relatively low cost, that they could have likely been added with a minor increment above the project's $3.6 million budget.

Table 4.1 shows the incremental costs that would be required to reach 25 kWh/m^2 space heating demand. Additional costs would apply for the building to meet the primary energy target (e.g. high efficiency fireplaces, DHW, make-up air unit, etc.).

TABLE 4.1 INCREMENTAL CONSTRUCTION COSTS TO ACHIEVE ENERPHIT HEATING DEMAND REQUIREMENT	
Airtightness testing[16]	$5,000 to $10,000
Soffit insulation	$20,000 to $30,000
High solar heat gain glazing	No cost
Reduced thermal bridging	$5,000 to $10,000
Total Incremental for EnerPHit Retrofit[17]	**$10,000 to $50,000**
% above construction budget	*0.3% to 1.4%*

[16] Covered by the research budget for the Belmont, but would otherwise need to be included in project costs.
[17] Total cost values were determined using the low cost for airtightness testing and reduced thermal bridging, and high cost for airtightness testing, reduced thermal bridging, and soffit insulation.

4.2 Market Readiness

Added market barriers to an EnerPHit retrofit include the following:

- Airtightness testing was conducted as part of the research work completed at the Belmont, however most projects undergoing a large renewals project do not typically include this testing. This would add an additional $5,000 to $10,000 cost to a similar retrofit project[18]. However, an additional challenge is that the Passive House standard test method requires a whole building test, which is very difficult in an occupied multifamily residential building. Compartmentalized, suite by suite testing is much more practical, but would require special approval for EnerPHit certification.
- There is concern among glazing manufacturers that high solar gain glazing can result in overheating of residential spaces without air conditioning; as a result, glazing manufacturers tend to recommend low solar gain products locally, as was installed at the Belmont. Further research is required in this area to understand overheating risks with various window to wall ratios, and how these risks could be alleviated through simple fixed exterior shading. Since PHPP is a simple single-zone tool, it may not appropriately assess overheating in multifamily buildings; further work is required in this area.
- The PHPP window inputs require that the windows be simulated in accordance with ISO standards, which are different from the NFRC standards to which North American products are tested. Few North American manufacturers have Passive House values readily available for their projects.
- This report demonstrates that the Belmont could have achieved EnerPHit (25 kWh/m^2) with locally available products and construction practices. However, achieving the more stringent new construction Passive House standard (15 kWh/m^2) would likely require less common products such as high efficiency HRVs and Passive House recommended windows. These products are currently costly due to the limited number of products in the North American market, though costs are anticipated to decrease as additional manufacturers enter the market with the growth of Passive House.
- Combustibility of windows may be a concern in other multifamily buildings. At the Belmont, an alternative solution to the Vancouver Building Bylaw was approved to allow “combustible” windows in a non-combustible building. High-rise buildings with higher window to wall ratios or “combustible” cladding materials (e.g. exterior foam insulation) may be challenged to find an acceptable solution. A limited number of metal frame Passive House level windows are available in Europe.
- Achieving Passive House and EnerPHit may be more challenging in a building with exterior balconies. The Belmont’s balconies were previously enclosed, allowing the building to be wrapped in insulation with minimal thermal bridging. A variety of retrofit options may be possible (e.g. insulating or removing balconies); further research would be beneficial to assess the economics of alternatives.

[18] Airtightness testing costs vary depending on the size and complexity of the building. Testing costs could be higher depending on the project.

5 Summary and Conclusions

This project was completed as an extension to The Belmont pilot project to understand how the planned building retrofit compares to the Passive House EnerPHit standard, and what additional measures (if any) would need to be incorporated to achieve the standard. Overall, this work showed that going the extra step to EnerPHit requires careful attention to detail, but could be achieved at the Belmont and other multifamily buildings with little to no added cost beyond the retrofit that was already completed.

The following sections summarize the key findings and lessons learned from this study.

5.1 Achieving EnerPHit at the Belmont

As designed and implemented, the deep energy retrofit of the Belmont will be close to the EnerPHit standard after the planned HRV installation is complete. Heating demand calculated using PHPP is 41 kWh/m^2, compared to the EnerPHit standard of 25 kWh/m^2.

Several ECMs are available to reach the EnerPHit target, such as thicker insulation, better windows, higher efficiency HRVs, and heat recovery for corridor ventilation. However, this work showed that only minor improvements were needed to reach the EnerPHit standard. Key changes that led to a compliant building included high solar gain windows, insulation of thermal bridges (specifically at the soffit, roof parapet, and window installation), and whole building airtightness testing per the Passive House standard (testing with vents sealed).

The incremental costs associated with these measures are minor; additional insulation of thermal bridges would add $10,000 to $50,000 to the project. High solar gain glass typically has no added cost, and airtightness testing was completed as part of the project (would have simply had to use a different method). This work could have easily been completed within the retrofit project scope and budget.

The primary energy requirement for EnerPHit was not evaluated with the scope of this project, but it is noted that additional upgrades would be required to achieve this target. This would likely include the removal or replacement of fireplaces and a high efficiency DHW system.

5.2 Achieving EnerPHit and Passive House Across Multifamily Retrofit Projects

While the EnerPHit standard proved to be well within reach for the Belmont, several additional barriers may be present for other multifamily residential building retrofit projects. Buildings with exterior balconies would be challenged by thermal bridging (balconies were previously enclosed at the Belmont). Higher window to wall ratios may limit the use of windows with low conductivity frames, and the availability of Passive House level metal frame windows is currently limited.

Though not the focus of this study, it is noted that the more stringent Passive House standard would be challenging to achieve in multifamily retrofits. The lower heating demand requirement would require retrofit measures with higher capital costs.

The pressurized corridor ventilation system may present a challenge to EnerPHit or Passive House construction. At the Belmont, the airflow rate required to provide minimum corridor ventilation was low enough that central heat recovery was not necessary to meet the heating demand standard. If heat recovery was necessary, this would add significant work to the project, either ducting return air to a rooftop HRV or adding floor by floor corridor HRVs with ducting through a suite. This would likely be required if the building was to achieve the more stringent Passive House standard.

5.3 PHPP as an Energy Modelling Tool

The Passive House and EnerPHit standards require certification through their energy simulation tool, PHPP. This software is very different from hourly energy modelling programs that are typically used in North America. This study allowed limited comparison between the two programs since the Belmont has also been modelled using the EnergyPlus platform developed by the US Department of Energy (via the DesignBuilder interface).

The following key differences were noted in this project:

- Floor areas
  Passive House references "Treated Floor Area" (TFA), which is measured to the interior of the building enclosure and excludes partitions and certain interior spaces (for example corridors are counted at 60%). The previous study work used "Gross Floor Area" (GFA), which includes all interior space measured to the outside of the building enclosure. The TFA is about 1,000 m^2 less than the GFA, and therefore has a significant difference on normalized energy metrics, including the key metric of heating demand.

- Energy reporting
  The key EnerPHit metric of 25 kWh/m^2 space heating is the demand or load experienced by the building prior to mechanical system energy. The previous Belmont work reported heating energy consumption, which considers mechanical system efficiencies and losses.

- Standard assumptions and base loads
  PHPP includes standard assumptions and base loads for certification purposes, including domestic hot water use, lighting, and miscellaneous electricity consumption. Compared to the Belmont's metered energy consumption, and RDH's previous research on energy consumption in multifamily buildings, the standard PHPP consumption is much lower than average multifamily residential use in British Columbia. PHPP also uses a heating temperature set point of (20°C), which was lower than the Belmont residents' average interior set point.

These differences mean that energy and demand consumption between PHPP and EnergyPlus are not readily comparable. Despite these differences, comparing PHPP and EnergyPlus heating energy showed the two programs provide similar results for the post-retrofit scenario with near-EnerPHit performance. However, the pre-retrofit and the Phase 1 retrofit (including enclosure measures but excluding ventilation upgrade) gave very different results in the two programs. This likely is due to a variety of factors, including thermal mass and PHPP's application of mechanical systems. Overall, PHPP seems appropriate for buildings at or near Passive House level performance, but not appropriate as a simulation tool for code minimum or the broader stock of existing buildings.

5.4 Recommendations

This study has identified several areas for additional research:

→ Develop guidelines on window combustibility requirements for fire codes, clarifying conditions where non-metal frame windows are permissible. This may include window to wall ratios, exterior cladding and insulation material, vertical and horizontal separation dimensions, etc.

→ Conduct research and develop guidelines on the use of high solar heat gain glazing in multifamily retrofits. This could include testing and simulation of indoor temperatures and comfort using a range of existing and replacement glazing options and shading strategies to produce guidelines on maximizing solar heat gain while minimizing the risk of overheating.

→ Develop guidelines for ventilation strategies in EnerPHit retrofits, including how to address kitchen and dryer exhaust. Further investigate and clarify airtightness testing approaches suitable for EnerPHit at existing, occupied multifamily residential buildings.

→ Conduct research on common residential suite heating set point temperatures, and how occupant thermostat control may change before and after a deep energy retrofit, and measured savings from programmable or smart thermostats. Additional work could also be completed on the impact of lighting and miscellaneous electrical energy use on heating and PHPP modelling.

→ Develop guidelines and research the economics of retrofit options for balconies in existing multifamily residential buildings, including enclosing balconies, adding exterior insulation, and other alternatives.

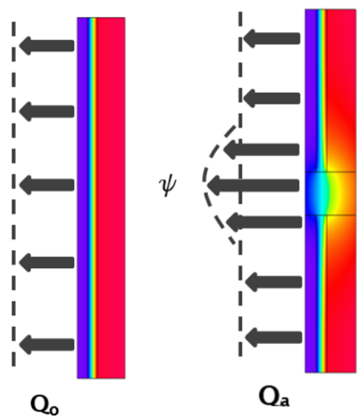
Appendix A

The Belmont Deep Energy Retrofit Project Details

Appendix B

Thermal Bridging Analysis

The Belmont thermal bridging details were modelled using the programs HEAT3 and THERM to determine the linear transmittance of each detail, represented by a psi-value (ψ). Linear transmittance or psi-value is the additional amount of heat flow through a wall assembly caused by a linear thermal bridging detail such as a window jamb, window head, outside corner of a wall, etc. It is determined by subtracting the heat flow of the clear field center-of-wall (i.e. the wall assembly with no detail in it) from the heat flow through same assembly but including the specific linear detail as shown in Figure B.1. The psi-value can then be used to quickly determine the thermal performance of a wall assembly with linear details, and can also provide a direct comparison of different detail arrangements.



$$\psi = \frac{Q_a - Q_o}{L \cdot \Delta T}$$

Figure B.1 Thermal gradients showing the difference in heat flow through the thermal bridge, and the corresponding psi-value formula

Table B.1 summarizes the psi-values for each detail first as it was constructed in the retrofit project, and then with improvements (if possible) modelled as an ECM in PHPP. These alternate values demonstrate how the psi-value can be significantly improved with minor changes to the detail.

TABLE B.1 DETAIL PSI VALUES

Detail Type	Detail Psi Value (W/m-K)	ECM Psi Value (W/m-K)	Percent Improvement (%)
Inside Corner	0.094	-	-
Outside Corner	-0.105	-	-
Base of Wall - Soffit	-1.250	-	-
Base of Wall - Ground Floor	0.824	0.130	84%
Parapet	0.371	0.123	67%
Window Sill	0.070	0.025	64%
Window Head	-0.016	-0.017	9%
Window Jamb	0.055	-0.007	113%

Figure B.2 and Figure B.3 show a typical inside corner, Figure B.4 and Figure B.5 show an outside corner, and Figure B.6 and Figure B.7 show a base of wall soffit. No alterations or ECMs were included for these three details.

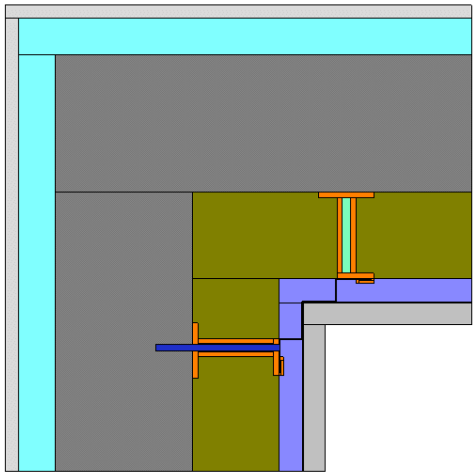


Figure B.2 Inside Corner Detail – Material

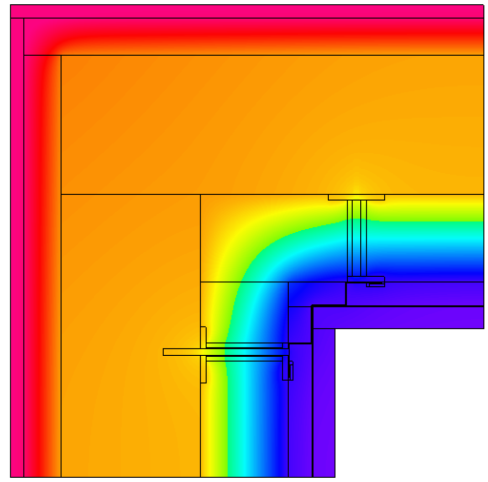


Figure B.3 Inside Corner Detail – Thermal

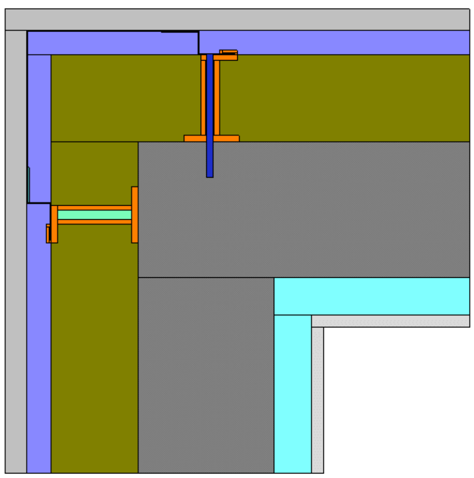


Figure B.4 Outside Corner Detail – Material

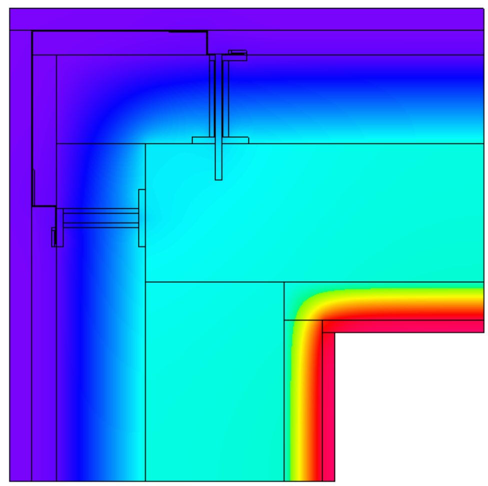


Figure B.5 Outside Corner Detail – Thermal

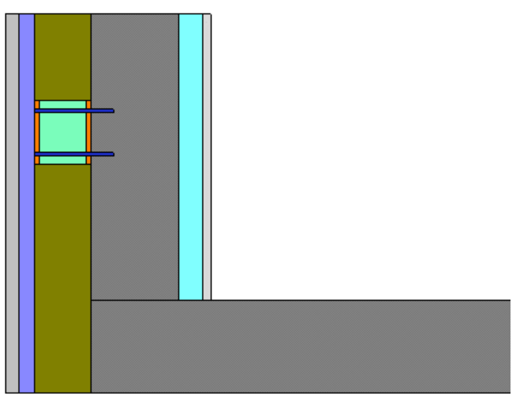


Figure B.6 Base of Wall - Soffit Detail – Material

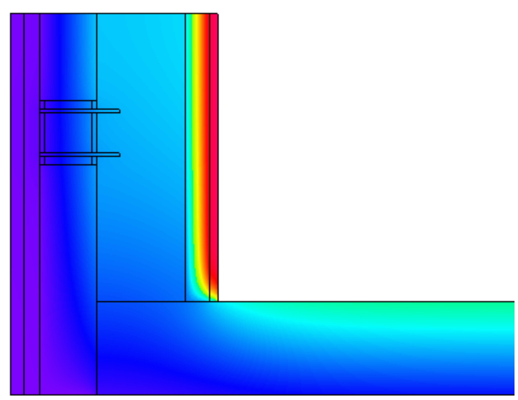


Figure B.7 Base of Wall - Soffit Detail – Thermal

Figure B.8 and Figure B.9 show the base of wall ground detail designed and constructed at the Belmont, whereas Figure B.10 Figure B.11 demonstrate the benefit from adding 3” CT board at the exterior base of the wall and 2” of horizontal XPS insulation at ground level, as well as extending the spray insulation along the underside of the podium.

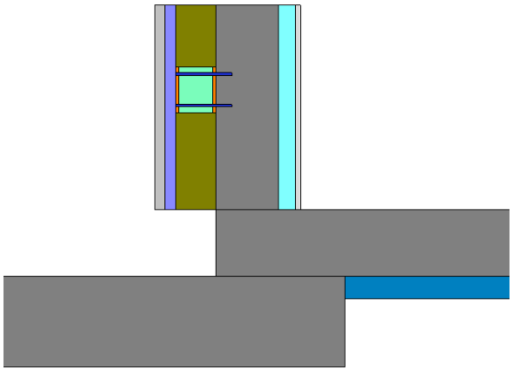


Figure B.8 Base of Wall – Ground Detail – Material

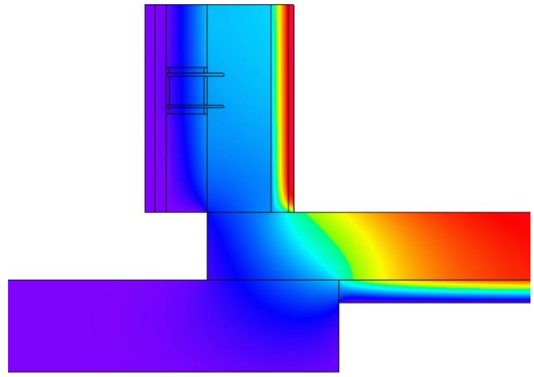


Figure B.9 – Base of Wall – Ground Detail – Thermal

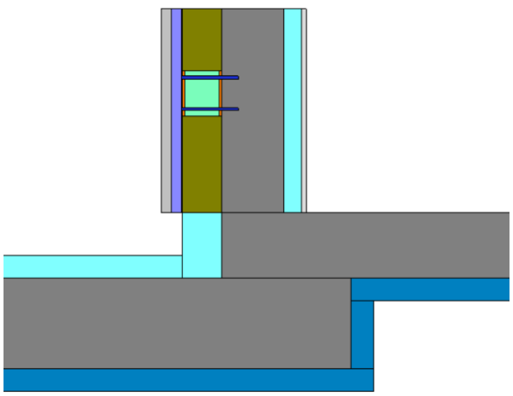


Figure B.10 – Improved Base of Wall – Ground Detail – Material

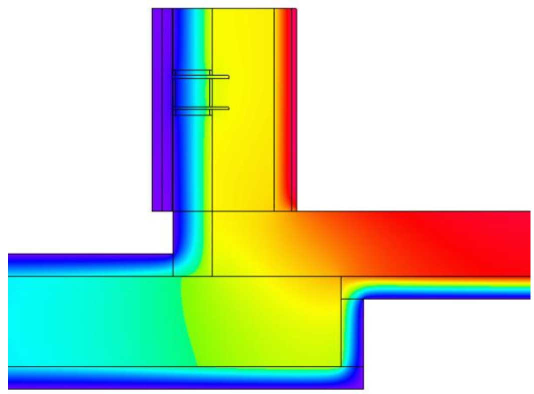


Figure B.11 – Improved Base of Wall – Ground Detail – Thermal

Figure B.12 and Figure B.13 show the parapet detail. In Figure B.14 and Figure B.15, the exterior mineral wool insulation was extended up the full length of the wall and 1.5” of XPS was added on the opposite side of the parapet wall.

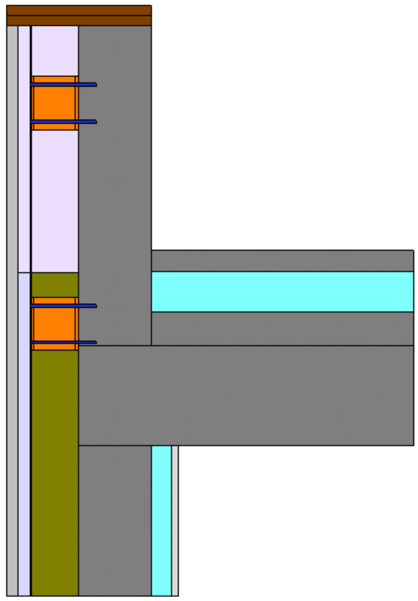


Figure B.12 Parapet Detail – Material

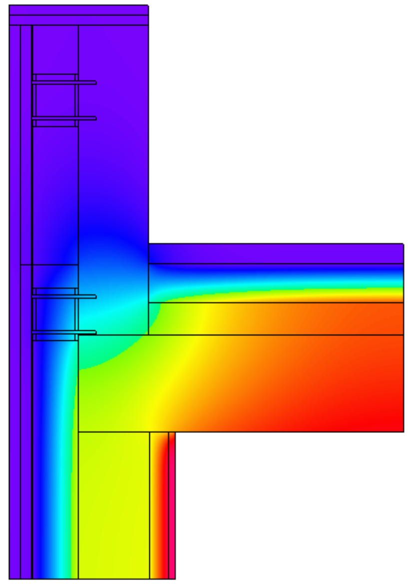


Figure B.13 Parapet Detail – Thermal

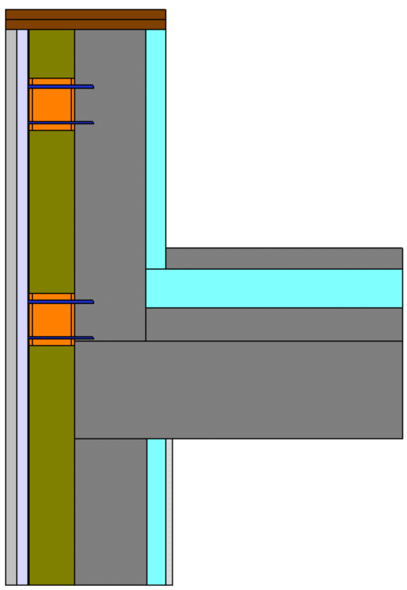


Figure B.14 Improved Parapet Detail – Material

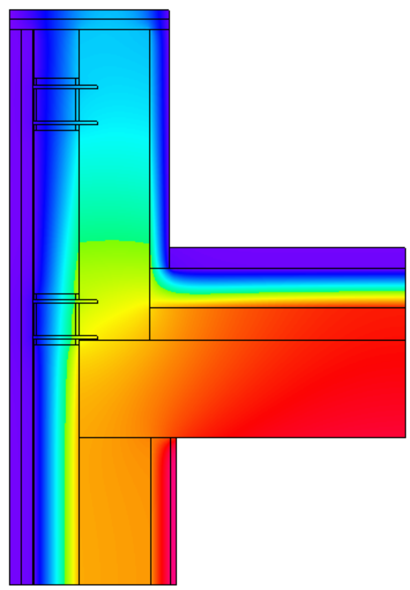


Figure B.15 Improved Parapet Detail - Thermal

Figure B.16 and Figure B.17 show the installed window sill detail, and Figure B.18 and Figure B.19 show an improved window sill detail. In the improved model, the window sill frame was moved in line with the mineral wool insulation layer, and the plywood and framing extended to meet the window sill at the new location. Though this assembly reduces the amount of wrapped mineral wool, it better aligns the thermal bridges, improving thermal performance. Cladding was not included in these models since it has very little impact of the R-value of the assemblies, and because the psi-value is a relative measure of performance.

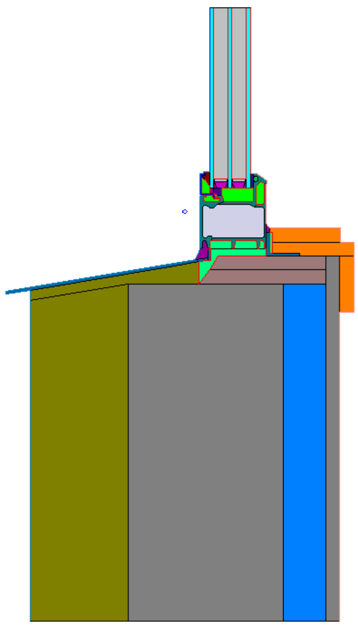


Figure B.16 Window Sill Detail – Material

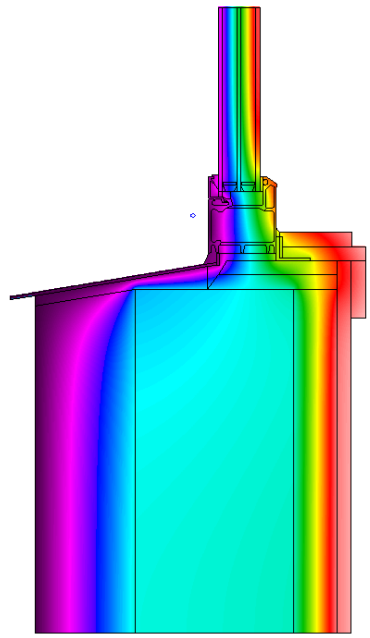


Figure B.17 – Window Sill Detail – Thermal

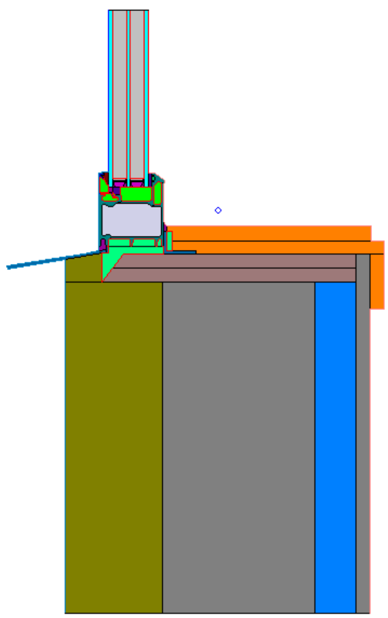


Figure B.18 – Improved Window Sill – Material

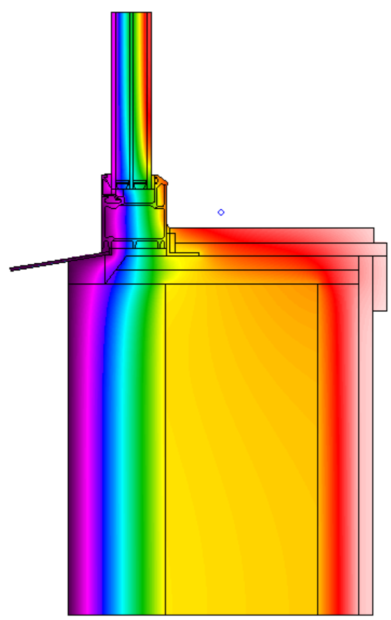


Figure B.19 – Improved Window Sill – Thermal

Figure B.20 and Figure B.21 show the window head detail, and Figure B.22 and Figure B.23 show a slightly alternate detail. In the alternate model, the mineral wool insulation was extended to terminate closer to the underside of the window frame, closing some space between the flashing and frame. Since the original psi-value was very good, only this one minor change was made. Cladding was not included in these models for the same reasons as the window sill models.

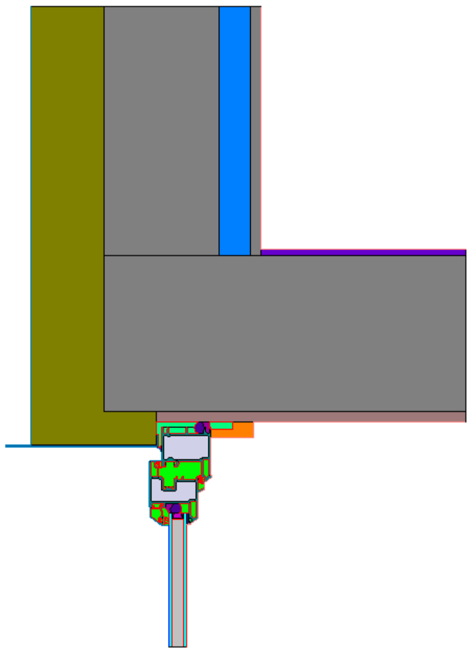


Figure B.20 – Window Head Detail – Material

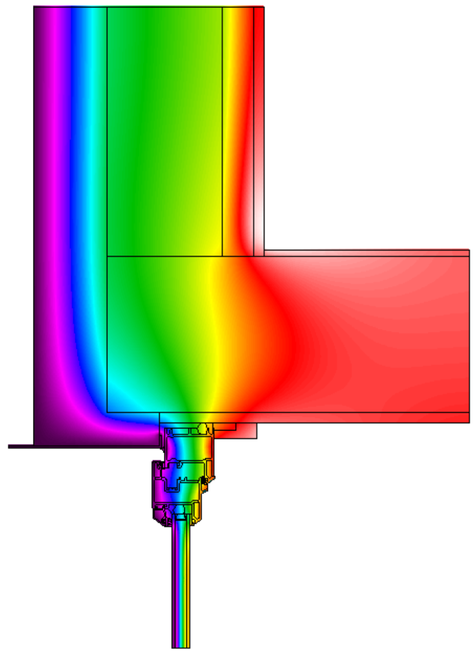


Figure B.21– Window Head Detail – Thermal

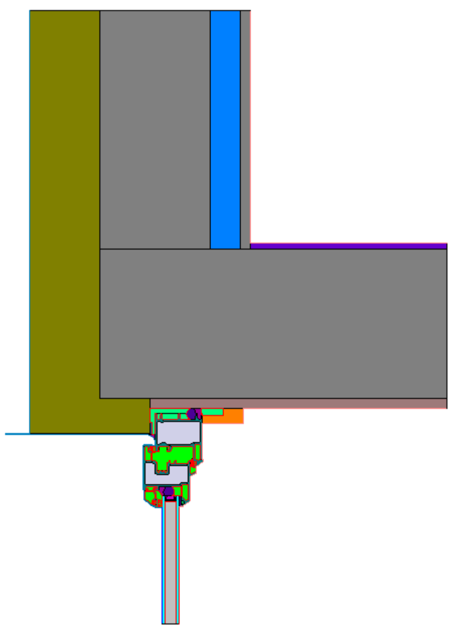


Figure B.22 – Improved Window Head Detail – Material

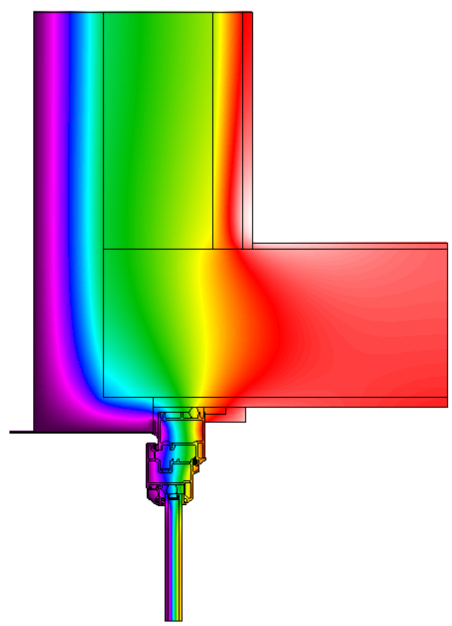


Figure B.23 – Improved Window Head Detail – Thermal

Figure B.24 and Figure B.25 show the window jamb detail and Figure B.26 Figure B.27 show an alternate detail. The alternate detail imitates the window head detail by wrapping the mineral wool insulation around the exterior front face of the wall and moving the stucco cladding closer to the window frame. This slight adjustment greatly improved the window jamb psi-value, going from 0.055 W/m-K to -0.007 W/m-K. Cladding was included in this model in order to include the sealant joint connecting the window frame.

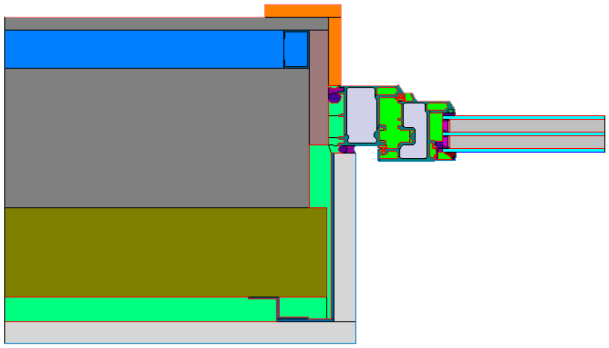


Figure B.24 – Window Jamb Detail – Material

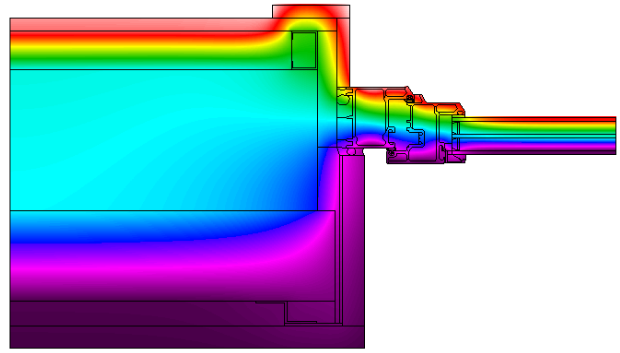


Figure B.25 – Window Jamb Detail – Thermal

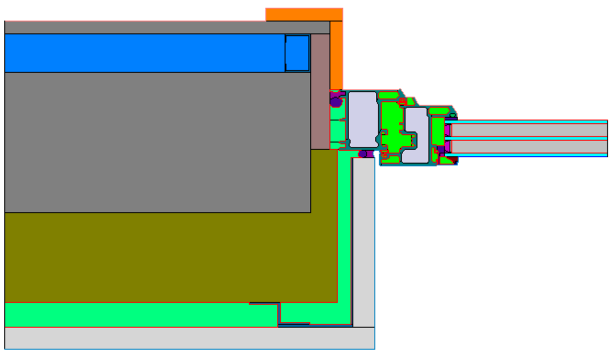


Figure B.26 – Improved Window Jamb Detail – Material

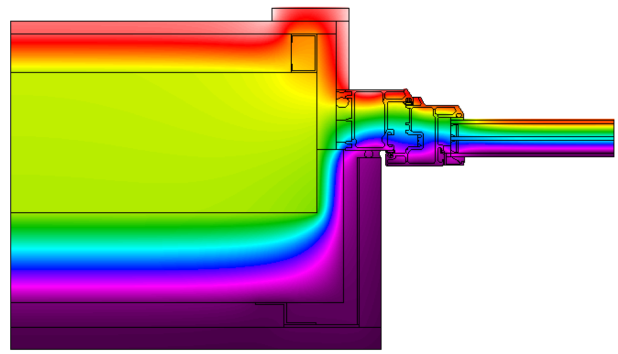


Figure B.27 – Improved Window Jamb Detail – Thermal