Passive House in Canada: Case Studies on a Near EnerPHit Retrofit and Post-Occupancy Research

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Case Study 1: Near EnerPHit Retrofit of a High-Rise Residential Building in Vancouver

Introduction

Multifamily residential buildings account for 62% of the housing stock in the City of Vancouver. Several studies have identified many opportunities to improve energy efficiency in these buildings [RDH 2012]. Deep energy retrofits focused on the building enclosure present one of the largest opportunities for significant energy and greenhouse gas reductions.

A pilot project was initiated in Vancouver to perform a deep building enclosure energy retrofit and HVAC upgrade of a 1980's vintage, 13-storey multifamily. Modelled energy savings were compared to metered post-retrofit energy consumption. Further details on this project are provided in other publications [Hanam et. al. 2014; Pape-Salmon 2016]. Although the project was not designed with EnerPHit in mind, the retrofit project was compared to the EnerPHit standard mid-way through the retrofit to highlight what additional measures would need to have been incorporated to achieve EnerPHit.

This paper provides a brief description of the study building and retrofit project that is in progress at the time of writing (enclosure retrofit is complete, ventilation retrofit is underway), with an analysis of the EnerPHit heating demand target as it relates to the planned retrofit.

Case Study Building Background

Originally constructed in 1986, the case study building 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 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 63% measured reduction in electric baseboard heating energy. Following the ventilation retrofit, the project is on track to reduce total building energy consumption by 30%, with an associated 39% reduction in greenhouse gas (GHG) emissions.

The following EnerPHit criteria were assessed in this study:

- Component approach
- Heating demand approach: 25 kWh/(m^2a) for cool-temperate climate
- Airtightness: 1 ACH50

Although EnerPHit also includes a Renewable Primary Energy (PER) requirement, this target was not assessed through the study as building heating and hot water systems were outside the scope of the retrofit project.

EnerPHit Component Approach

EnerPHit certification can be achieved through one of two paths: the component method, or the energy demand method.

First considering the component method, Vancouver falls under the cool-temperate climate zone. Table 1 shows the retrofit assemblies compared to the retrofit performed at the case study building. The wall and window retrofits completed for this project do not meet the EnerPHit requirements, and the project would not have certified following the component approach. Certifying using this methodology would have required additional wall insulation, Passive House suitable windows with high solar heat gain glazing, and additional insulation at the roof and ground floor (above the parkade).

Component	EnerPHit Criteria	Project	Comments
Opaque Envelope against Ambient Air	Max U-value, W/m^2-K Exterior insulation[a)]: 0.15 Interior insulation: 0.35	Walls: 0.35 W/m^2-K Roof & Ground Floor: 0.62 W/m^2-K	Roof and floor insulation was not increased as part of the retrofit.
Windows – Overall	Max U-value, W/m^2-K 0.85	0.97 W/m^2-K [b)]	Windows were triple glazing with insulated fibreglass frame optimized for North American energy standards.
Windows – Glazing	g-value ≥ 0.53	g-value 0.21	Low solar heat gain glazing was selected, typical local practice
Ventilation	Minimum heat recovery rate 0.75	82%	Proposed; ventilation unit selection is in progress and not yet confirmed
Airtightness	1.0 ACH50	1.35 ACH50	Tested prior to HRV installation (includes losses through bathroom exhaust fans) [c)]

Footnotes: a) While the initial building had only interior insulation at opaque walls, the retrofit added exterior insulation to the walls; b) Window U-value assessed using ISO 10077 and EN 673; c) Compartmentalized airtightness testing was performed due to the challenges in completing whole building testing in a large, occupied multifamily residential building.

Table 1: EnerPHit component method criteria compared to case study retrofit.

Although the tested airtightness rate was higher than the EnerPHit requirement, this test was performed prior to the installation of HRVs, with bathroom and kitchen exhaust fans that were not sealed during the test. Considering this would have accounted for significant air leakage, it is anticipated that the building should easily meet the 1.0 ACH50 requirement when tested with HRVs installed and HRV ducts sealed.

PHPP Modelling and Upgrades to Achieve EnerPHit

Compliance with the energy demand method was assessed by modelling the case study building in PHPP. 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 2017 HRV retrofit

PHPP results for these three phases are summarized in Table 2. The three stages of the building's renewals cycle (pre-, intermediate, and post-retrofit) show the significant improvement achieved. As designed, the post-retrofit heating demand of 42 kWh/(m^{2}a) is 68% higher than the EnerPHit requirement of 25 kWh/(m^{2}a) for the cool-temperate climate.

	Space Heating Demand, kWh/(m^{2}a)
Pre-Retrofit	213
Phase 1 Post-Retrofit	69
Phase 2 Post-Retrofit	42

Table 2: PHPP simulation results for the case study building.

Despite being significantly higher than the EnerPHit heating demand target as implemented, several simple strategies could have brought the project within reach of the heating demand target:

- Reduced air leakage to 1.0 ACH50: likely to be achieved with HRV installation
- Soffit 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. 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 in south- and west-facing suites.
- Reduced thermal bridging: Several details were identified that could be improved to reduce thermal bridging.

These measures were assessed in the PHPP model to view the impact on heating demand and to assess whether the project could meet EnerPHit. Together, these measures yield a heating demand of 23 kWh/(m^{2}a), as shown in Table 3.

	Heating Demand, kWh/(m^{2}a)
Phase 2 post-retrofit	42
EnerPHit package: • Reduce air leakage • Reduce thermal bridging • Soffit insulation • High solar gain glazing	23

Table 3: PHPP results for EnerPHit measures.

Economics and Market Readiness

The additional cost of the measures required to achieve EnerPHit was assessed, as follows:

- Reduced air leakage to 1.0 ACH50: This would likely be achieved (or very close) if the building were tested with HRV vents sealed per the Passive House testing standard. If additional air sealing was 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 little added cost to the project.
- Soffit insulation: 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: Estimate $5,000 to $10,000 to improve ground, parapet, and window installation details.

Table 4 shows the incremental costs that would be required to reach 25 kWh/(m^{2}a) 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.).

Airtightness Testing	$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 cost for EnerPHit Retrofit	**$10,000 to $50,000**
% above construction budget	*0.3% to 1.4%*

Table 4: Incremental construction costs to achieve EnerPHit heating demand requirement.

Added market barriers to an EnerPHit retrofit include the following:

- Airtightness testing: 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 in existing occupied buildings, but may also be cost prohibitive in large buildings and comes with other challenges such as pressurizing adjacent suites.
- There is concern among many North American window fabricators that high solar gain glazing can result in overheating of residential spaces without air conditioning; as a result, window fabricators tend to recommend low solar gain products locally, as was installed at this project. Further research is required in this area to understand

overheating risks in high-rise multifamily buildings with various window to wall ratios, and how these risks could be alleviated through exterior shading.

- Combustibility of window frames may be a concern in other multifamily buildings. At the case study building, an alternative solution to the Vancouver Building Bylaw was approved to allow “combustible” window frames (i.e. fiberglass or PVC) in a non-combustible building. High-rise buildings with higher window to wall ratios or “combustible” cladding materials (e.g. exterior foam insulation or certain claddings) may be challenged to find an acceptable solution.
- The case study building’s balconies were previously enclosed, allowing the building to be wrapped in insulation with minimal thermal bridging. However, many Vancouver multifamily buildings have non-thermally broken balconies that pose a retrofit challenge. 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.
- The pressurized corridor ventilation system, common in North American multifamily buildings [RDH 2012], may present a challenge to EnerPHit retrofits. At the study building, 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.

Summary and Conclusions

As designed and implemented, the deep energy retrofit of the case study building will be close to the EnerPHit standard after the planned HRV installation is complete. Heating demand calculated using PHPP is 42 kWh/(m^2a), compared to the EnerPHit standard of 25 kWh/(m^2a).

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 with HRVs installed and ducts 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 (0.3% to 1.4% of the project budget). High solar gain glass typically has no added cost (though shading may have been required to prevent overheating), and airtightness testing was already completed as part of the project (though a different test method would have been necessary). This work could have easily been completed within the 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.

While the EnerPHit standard proved to be well within reach for the case study building, several additional barriers may be present for other multifamily residential building retrofit projects. Buildings with exterior balconies would be challenged by thermal bridging. Higher window to wall ratios may limit the use of windows with low conductivity frames.

Overall, this work showed that going the extra step to meet the EnerPHit heating demand target requires careful attention to detail, but could have been achieved with little added cost beyond the deep energy retrofit that was performed. This project demonstrates how EnerPHit could be implemented cost-effectively for existing mid- and high-rise multifamily retrofits in North America.

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Case Study 2: Post-Occupancy Research at the North Park Passive House, Victoria, Canada

Introduction

The North Park Passive House, a 6-unit condominium building located in Victoria BC, was occupied in September 2015. It is the first market strata-title certified Passive House development in Canada.

While well-established elsewhere, the potential benefits of Passive House and other low energy design approaches are not as well documented in Canada, and there are limited data on the actual performance of these buildings in the Canadian west coast climate.

To address this gap, RDH, in partnership with the Canadian Mortgage and Housing Corporation, the Homeowner Protection Office of BC Housing, and FP Innovations, has undertaken detailed quantitative and qualitative performance measurement of the North Park

Passive House. The intent of this research is to develop a comprehensive case study for a Passive House project in the Pacific Northwest climate.

The building's performance was considered in two separate, but interrelated, components: occupant experience and building performance. Occupant experience relates to the interaction of the occupants with the building. This includes indoor air quality (IAQ), interior comfort, and energy consumption. Building performance relates to the building enclosure's effectiveness at managing heat, air, and moisture phenomenon.

Two suites within the 6-plex were selected for the study: both with the same exposures (south, north, and west) and similar floor layouts, but on different floors.

The following data were collected over a full year post-occupancy:

1) Thermal comfort and Indoor Air Quality (IAQ) conditions:
    a. Air temperature
    b. Interior surface temperatures
    c. Relative Humidity (RH)
    d. Carbon Dioxide (CO_2) concentration
    e. Two occupant surveys to compare measured data with perceived comfort in two different seasons
2) Building Enclosure performance:
    a. Moisture content, relative humidity, and temperature sensors at critical wall and roof sheathing interfaces
    b. Whole building air leakage
3) Energy Consumption:
    a. Overall annual building energy consumption and energy usage intensity
    b. Overall annual and monthly energy use of test suites
    c. Suite level end use energy consumption

This paper will present the study results for quantitative thermal comfort monitoring and building enclosure performance monitoring, demonstrating the viability of Passive House and the chosen building enclosure strategy in this climate. Energy data and interview results were still being processed at the time of this writing and are excluded from this paper.

Thermal Comfort and IAQ Results

Temperature, RH, and CO_2 sensors were installed at two locations in each of the two test suites: at ceiling level in the main living space (which includes the open kitchen), and one just below ceiling level in the bedroom. The RH readings in all cases did not exceed 61%, which is within acceptable thresholds for humidity and comfort and so will not be discussed in detail.

Figure 1 below shows the temperature boxplots for three in-suite locations.

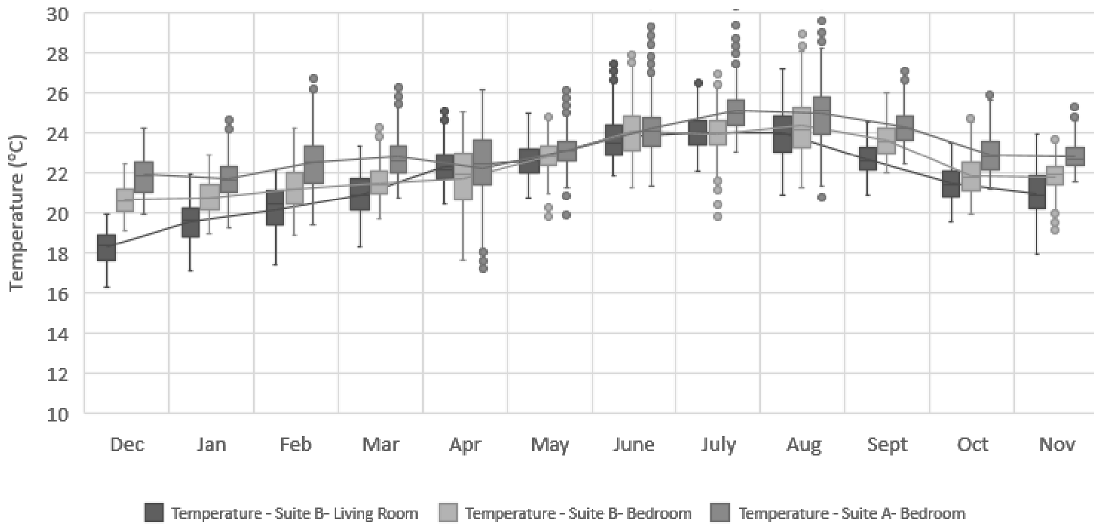

Figure 1: Monthly Temperature Boxplots for Suite B Living Room and Bedroom and Suite A Bedroom

Both suites maintain temperature very close to or above 20°C throughout the heating season. Suite A had a slightly higher indoor temperature due to occupant stated comfort preferences. The indoor temperature of all suites rises in the summer months, with the 75% percentile data straddling 25°C from June to August.

Table 1 below shows the frequency of overheating, for data collected from December 20, 2015 through November 22, 2016. Suite A is located above Suite B; is on the top floor of the building, and has a larger building enclosure area and increased solar exposure than the lower suites. Both suites have operable exterior shading devices on the west facing windows.

	Suite A Living	Suite A Bed	Suite B Living	Suite B Bed
Hours > 25°C	-	1174	355	482
Total Hours logged	-	8055	8054	8055
% of hours > 25°C	-	14.6%	4.4%	6.0%

Table 1: Hours and % of hours over 25°C.

The temperature threshold for Suite A's bedroom is identified as "Poor" comfort performance for summer conditions according to the Passive House Planning Package (PHPP). As data is updated to include the full year's monitoring period, the percentage of hours greater than 25°C will be reduced, although it will likely remain above the 10% threshold for Suite A. These data point to a potential to revisit operating conditions with the suite occupants, but also to potential challenges in assigning an overall building thermal comfort value in a compartmented multifamily building.

The probability of CO_2 readings exceeding a given value for the full measurement period is shown in Figure 2 below, and a weekly snapshot is provided to demonstrate daily fluctuations.

Both suites show ranges of CO_2 values that generally conform to a satisfactory level of CO_2, per ANSI/ASHRAE Standard 62.1-2016, Appendix D. According to this reference, maintaining a space CO_2 concentration of no greater than 700 ppm above outdoor air levels will satisfy the majority of occupants. Ambient levels are approximately 400 ppm, meaning that total CO_2 levels less than 1100 ppm would be considered acceptable. Note that the "Living Room" CO_2 sensors are located between the open kitchen and living space and therefore vary widely as cooking and other activities occur throughout the day. Differences between the living spaces in the two suites likely result from variation in occupant behaviour and the number of pets living in the space. The CO_2 levels in the bedrooms are much lower and more stable, as expected.

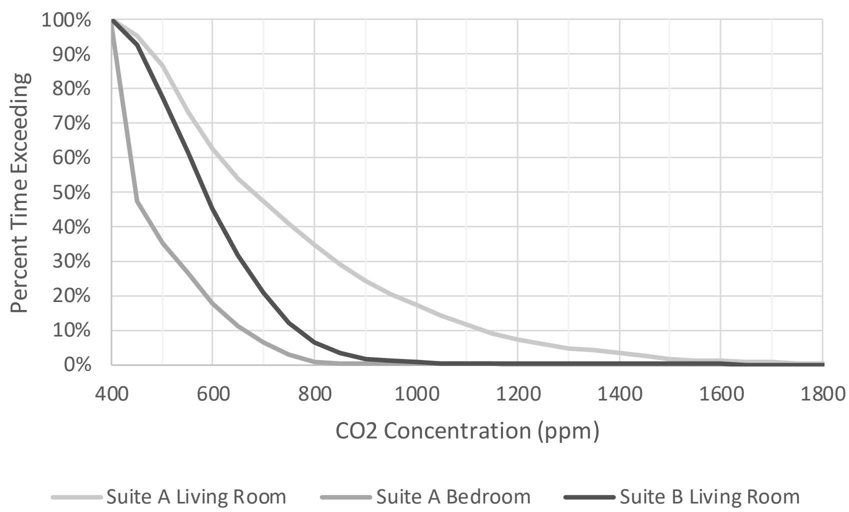

Figure 2: Cumulative Density Function for Percent Time Exceed CO_2 Levels for Suite A, Living Room and Bedroom, and Suite B Living Room

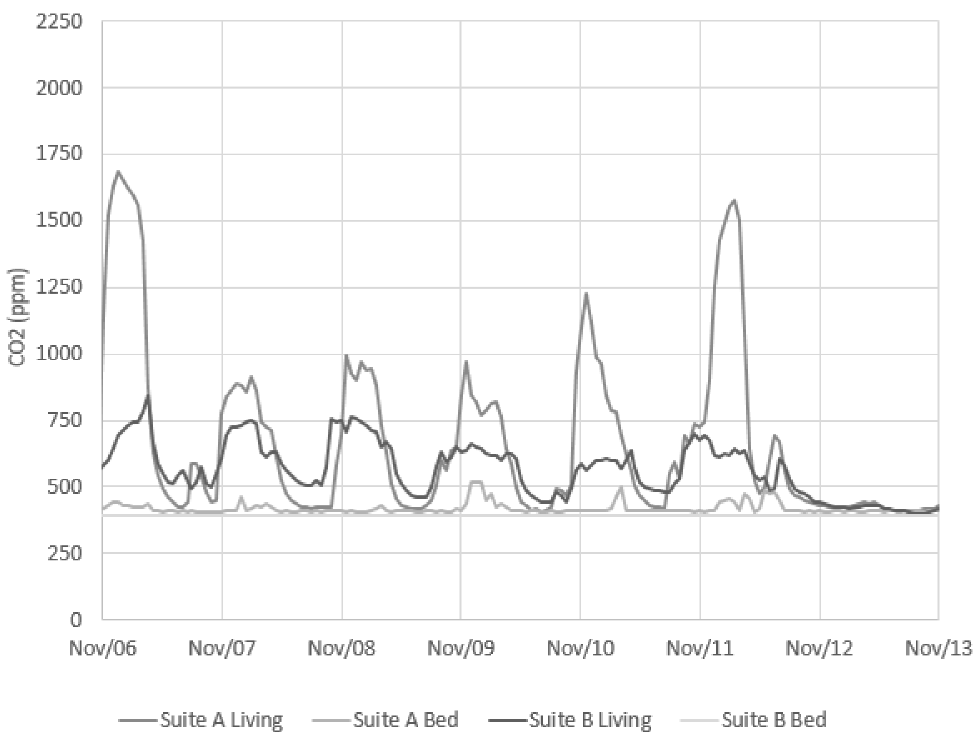

Figure 3: Hourly CO_2 Measurements for the Week of November 6th, 2017.

Enclosure Performance

The wall assembly for the North Park Passive House is a deep-stud cavity wall with additional service wall. The details of the assembly are shown in Figure 4.

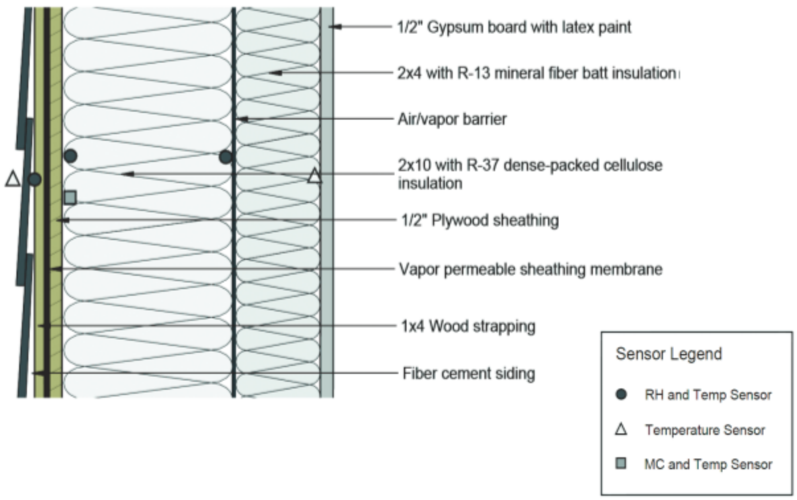

Figure 4: Wall Assembly

The enclosure performance aspect of the research ascertained the hygrothermal performance of a deep-stud wall assembly in the Pacific Northwest Climate. The moisture durability of the sheathing was of principle interest, followed by other parameters such as the impact of solar heating and inward driven moisture. The factors that were characterised as part of this project were as follows:

- Moisture durability of the exterior and interior sheathing
- Hygric buffering capacity of the densepack cellulose
- Impacts of solar radiation on temperature profiles through the assembly
- Impacts of solar radiation on the hygric profiles through the assembly

The performance metrics of the wall assemblies were measured with relative humidity sensors, moisture content sensors, and temperature sensors, which were hard wired to a laboratory grade data acquisition system.

The sensor packages for each wall assembly were designed to provide the maximum amount of information while minimizing complexity and cost. It was determined that at a minimum, two moisture content sensors were required to monitor the moisture content of the sheathing. The temperature sensors were included to provide the surface temperatures that form part of the boundary condition. The relative humidity sensors were used to assess the impact of the hygric performance of the dense-pack cellulose, and to provide an indication of the influence of exterior cavity humidity conditions on the insulation. Sensor locations in the exterior wall assemblies are shown in Figure 4 above. Analogous sensors were also installed in north and south facing roof assemblies.

Figure 5 shows moisture content profiles at the exterior sheathing of the four wall monitoring locations. The north wall was expected to be colder and wetter than the south wall, and the data validates this expectation.

At the third floor (“Suite A”) north wall sensor location, the moisture content was close to 20% at the start of the monitoring period, which also coincided with the rainy season. However, the data is suggesting a drying trend over the measurement period, which may indicate drying of construction related moisture.

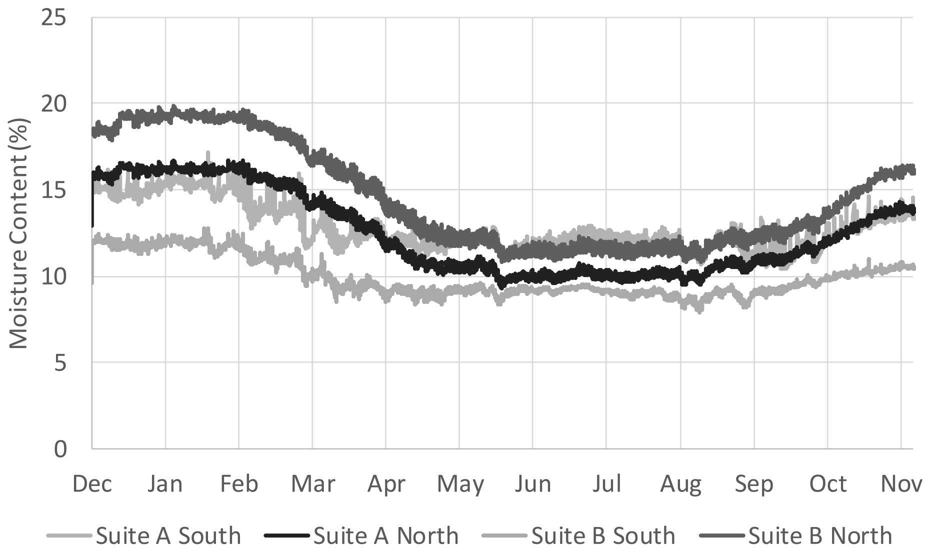

Figure 5: Moisture Content for Suite A and B, North and South Walls

Conclusions

The interior IAQ sensor packages were able to demonstrate that the interior CO_2 levels and relative humidity fall within standard norms of comfort. On some occasions, the interior temperature of the uppermost suite exceeded the recommended comfort levels from PHPP. However, as the PHPP model only considers the entire building, localized areas of overheating cannot be readily captured.

For future multifamily Passive House projects, consideration may be given to the likely concentration of overheating hours in only a few suites and to provide a simplified method of modelling and managing overheating in these suites.

The hygrothermal assessment of the enclosure indicates that for interior conditions not exceeding 60%RH in the winter time, this wall assembly performs well in the Pacific Northwest climate. The moisture content of the sheathing is demonstrating drying from initial construction moisture, and first-winter data suggest the sheathing is staying below the recommended 19% moisture content limit for durability. Additional research would be required to ascertain the effects of elevated interior RH or the risk of air leakage induced condensation. Due to the strict air leakage requirements of Passive House, though, the risk of air leakage induced condensation is minimized.