Deep Building Enclosure Energy Retrofit Study – Final Report | Project 3033.300

Multi-Unit Residential Building Deep Energy Retrofit Study – Enclosure Retrofit

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We would also like to acknowledge The Owners of the case study building for their significant contributions to the success of this study. The forward-thinking approach to their building and energy efficiency that they displayed in carrying out this project is a model for others. It has been a pleasure working with them.

This report was produced by RDH Building Science Inc. The following have been major contributors to this project:

- Lorne Ricketts
- Brittany Coughlin
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- Graham Finch
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Executive Summary

Buildings require significant renewals work on an ongoing cycle to maintain performance and aesthetics. These renewals projects represent significant opportunities to integrate cost effective energy conservation measures to reduce energy consumption and greenhouse gas emissions. Based on the results of an initial study of multi-unit residential building energy consumption in British Columba, a case study building was selected to perform a pilot deep energy building enclosure retrofit to demonstrate and verify the potential impact of these types of retrofits, as well as to identify lessons learned from the process that can be used as a template for future renewal opportunities.

Originally constructed in 1986, the selected case study building is a 13-storey residential building on the west side of Vancouver, BC, with a gross floor area of approximately 54,000 ft² (≈5,000m²) and 37 residential strata units. The building construction was representative of other mid and high-rise buildings. Glazed windows and doors make up 51% of the vertical enclosure area. The annual energy consumption levels of the building were determined to be similar to the average building energy consumption for buildings of this type in south-western British Columbia, and therefore was a good candidate to use for the case study.

The renewals project was intended to address aging building enclosure components (including walls, windows, decks and roof), address localized building enclosure performance issues, improve the aesthetics, and make the interior space more comfortable. Given the extent of the work to be performed, this project also presented an excellent opportunity to reduce energy consumption at the building by integrating energy conservation measures with little to no incremental cost.

Calibrated energy modeling and analysis was completed to assess the potential savings and financial feasibility of various energy conservation measures. The adopted energy conservation measures included: selecting thermally efficient triple-glazed replacement windows with fiberglass frames instead of the minimum required by the building code; adding three and a half inches (3.5”) of exterior mineral wool insulation with thermally efficient cladding attachment clips; and improving air barrier detailing at window transitions. Based on this package of energy conservation measures, a 20% reduction in total building energy consumption was predicted, which reflects a predicted 87% reduction in electric baseboard space heating energy consumption. Including an incentive that was provided through the BC Hydro PowerSmart, each of the selected measures provided an estimated simple payback of less than six years. The overall package of measures was predicted to have an approximate payback period of 4 years without incentives, or 2.7 years with incentives.

A monitoring and testing protocol was implemented at the building to measure the performance of the building pre- and post-retrofit. In addition to existing utility meters, additional monitoring equipment was installed to measure key indicators of building performance including temperature, relative humidity, carbon dioxide concentrations, and pressure difference. A weather station was also installed on the roof of the building to measure location specific weather data. Sub-metering of natural gas consumption for the make-up air unit and domestic hot water boiler was also installed.

The building enclosure renewal and implementation of associated energy conservation measures took place from approximately May to December 2012. Despite the significant work being implemented, residents of the building were able to remain in their suites for the duration of the renewals work. The success of this approach and of the project in general was highly dependent on the experience of the design and construction management teams, clear communication between all parties, and consistent engagement with the building owners.

Once the work was complete, a measurement and verification plan was implemented to evaluate the impact. As part of this, airtightness testing was performed pre- and post-retrofit. The measured airtightness of the exterior building enclosure pre- and post-retrofit were 0.71 cfm/ft² and 0.32 cfm/ft² respectively at 75 Pa, which is an improvement of 55%. This is relatively consistent with the pre-retrofit energy modeling assumption that airtightness would be improved by 50%.

While some unexpected variation in the results occurred as a result of summertime heating and reduction in gas fireplace consumption post-retrofit, the measurement and subsequent calibrated energy modeling indicated a weather normalized energy use intensity reduction of 43 ekWh/m^2 from 226 kWh/m^2 pre-retrofit to 183 kWh/m^2 post-retrofit, a 19% reduction which is relatively consistent with the predicted savings. The residents of the building also confirmed a number of ancillary benefits including improved thermal and acoustic comfort.

In addition to the measured results of the building enclosure retrofit, the study also measured the performance of the building mechanical ventilation system. The existing corridor pressurization-based ventilation system was found to provide uneven distribution of ventilation air to the corridors and suites of the building with lower suites receiving orders of magnitude less ventilation air from the make-up air unit and receiving less air exchange with the outdoors. Numerous suites receive small fractions of modern ventilation requirements. Measurements of indicators of indoor air quality confirmed the impact of these measure ventilation rates. Overall, the measured poor performance of the ventilation system at the case study building is likely typical of this ventilation system design, and was found to not have been impacted by the enclosure retrofit. An optimal mechanical ventilation system retrofit approach is likely to include compartmentalization of the suites and recovery of heat from exhaust air. The applicability of these solutions to new construction and retrofit projects should be the focus of future research efforts.

Overall, this study successfully demonstrated the energy savings possible in multi-unit residential buildings from the cost-effective integration of building enclosure energy conservation measures as part of already-planned major renewals work. The next phase of this project would be to implement a ventilation system retrofit to improve both the efficacy and efficiency of the system. While there is the potential for economic savings by integrating a ventilation retrofit concurrently with an enclosure retrofit, appropriate planning during the enclosure retrofit can accommodate a future mechanical retrofit at minimal additional cost.

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Appendices

1 Introduction

Many multi-unit residential buildings (MURBs) in North America have or are undergoing comprehensive building enclosure renewals to repair or replace aging building components, extend the service life of the building and, in some cases, to remedy moisture-related problems. Historically, little attention has been directed at incorporating energy conservation strategies and/or greenhouse gas emissions reduction strategies as part of these retrofits, as a lowest capital cost strategy is commonly undertaken; however, significant building enclosure renewals work potentially presents a unique opportunity to cost-effectively implement energy savings measures as part of already needed work.

To further explore this potential opportunity, a study was undertaken to identify how energy is consumed in mid- to high-rise (5 stories and higher) multi-unit residential buildings, and to assess the impacts of building enclosure renewals and rehabilitations on these buildings[1] (referred to as Parts 1 and 2). These findings were used to determine better building enclosure design strategies to reduce energy consumption and associated greenhouse gas emissions, while considering the other building functions for both new and existing buildings. The study found that significant energy savings can be achieved by incorporating energy conservation measures into a building enclosure renewal or retrofit project.

As a follow-up to the original study, the current study undertook a pilot project to implement energy conservation measures as part of a building enclosure renewals project (referred to as Part 3) to allow for verification and demonstration of the impact of these measures. This project includes performing measurement and verification of energy savings, plus additional testing and monitoring to verify airflow and indoor environmental quality before and after the renewals work.

A series of five interim reports document the results of this pilot project. The five interim reports cover the following topics and forms an outline for the content of this report.

- → Interim Report 1 - Retrofit Building Candidate Feasibility Assessment
- → Interim Report 2 - Design of Airflow and IAQ Monitoring
- → Interim Report 3- Pilot MURB Envelope Retrofit Process – Planning and Management Guidance for Stratas
- → Interim Report 4 - Airflow Monitoring and Analysis Post Enclosure Retrofit
- → Interim Report 5 - Data Analysis

This final report compiles the findings of these interim reports and provides overall discussion and conclusions regarding the project.

2 Retrofit Building Candidate Feasibility Assessment

This section describes the retrofit building candidate feasibility assessment, including analyzing energy consumption data for the existing building, creating and calibrating a model of the building energy consumption, and assessing Energy Conservation Measures (ECMs) through modeling and cost-payback analysis.

2.1 Introduction and Criteria to Identify Candidate Buildings

It is estimated that approximately 70% to 80% of the buildings standing in 2030 already exist today[1]. The sustainable and energy efficient retrofit of existing buildings is essential to reducing our environmental footprint. Buildings constantly go through retrofits as components come to the end of their service life. Rather than replacing components like-for-like, this presents a good opportunity to reduce energy consumption and improve sustainability at an economically feasible incremental cost.

There are many benefits to an energy efficient retrofit project, aside from reduced energy costs. These retrofits also improve the comfort of indoor spaces, upgrade the aesthetics of the building, and likely result in higher property value. Building owners who are considering whether to retrofit an existing MURB with energy conservation measures need to consider the following:

- Does the building have aging enclosure or mechanical components nearing the end of their service life, or with performance issues?
- Is there a desire to upgrade the aesthetics of the building? A retrofit project can be an opportunity to change the appearance of the building, or it can be planned such that the existing appearance is maintained.
- Do the building owners wish to lower the building energy costs? Do the owners understand how much energy they are using overall, including energy costs that are part of their strata fees?
- Do the building occupants experience discomfort due to cold drafts, cold surfaces, stuffiness, overheating, or other indoor air quality issues?
- Do the owners wish to increase the property value of the building?
- Do the owners wish to extend the service life of the building?
- Is there an opportunity for GHG credits, or to lower the cost of GHG offsets?
- Is there an opportunity to reduce maintenance costs?
- Is there an opportunity for industry support and incentive funding?
- Are Payback Period, Internal Rate of Return (IRR), and Net Present Value (NPV) important decision-making metrics to the owners?

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[1] ASHRAE. The Key to Energy Efficiency in Buildings: ASHRAE's Response to the McKinsey Report 'Unlocking Energy Efficiency in the U.S. Economy".
www.ashrae.org

The case for an energy efficient retrofit project will be strengthened by completing an analysis for the candidate building, including assessing historical energy consumption data from utility bills, and comparing consumption to the average for multi-unit residential buildings in the Lower Mainland, as found in Section 2 and 3 of this study. Buildings with an energy consumption above the average value of 213 kWh/m^2 per year (average from the Part 1 and 2 analysis of 39 study buildings[2]) will likely have several opportunities for savings to improve their energy performance.

Another important factor in a successful energy efficient retrofit project is professional guidance and client/consultant trust. An involved owner group who takes time to understand the issues and solutions presented by the consultant lends to better results.

This report presents an example of the feasibility assessment performed for a candidate building considering an energy efficient retrofit project. The following sections describe the candidate building, show an assessment of the historical metered building energy consumption, and present energy simulation and financial analysis results used to assess potential Energy Conservation Measures (ECMs).

2.2 Building Description

A building that was about to undergo a large building enclosure retrofit project to renew aging building enclosure components was selected to serve as a pilot project building for this study. After weighing various options on how best to maintain and reinvest in their property, the building owners decided to proceed with a comprehensive building enclosure retrofit project in 2012. Energy efficiency measures were incorporated in the retrofit project during the planning stages to deliver significant energy savings at low incremental cost.

Originally constructed in 1986, the retrofit building is a 13-storey residential building on the west side of Vancouver. The building has a gross floor area of approximately 54,000 ft^2 (≈5,000m^2), with 37 residential strata units. Glazed windows and doors make up 51% of the vertical enclosure area. Elevations are shown in Figure 2.1 and Figure 2.2, prior to the retrofit work. Figure 2.3 shows a drawing of the retrofit building with the proposed retrofit colour scheme and the partial floor plan.

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[2] RDH. (2011) "Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia".

Figure 2.1 North elevation (left) and partial north and west elevations (right).

Figure 2.2 Partial south elevation (left) and partial south and east elevations (right).

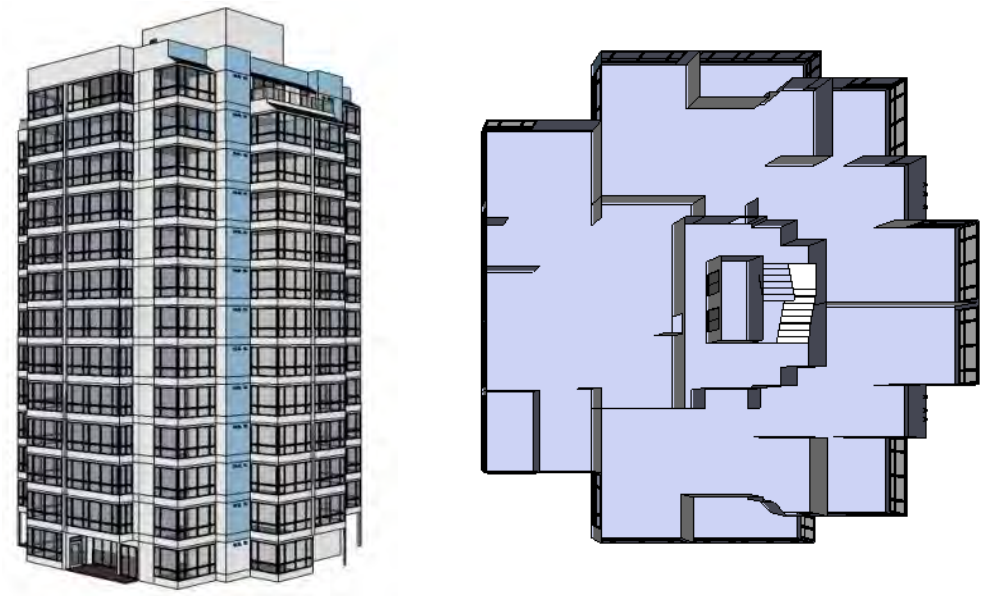


Figure 2.3 Sketch of the retrofit building with proposed retrofit colour scheme (left) and partial floor plan (right).

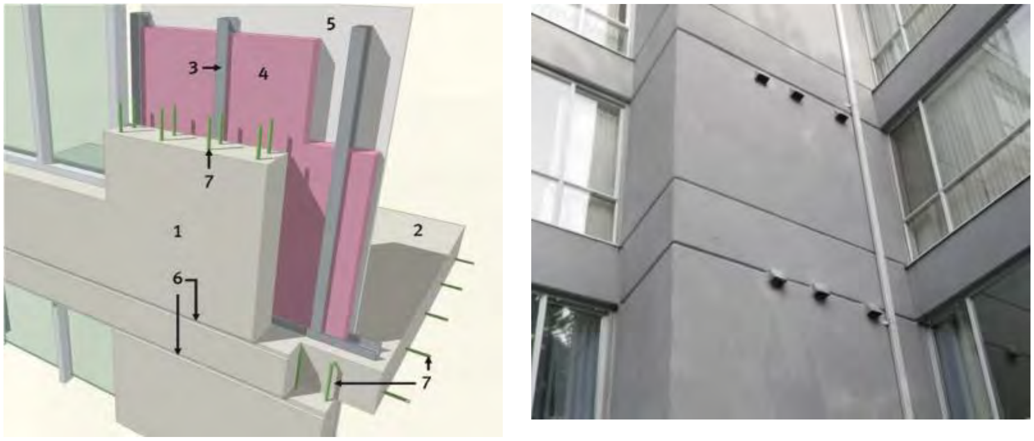
2.2.1 Building Enclosure

The original exterior walls consist primarily of exposed cast-in-place concrete walls. There are also several small areas of steel stud walls with stucco cladding at the roof and ground floor levels. Based on architectural drawings and exploratory openings, the typical concrete wall assembly from outside to inside consists of:

- → Acrylic coating
- → Cast in place concrete walls
- → Rigid foam insulation between steel studs
- → Interior gypsum board

The thermal performance of the building enclosure components is given in terms of the thermal resistance (R-value), or the thermal transmittance (U-value) of the assembly (where the U-value is the inverse of the R-value). This report uses imperial units of hr-ft^2-F/Btu for R-values and Btu/hr-ft^2-F for U-values. The metric equivalent would be m^2-K/W for R-values and W/m^2-K for U-values, though not used in this report.

At the inside of the concrete walls is 2” of rigid foam insulation between steel studs. The insulation has a nominal R-value of approximately R-10 (IP Units, hr-ft^2-F/Btu). However, the steel studs and uninsulated concrete slab edges that project through the exterior walls reduce the effective R-value of the walls, resulting in an overall opaque wall effective R-value of approximately R-4 (determined through 3-dimensional heat transfer modeling). Figure 2.4 and Figure 2.5 show typical details of this assembly.



1. Concrete wall / column
2. Concrete floor slab
3. Steel stud framing
4. Rigid foam insulation
5. Interior gypsum board
6. Concrete joint
7. Steel reinforcing (rebar)

Figure 2.4 Conceptual sketch of the cast in place concrete wall at the retrofit building (left) and photo of wall (right).

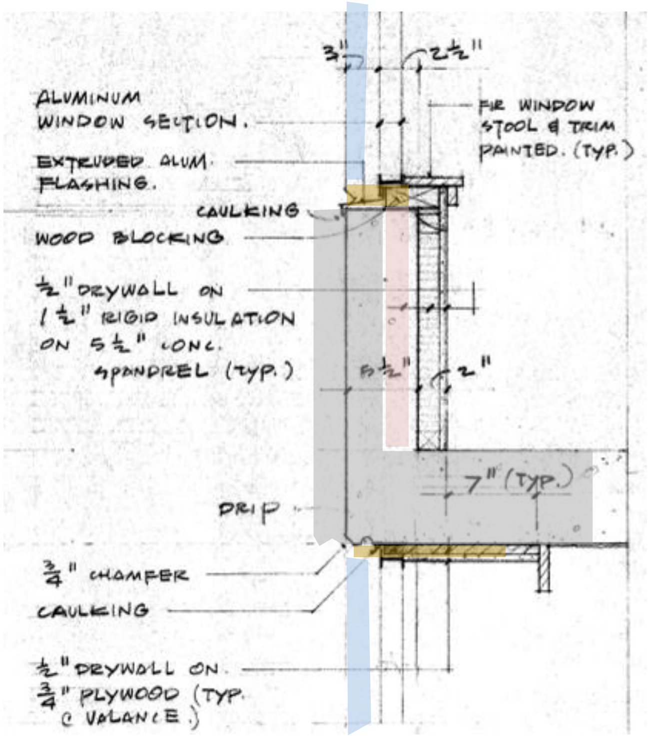


Figure 2.5 Original detail drawing of a window head and sill, coloured.

The original roof consisted of an inverted insulated assembly constructed with 1-½” of extruded polystyrene (XPS) foam insulation on top of a waterproofing membrane (illustrated in Figure 2.6). This assembly has an effective R-value of approximately R-9.5.

Exterior

1. Ballast
2. Filter Fabric
3. Extruded Polystyrene Insulation
4. 2-Ply SBS Modified Roofing Membrane and Drain Mat
5. Concrete Slab Sloped to Drain

Interior

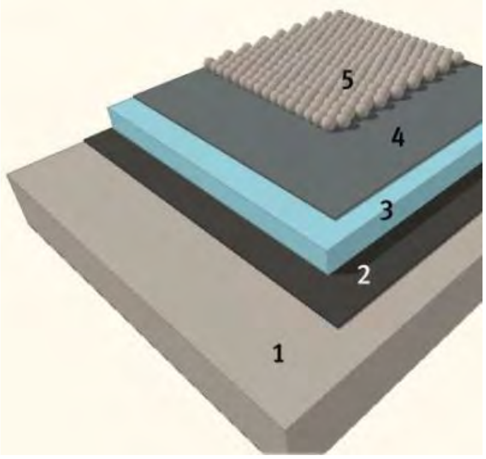


Figure 2.6 Existing roof assembly at the retrofit building.

The original windows and sliding glass doors are non-thermally broken aluminum frame windows with double glazed insulated glazing units (IGUs). Some of the sliding glass doors at the penthouse level are installed immediately below a skylight assembly. Operable vents are typically sliding style. The replacement of IGU’s was previously the responsibility of individual owners and, as a result, the glazing in windows varies from suite-to-suite. IGU’s that were changed were likely done so as a result of fogging between the glass lites. Many of the suites are experiencing condensation on glazing and frames, as well as water ingress during heavy rain events coupled with driving wind. Due to the variety of glazing arrangements at the building, the windows were assumed to have an average U-value of 0.55 for energy modeling purposes, typical of a non-thermally broken aluminum frame window with air fill and a low-performing low-e coating (2013 ASHRAE Handbook of Fundamentals, Chapter 15 Table 4). Otherwise, the different glazing units and the previous owner responsibility for replacing IGUs did not impact the retrofit project (i.e. all windows were replaced regardless of their existing condition).

The air barrier system of the original building consists of the concrete wall, connected to windows and penetrations through sealant. Sealant is typically in poor condition, and has failed at many locations due to normal aging and weathering (cracks, inadequate bond, or other deterioration was observed). The seals and interfaces of the sliding windows are also likely a significant source of air leakage.

Table 2.1 provides a summary of the pre-retrofit overall effective building enclosure U-values and R-values for the retrofit building (based on the R-values presented above). The building has an overall effective R-value of approximately R-2.8 including wall, window, deck, and roof areas.

TABLE 2.1 SUMMARY OF PRE-RETROFIT ABOVE GRADE BUILDING ENCLOSURE R-VALUES FOR THE RETROFIT				
	Area (ft^2)	**Percent of Enclosure**	**Effective U-Value ($Btu/hr\text{-}ft^2\text{-}^\circ F$)**	**Effective R-Value ($hr\text{-}ft^2\text{-}F/Btu$)**
Roofs and Doors	4,160	11%	0.11	9.5
Opaque Wall Components	16,290	44%	0.25	4
Windows and Doors	16,960	45%	0.55	1.8
Overall Building	**37,410**		**0.37**	**2.7**

2.2.2 Mechanical Systems

Space heating at the retrofit building is partially provided by electric baseboard heaters within the suites. Suites at the upper floors (9 to 13) also have supplemental decorative gas fireplaces, with a total of 14 suites in the building having a gas fireplace.

The original fireplaces are Fire-Song model number 220N, on/off control (with a pilot light), with an input of 30,000 Btu/hr. The heating efficiency of these units is not known; however, the label reads “vented decorative gas appliance…do not use as a full time heating means”, therefore it is assumed that these units have a lower heating efficiency than fireplaces that are intended to provide space heating. Two of the units have been replaced with fireplaces that are intended to provide space heating. The replacement inserts are Regency model E21-NG3 with an input of 23,500 Btu/hr, and Regency model GR54-3 with an input of 22,800 Btu/hr. The efficiency of these units is not known, though they are likely higher than the original units since they are intended to provide space heating.

Ventilation air is heated at a gas-fired rooftop make-up air unit and provided to the central corridors prior to flowing into the suites through door undercuts. Intermittent exhaust fans are located in bathrooms and kitchens of the suites. Bathroom and kitchen exhaust fans are occupant controlled and humidistats or timers are not present. Windows are typically opened by occupants to provide adequate outdoor air at occupants’ discretion.

The ventilation system is designed so that outdoor air flows into the suites through suite door undercuts, as the corridor is intended to be positively pressurized with respect to the suites; however, this corridor pressurization may not always be positive and significant amounts of fresh air may flow through unsealed hallway doors into stairwells and the elevator shaft, resulting in less make-up air to the suites.

The rooftop make-up air unit has a capacity of 3300 cfm at 1” static pressure and a nominal (nameplate) efficiency of 80% per the original mechanical drawings. It is not known whether the installed AHU meets these specifications as the unit does not have a nameplate with this information; the manufacturer of the unit is Reznor and the model number is unknown.

The domestic hot water system consists of an A.O. Smith gas fired boiler and two hot water storage tanks located in the rooftop mechanical room (Model No. HW-610). This boiler had a nominal (nameplate) efficiency of 82% and was installed in 2003. A new boiler was installed at the start of the retrofit work, in March 2012. The new DHW boiler is manufactured by Slant Fin, Galaxy model with a nominal (nameplate) efficiency of 82% (storage tanks were not replaced). The new boiler was chosen and installed at the advice of the owners' mechanical contractor, immediately following the failure of the existing boiler. A cost-payback analysis of more efficient options (such as a condensing boiler) could have been performed and was recommended for future equipment replacements.

2.2.3 Renewal Options

Following a condition assessment to investigate the state of the building enclosure, the Owners were initially presented with three options for maintenance and renewals, and associated budgetary costs:

- → Option 1: Water-shedding improvements, \$15/ft² of floor area. Note that this recommendation was provided as a shorter-term measure. Some further renewals work and ongoing maintenance work would still be required with this option.
- → Option 2: Replace Windows & water-shedding, \$55/ft² of floor area. Note that this recommendation will result in improved performance compared to Option 1; however, increased maintenance and renewals costs were anticipated in the future compared to option 3 below.
- → Option 3: Replace windows & over-clad walls, \$65/ft² of floor area. This is the preferred option in terms of addressing performance issues and reducing future maintenance requirements.

For this retrofit project, the Owners' initial decision to proceed with a building enclosure renewals project (Option 3) was a result of the preference to extend the service life of the building and address localized enclosure performance issues, as well as their desire to improve the thermal comfort of the space and upgrade the aesthetics of the building.

2.3 Energy Consumption

2.3.1 Historical Metered Energy Data

Electric and gas utility data for the retrofit building from July 2006 to August 2011 was provided by BC Hydro and FortisBC. The utility metering date does not typically fall on the first day of the month; therefore, the meter data was sorted into calendar month consumption for analysis (calendarized). This is necessary in order to compare metered utility data to simulated energy consumption.

Figure 2.7 and Figure 2.8 show the metered monthly electricity (kWh) and gas (GJ) consumption for July 2006 through July 2011. Electricity consumption is shown for all suites combined (labeled "suites"), and all common usage (labeled "common"). Total gas and electricity consumption is shown in Figure 2.9 in common energy equivalent units of kWh (measured GJ is multiplied by a conversion factor of 277.8). Analysis of the five years of data indicates that approximately 55% of the building energy consumption is from electricity, and 45% is from gas. Seasonal trends are observed in both the gas and electrical energy consumption at the building; gas is influenced primarily by the make-up air unit heating and fireplaces, while electricity is influenced primarily by the electric baseboard heaters in the suites and lobby. Other factors may result in lesser seasonal trends, such as varying municipal water temperatures impacting DHW and daylight hours impacting lighting energy. Water consumption was not obtained for this study.

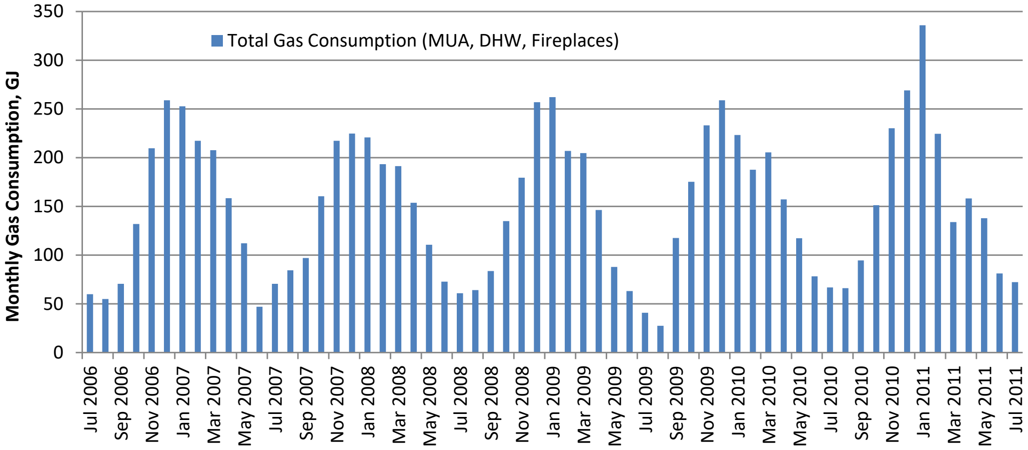


Figure 2.7 Electricity consumption, July 2006 through August 2011.

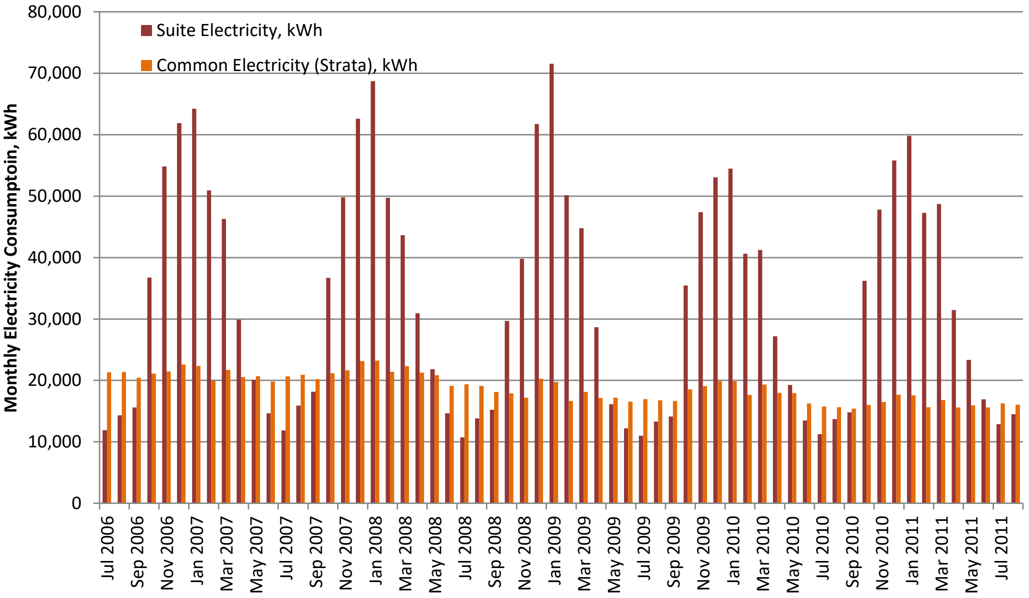


Figure 2.8 Gas consumption, July 2006 through August 2011.

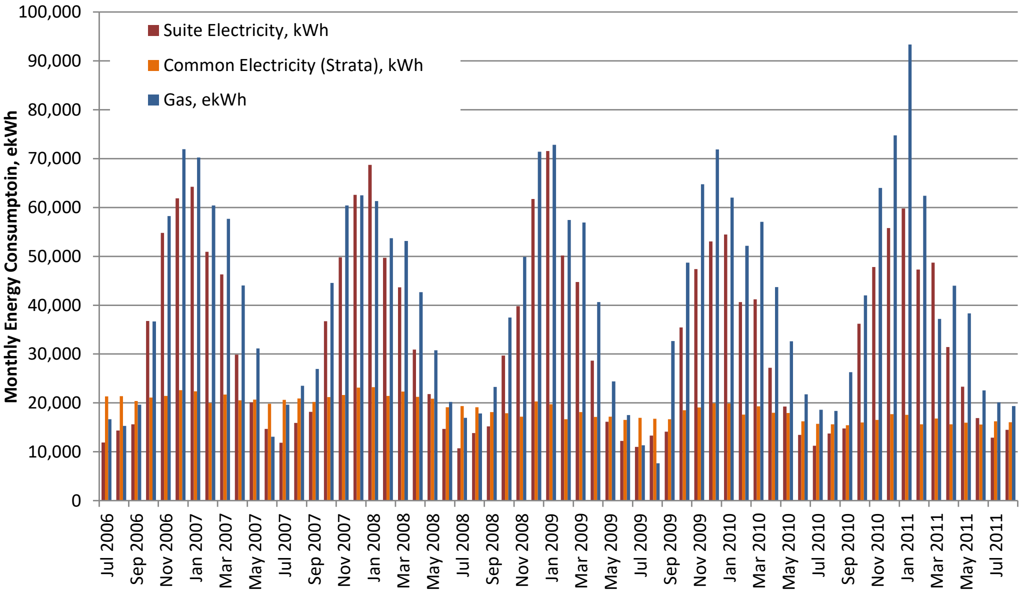


Figure 2.9 Monthly gas and electricity consumption, July 2006 through August 2011.

2.3.2 Weather Normalized Energy Data

To determine the typical annual energy use at the retrofit building for comparison to an energy model, the utility data is weather normalized using regression. To determine the weather normalized correlations, monthly energy consumption is plotted versus the monthly heating degree day (HDD) value. Various regression techniques are performed to determine the best relationship (e.g. linear, polynomial, logarithmic, or exponential). From this analysis, a baseline energy consumption is determined (e.g. summer consumption without heating), as well as a relationship between heating degree days and energy consumption. Consumption data for a typical weather year is then calculated based on average degree days.

Plots showing the relationship between energy consumption and HDDs for suite electricity, common electricity, and gas consumption are shown in Appendix A. For suite electricity, a second order polynomial gave the best fit relationship. For common electricity and gas, a linear relationship gave the best fit. These relationships are used to calculate the annual energy consumption for a weather normal year, using HDD values from the Vancouver Canadian Weather for Energy Calculations (CWEC) data[3]. Resulting weather normalized electricity and gas data is shown in Figure 2.10.

From the weather normalized data, the total building energy consumption intensity is 225 kWh/m^2 per year. The energy consumption consists of 36% suite electricity, 18% common area (strata) electricity, and 46% total (suite and common) gas consumption (see Figure 2.11). Of the total building energy consumption, 36% is paid by owners (in-suite electricity consumption) and 64% is paid by the strata (common electricity and gas consumption).

The building energy consumption patterns at the retrofit building are very similar to the typical and average building energy consumption profile for mid- and high-rise multi-unit residential buildings (MURBs) identified in Parts 1 and 2 of this study; therefore, the

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[3] CWEC data is available from the National Climate Data and Information Archive of Environment Canada, http://www.climate.weatheroffice.gc.ca

building was deemed likely to have several opportunities for ECMs. By comparison, the average energy use intensity for MURBs in the Lower Mainland and Victoria is 213 kWh/m^2 per year for the 39 buildings analyzed in Parts 1 and 2 of the study. Since the retrofit building has a similar energy consumption to the average building in its region, the building is representative of many typical MURBs and, therefore, findings from this study are applicable to numerous buildings.

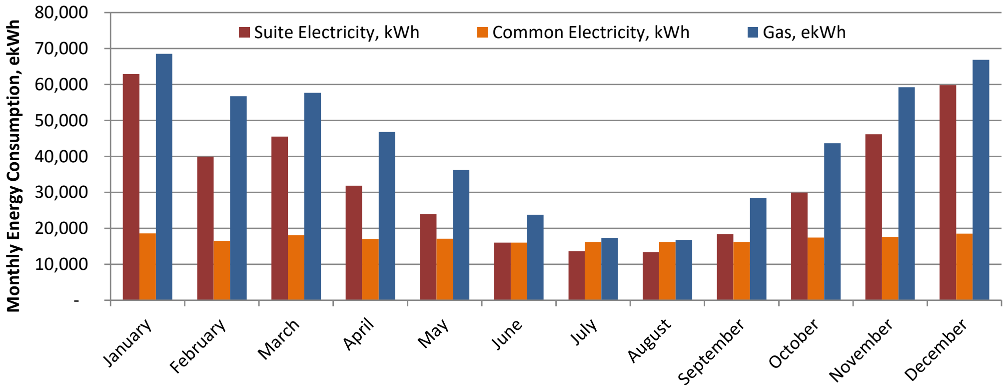


Figure 2.10 Weather normalized energy consumption, ekWh.

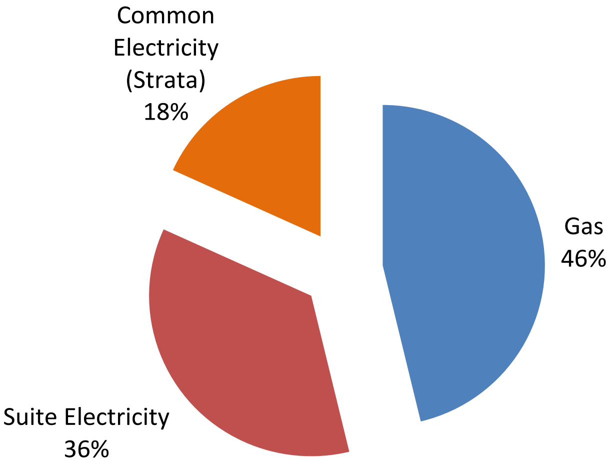


Figure 2.11 Percentage breakdown of suite electricity, common area electricity (strata), and gas consumption.

2.4 Whole Building Simulation and Calibration

Whole building energy modeling was performed for the retrofit building to understand the end-use breakdown of energy consumption at the building, and to determine the impact of potential energy efficiency measures that could be incorporated as part of the retrofit project. The energy model was calibrated to align with metered energy consumption to ensure that the model was representative of actual building energy consumption. This section presents the energy model inputs and calibration to metered energy data.

Energy modeling was performed using the software program FAST (Facility Analysis and Simulation Tool), a software package developed by Enersys Analytics that uses the DOE2 engine. This program was used since it has been customized to simulate MURBs, allowing for the development of a quick and simple model, and because of the team's experience with the program in Part 2 of the study. However, other hourly energy modeling programs could also be used for this analysis. Future tasks in this study will assess simulation results using EnergyPlus, a more detailed energy modeling program.

Energy model inputs were determined based on existing drawings and field review of the building. Where inputs were unknown, these values were calibrated so that the modeled energy consumption aligned with the metered energy consumption. Certain inputs for existing residential buildings can be particularly difficult to predict due to differences in occupant behaviour and operation, mechanical system performance, air leakage and open windows, etc. Meter-calibrated energy modeling corrected for these initial assumptions and used monthly weather normalized data from utility meters to improve estimates of space heat energy, and was better suited to assess the influence of energy saving measures. A complete list of energy simulation inputs is given in Appendix A. Inputs that were calibrated include the following parameters:

- Air leakage rate (this was tested; however, due to scheduling the test was completed after the retrofit project feasibility assessment had been performed; also, the impact of open windows is not known)
- Make-up air unit fan efficiency
- Domestic hot water consumption
- Lighting power density
- Miscellaneous electrical loads (e.g. appliances, entertainment systems, elevators, etc.)
- Heating set point temperatures
- Fireplace use and efficiency
- Schedules, including occupancy, lighting, miscellaneous electrical loads, domestic hot water, fireplace use, infiltration (for operable windows), etc.

Table 2.2 shows the metered and modeled energy consumption and percent difference for the retrofit building. Figure 2.12, Figure 2.13, and Figure 2.14 show plots of the metered and modeled suite electricity, common electricity and gas consumption, respectively. The metered data used for model calibration is the weather normalized data, presented in Section 2.3. The energy model is calibrated to align with the metered data by adjusting inputs that are not known, listed above. Despite best efforts to calibrate the model to metered consumption, some error was unavoidable due to occupant behaviour, operating efficiencies, weather, and other variables. Overall, suite electricity, common electricity and gas consumption have less than 5% annual difference between metered and modeled data after the calibration. Average absolute monthly percent differences are 9% for suite electricity, 5% for common electricity, and 4% for gas. Higher percent differences that occur primarily in the spring and fall months were likely due to occupant behaviour and variations in building use that cannot be modeled.

TABLE 2.2 METERED AND MODELED ENERGY CONSUMPTION AND PERCENT DIFFERENCE FOR THE RETROFIT BUILDING

	Suite Electricity, kWh			Common Electricity, kWh			Gas, GJ		
Month	**Meter**	**Model**	**% Diff**	**Meter**	**Model**	**% Diff**	**Meter**	**Model**	**% Diff**
Jan	62,920	58,272	7%	18,618	17,012	9%	247	246	0%
Feb	39,936	45,662	-14%	16,514	15,226	8%	204	196	4%
Mar	45,507	44,498	2%	18,110	16,769	7%	208	203	2%
Apr	31,851	29,663	7%	17,084	16,209	5%	169	156	7%
May	23,976	18,376	23%	17,104	16,624	3%	130	117	11%
Jun	16,014	13,967	13%	16,006	15,958	0%	86	79	8%
Jul	13,674	13,762	-1%	16,223	16,415	-1%	63	65	-4%
Aug	13,430	13,865	-3%	16,195	16,469	-2%	60	63	-5%
Sep	18,428	18,525	-1%	16,226	16,115	1%	103	95	7%
Oct	29,972	37,123	-24%	17,455	16,781	4%	157	157	0%
Nov	46,149	50,855	-10%	17,666	16,461	7%	213	212	1%
Dec	59,828	59,152	1%	18,539	17,013	8%	241	244	-1%
Ann	**401,685**	**403,721**	-1%	**205,740**	**197,051**	4%	**1,880**	**1,834**	2%

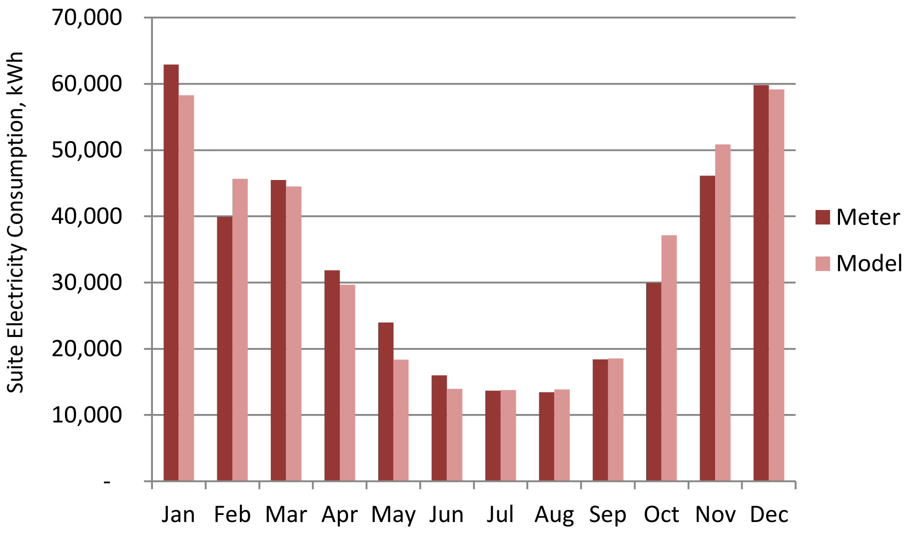


Figure 2.12 Metered and modeled suite electricity consumption, kWh.

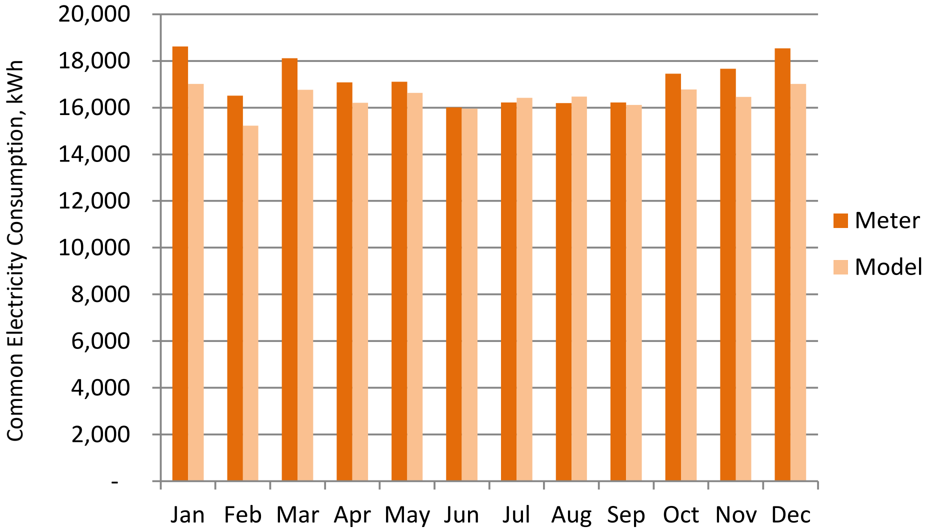


Figure 2.13 Metered and modeled common area (strata) electricity consumption, kWh.

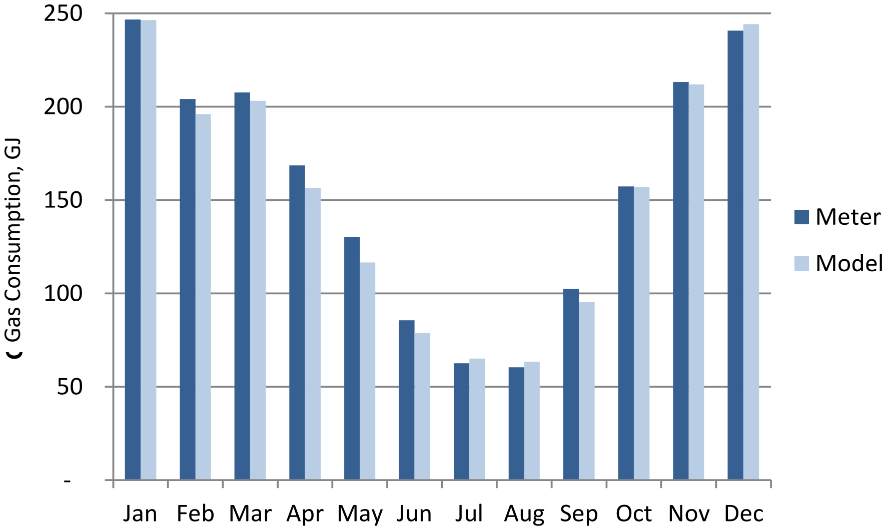


Figure 2.14 Metered and modeled gas consumption, GJ.

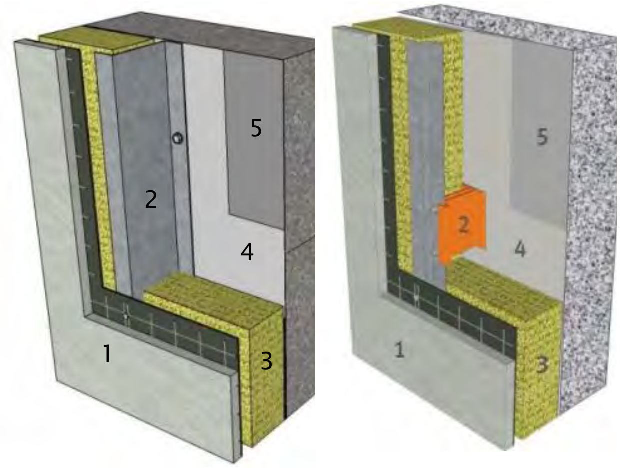
2.5 Energy Conservation Measures

The calibrated energy model was used to simulate several potential Energy Conservation Measures (ECMs) that could be undertaken as part of the project at the retrofit building to reduce its above average energy usage. The calibrated energy model was used to evaluate ECMs in terms of their annual energy savings and payback period, to assess cost effectiveness. The incremental cost of each of the ECMs is current as of the time of the initial feasibility assessment (April 2012). When doing a financial analysis, it is important to include up to date ECMs and energy costs since construction costs vary significantly over time.

The retrofit project planned for the retrofit building included over-cladding walls with exterior insulation, replacing the windows, air sealing, and re-roofing. Mechanical ECMs are modeled as part of this study to view approximate savings; however, a future second phase will address mechanical measures. This approach was selected so that the performance of the system could be evaluated and used to inform the design of a potential retrofit strategy. In general, there are likely some minor efficiencies that could be realized by combining the implementation of mechanical and enclosure retrofit measures but, in general, this would be relatively small if the potential for a mechanical retrofit is planned for as part of the enclosure work. As discussed later in this report, this study has largely demonstrated that pressurized corridor-based ventilation systems are unlikely to provide reliable effective ventilation of mid- to high-rise multi-unit residential buildings; consequently, in future buildings where extensive measurement and testing work is not possible, it may be prudent to assume the system would provide similar performance has measure here and thus plan for some level of retrofit.

Energy simulations were performed to assess the following potential ECMs:

→ ECM1 Wall insulation: Low conductivity cladding attachment system to improve the effective R-value of the wall to R-16 hr-ft^2-F/Btu compared to standard metal girts bridging insulation (shown in Figure 2.15).



1. New cladding Stucco or metal panels
2. Continuous metal girts (left, baseline assembly)
   Or, furring (fibreglass spacer with 1" steel "z-girt") to create rainscreen cavity (right, ECM assembly)
3. Mineral wool insulation (3.5")
4. Vapour permeable coating at cracks and penetrations
5. Existing finished concrete

Figure 2.15 Exterior insulated rainscreen wall assembly proposed for the retrofit building, baseline retrofit (left) and ECM1 (right).

→ ECM2 Windows: Double (ECM2a) or triple (ECM2b) glazed fibreglass frame windows (Figure 2.16) compared to standard aluminum frame code minimum windows. Double glazed windows have a U-value of 0.28 and SHGC of 0.29, and triple glazed windows have a U-value of 0.17 Btu/hr-ft2-F and SHGC of 0.20 (NFRC certified values from Cascadia Windows).

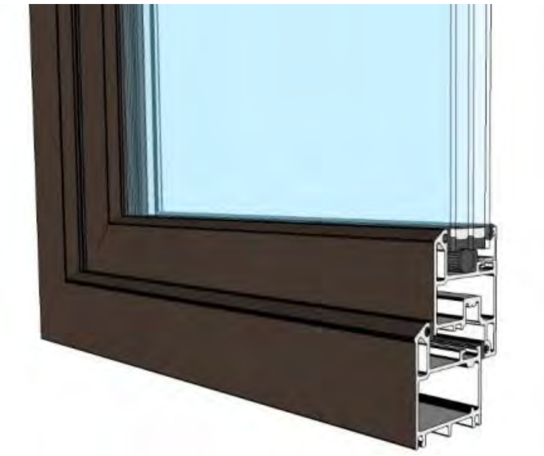


Figure 2.16 Triple glazed fibreglass frame windows.

- ECM3 Airtightness: Air sealing improvements to reduce whole building air leakage. A 50% reduction in air leakage was assumed in the model. This was estimated based on the literature review on air leakage completed in Part 1 and Part 2 of the study[4].
- ECM4 Fireplaces: Replace decorative fireplaces with heating fireplaces. Decorative fireplaces are not effective at space heating and should not be considered for this function. If heating style fireplaces are desired then EnerChoice fireplaces should be used[5]. To qualify, EnerChoice fireplaces must have an efficiency greater than 61% for fireplace inserts (replacement fireplaces, where there is an existing cavity). However, current EnerChoice models have a range of efficiencies, with efficiencies up to 91%. Since a specific model has not been selected for this project, an efficiency of 80% is assumed for an EnerChoice fireplace unit, since this value represents a mid-range efficiency of the EnerChoice products that are currently available.
- Individual monitoring or allocation of energy costs to the occupant should also be considered where possible as an additional energy efficiency measure, though this is difficult to predict and, therefore, is not considered in this analysis.
- ECM5 In-suite heat recovery ventilation (HRV): Install in-suite HRVs to improve indoor air quality, and reduce make-up air unit airflow rate to minimum for corridor pressurization. A specific model has not been selected at this time, so a sensible efficiency of 60%, and a fan power of 24 W is assumed for each unit based on several units that are being considered. An airflow rate of 90 cfm per unit was used, based on outdoor air requirements in CSA F326-M91 "Residential Mechanical Ventilation Systems" (note this rate may be updated as the design work progresses). HRVs were modeled to operate at this flow rate 24 hours a day.

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[4] RDH. (2011) "Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia".

[5] The EnerChoice Fireplace Program is administered by FortisBC to provide rebates for energy efficient fireplaces. The program currently applies to residential customers (the retrofit building is a commercial customer). For additional information, see
http://www.fortisbc.com

This measure also includes reducing the make-up air unit flow rate to 100 cfm per floor for corridor pressurization only, based on standard design practice.

- When a building is retrofitted to be more airtight, ensuring adequate mechanical ventilation becomes even more important for occupant health and to prevent condensation on indoor surfaces. Therefore, the energy savings from this retrofit measure are also tied to ECM3 (airtightness), and measures should be selected based on the whole building impact of packaged ECMs. However, the individual measure is simulated separately to view relative savings compared to other ECMs.
- ECM6 Make-up air unit: Replace make-up air unit with a high efficiency condensing unit. A specific model has not been selected at this time, so an efficiency of 94% is assumed.

Two packages of ECMs were also assessed to view the impact of combining all the enclosure ECMs (Phase 1) and both enclosure and mechanical ECMs (Phase 2):

- Package 1: Enclosure ECMs (ECM1, ECM2b, ECM3).
- Package 2: Enclosure and mechanical ECMs (ECM1, ECM2b, ECM3, ECM4, ECM5, ECM6).

2.5.1 Predicted Annual Energy Savings

Table 2.3 shows the modeled gas and electrical energy consumption and percent savings for each ECM, as well as the enclosure and mechanical combinations of ECMs. Figure 2.17 shows a plot of the modeled gas and electricity consumption for each measure.

Of the individual ECMs, triple glazed windows result in the greatest electrical energy savings, reducing electricity consumption by 17%. The enclosure ECMs 1, 2a and 2b show a small (1%) gas savings; this is due to the model simulating some reduction in fireplace consumption; however, in reality this is highly dependent on occupant behaviour and, therefore, cannot be reliably predicted through a computer model. Likewise, the energy savings prediction for fireplaces (ECM4) is difficult since this is highly dependent on occupant use. The current model assumes a fixed schedule and, therefore, savings from this ECM are shown as a reduction in electricity (less electric baseboard heating). In reality, it is likely that there would be gas savings with this ECM since heating fireplaces likely could not run for the same extended periods without overheating the space. This should be investigated further through more detailed energy modeling, and Measurement and Verification of a pilot project.

In-suite HRVs (ECM5) result in the greatest gas savings, reducing gas consumption by 30% but increase electricity by 13%. Overall the total energy consumption for this measure (gas plus electricity) is a net savings of 6%. The increase in electricity for this measure merits additional explanation. The gas savings occur because the make-up air volume is reduced to provide only the minimum airflow rate required for corridor pressurization, which means less outdoor air is heated to the setpoint temperature. However, electricity increases due to the additional load on electric baseboard heaters (since semi-conditioned outdoor air is brought into the space) and the additional fan power for each individual HRV. For example, if the HRV has a sensible heating efficiency of 60%, this means that outdoor air brought into the space recovers 60% of the heat required to reach the indoor temperature from exhaust air, but still requires additional heat to reach the indoor setpoint temperature; this additional heat is supplied by the electric baseboard heaters.

Although this measure increases electricity consumption and overall total energy costs using current pricing in British Columbia, it also provides more ventilation and a better indoor air quality to the space compared to the pressurized corridor approach since a constant volume of outdoor air is provided directly to the suite. When a building is retrofitted to be more airtight, ensuring adequate mechanical ventilation becomes even more important for occupant health and to prevent condensation on indoor surfaces. Therefore, the energy savings from this retrofit measure are also tied to ECM3 (air tightness), and measures should be selected based on the whole building impact of packaged ECMs.

TABLE 2.3 MODELED ENERGY SVAINGS FOR ECMS

	Gas		**Electricity**		**Total**	
	Consumption GJ	**% Savings**	**Consumption kWh**	**% Savings**	**Consumption ekWh/m^2**	**% Savings**
Current Energy Consumption	1,834	-	606,195	-	222	-
ECM1: Walls	1,822	1%	560,231	8%	212	4%
ECM2a: Double Glazed Windows	1,810	1%	534,256	12%	206	7%
ECM2b: Triple Glazed Windows	1,807	1%	501,893	17%	200	10%
ECM3: Air Tightness	1,835	0%	588,446	3%	218	2%
ECM4: Fireplaces	1,831	0%	585,923	3%	218	2%
ECM5: In-suite HRVs	1,289	30%	686,801	-13%*	208	6%
ECM6: Make-up Air Unit	1,617	12%	606,195	0%	210	5%
PKG1: Enclosure ECMS (ECM1, 2b, 3)	1,769	4%	398,626	34%	177	20%
PKG2: Enclosure and Mechanical ECMs (PKG1. ECM4, ECM5, ECM6)	1,165	37%	461,966	24%	156	30%

*Due to additional fan power and electric baseboard heating energy from in-suite HRVs.

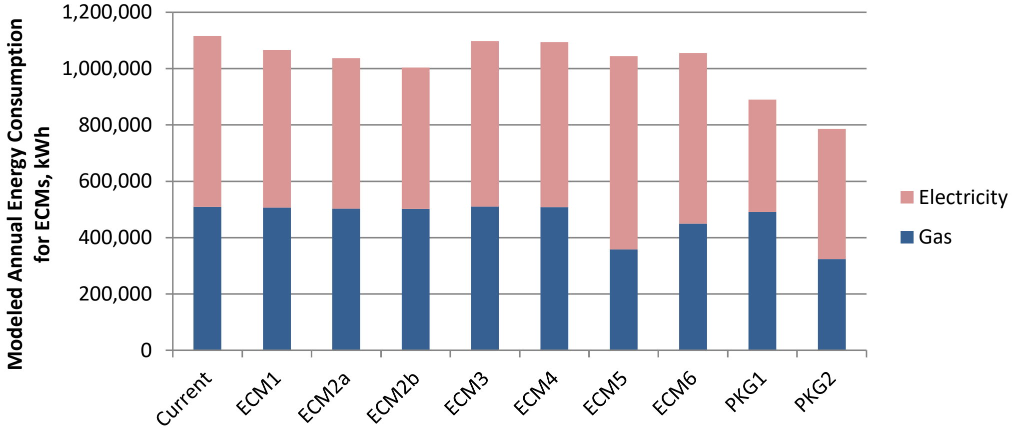
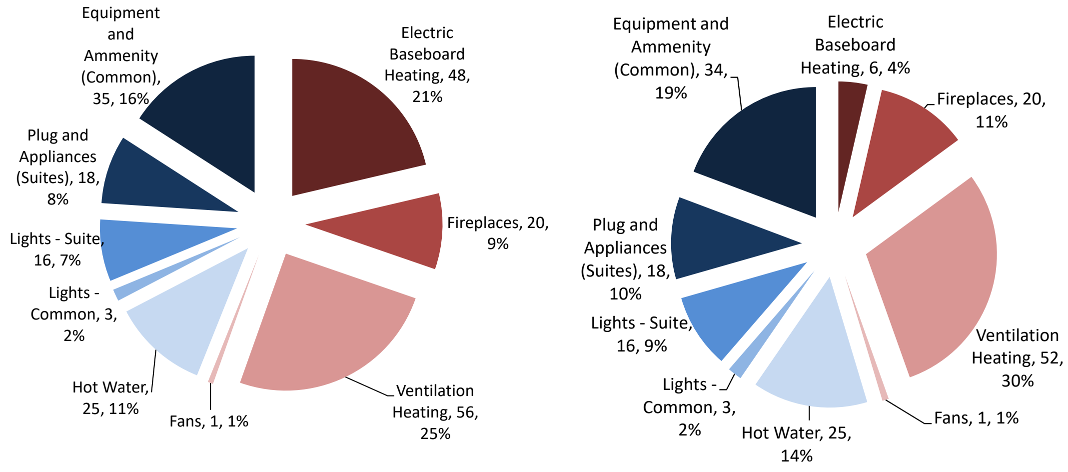


Figure 2.17 Plot of modeled energy savings for ECMs.

Figure 2.18 and Figure 2.19 show the modeled energy end-use breakdown of current energy consumption, and with Packages 1 and 2. The group of enclosure ECMs (Package 1) results in an estimated 34% electricity savings and an overall energy savings of 20% (once again, the modeled gas savings of 4% is not reliable due to occupant fireplace use). The electric baseboard space heating energy consumption is reduced by 87% with this package of ECMs. Measurement and verification will be important to compare actual savings to modeled savings, as this electricity savings could be affected by occupant behaviour such as opening windows during cold periods. The group of mechanical and enclosure ECMs (Package 2) results in an estimated 24% electricity savings and 37% gas savings, for a total savings of 30%. Electricity savings are lower for Package 2 than for Package 1 due to the additional electricity consumption from in-suite HRVs, though total energy savings (gas plus electricity) are greater for Package 2 than Package 1.



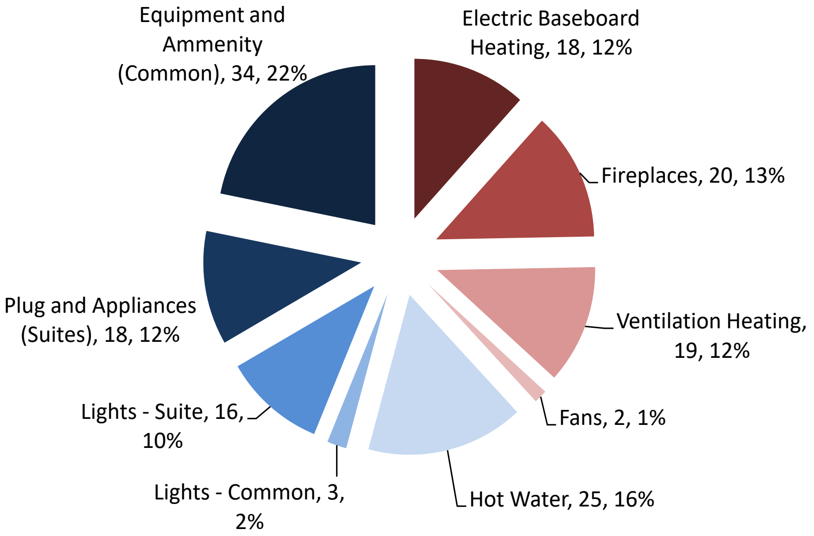
a) Pre-Retrofit

b) Post-Retrofit (Package #1)

Total Energy Intensity 222 kWh/m² per year

Total Energy Intensity 177 kWh/m² per year (20% savings)

Figure 2.18 Simulated energy consumption by end-use, kWh/m² per year and percent of total for a) Pre-Retrofit and b) Post-Retrofit Package #1



Total Energy Intensity 156 kWh/m² per year (30% savings)

Figure 2.19 Simulated energy consumption by end-use with enclosure kWh/m² per year and percentage of total for Post-Retrofit Package #2 (includes enclosure and mechanical ECMs)

2.5.2 Cost-Payback Analysis

Cost effectiveness is an important factor in selecting ECMs to incorporate into the retrofit project. A cost-payback analysis was completed to assess the financial feasibility of each measure. Costing for each ECM was based on estimates at the time of the renewals planning and for the enclosure work actual bid pricing. Note that construction costs can vary considerably over time and all costing analyses should be as current as possible when ECMs are being assessed.

Utility rates used in the cost payback analysis are $8.66/GJ for gas[6], and for electricity a stepped rate of $0.069/kWh for the first 1,350 kWh in a two-month billing period (or 22.1918 kWh per day) and $0.1034 above 1,350 kWh in a billing period[7]. These rates were current as of April 2013, exclusive of tax and fixed fee charges. The current financial analysis does not account for increasing energy prices; if this was incorporated, payback periods would be lower (therefore, the current analysis is conservative). The time-value of money is not accounted for in this analysis.

Calculating gas costs and savings is straightforward since there is a single step price per GJ of energy consumed. Calculating electricity costs is more complicated due to the stepped structure applied to all residential customers (e.g. 37 suites) plus the common account. Annual electricity costs were calculated using the stepped rate structure, multiplying the step level of 22.1918 kWh per day by 37 suites, since this rate structure would be applied individually to each customer's account. For each month, consumption less than 22.1918 x 37 = 821 kWh per day (multiplied by the number of days in the

[6] FortisBC Lower Mainland Rate 2, commercial with consumption less than 2000 GJ annually (http://www.fortisbc.com)

Carbon tax of $1.50/GJ, http://www.sbr.gov.bc.ca

[7] BC Hydro residential rates, https://www.bchydro.com

month) used a rate of $0.069 per kWh, while consumption over this point used a rate of 0.1034 per kWh.

Note that the retrofit building electricity meters are residential-type accounts and, therefore, do not have demand charges. If the building did have demand charges, this would be an important aspect to review as part of the financial analysis.

The cost-payback analysis was completed using the incremental costs above the renewals budget, since the renewals were being completed for a number of reasons and not just energy savings. For reference, the total baseline renewals project budget is $65 per square foot of floor area, which includes access, permitting, design, construction, contingency and taxes. This includes a budget of $20/ft^2 for the supply and installation of new windows and $15/ft^2 for the wall retrofit (including membrane, flashing, insulated rainscreen assembly, cladding, painting, caulking, and interior repairs). Other costs included deck and roof membrane replacement costs, scaffolding, demolition, permitting, design, construction, and taxes.

Table 2.4 shows the modeled energy cost and savings, plus the incremental cost of each ECM, the simple payback period (incremental cost divided by annual savings), and the internal rate of return (IRR). Figure 2.20 shows the payback period and IRR graphically, including incentive funding. Other financial metrics may be used as part of a financial analysis, including discounted payback; however, only simple payback and IRR were calculated at this time. ECM1 (wall insulation) and ECM3 (air tightness) had zero incremental cost above the retrofit budget and, therefore, payback is not calculated for these measures. The low conductivity cladding attachment system is cost neutral compared to the standard metal girt cladding attachment system, and air tightness improvements were performed as part of the retrofit budget to also improve water penetration resistance of the enclosure. Costing for the windows was obtained from bid prices submitted by the contractor and is therefore fairly accurate. Costing for the mechanical ECMs were estimated based on experience and discussion with mechanical equipment suppliers; however, this costing is less reliable since specific units have not been selected.

Incremental cost and simple payback are shown for two cases: first excluding any incentive funding and, second, including the incentive funding from BC Hydro’s New Construction Program (NCP) and Fortis BC’s equipment rebates. Incentives were estimated for ECM2 (windows) and ECM6 (make-up air unit replacement).

TABLE 2.4 COST-PAYBACK ANALYSIS FOR ECMS.

	Total Energy Cost	Est. Annual Savings	Excluding Incentives		With Incentive, if applicable			
			Inc. Cost	Simple Payback	Inc. Cost	Simple Payback	10-yr IRR*	30-yr IRR**
Current Energy Cost	$68,257	-	-	-	-	-	-	-
ECM1: Walls	$63,395	$4,861	$0	n/a	$0	n/a	n/a	n/a
ECM2a: Double Glazed Windows	$60,603	$7,654	$21,264	2.8 yrs	$2,722	0.4 yrs	280%	280%
ECM2b: Triple Glazed Windows	$57,237	$11,019	$88,129	8.0 yrs	$59,978	5.5 yrs	13%	18%
ECM3: Air tightness	$66,423	$1,834	$0	n/a	$0	n/a	n/a	n/a
ECM4: Fireplaces	$66,131	$2,126	$14,000	6.6 yrs	$14,000	6.6 yrs	8%	15%
ECM5: In-suite HRVs	$71,871	-$3,615	$74,000	n/a	$74,000	n/a	n/a	n/a
ECM6: Make-up Air Unit	$66,376	$1,880	$27,500	14.6 yrs	$23,523	12.5 yrs	-6%	5%
PKG1: Enclosure ECMs (1, 2b, 3)	**$46,225**	**$22,031**	**$88,129**	**4.0 yrs**	**$59,978**	**2.7 yrs**	**35%**	**37%**
PKG2: Enclosure and Mechanical ECMs (PKG1, ECMs 4, 5, 6)	$47,543	$20,714	$198,129	9.6 yrs	$166,796	8.1 yrs	1%	10%

* Calculated over a period of 10 years, assuming no change in energy prices.

** Calculated over a period of 30 years, assuming no change in energy prices.

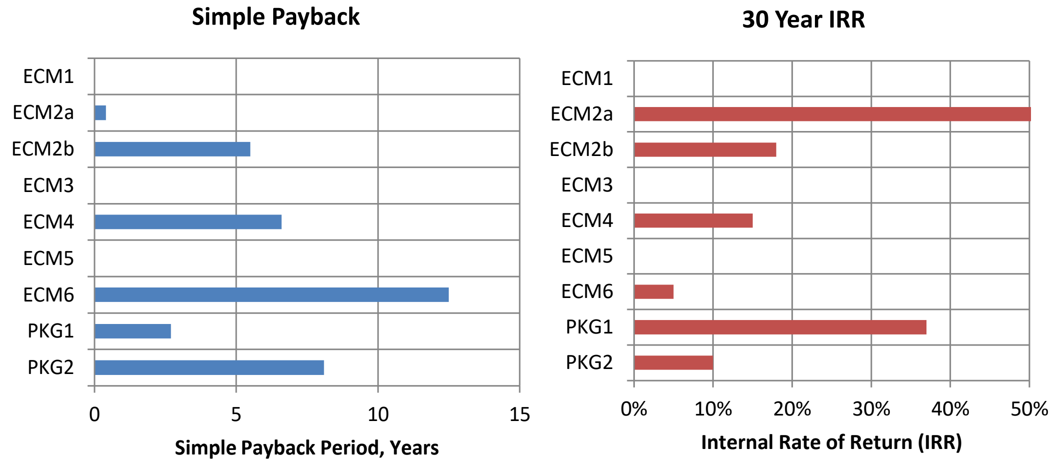


Figure 2.20 Simple payback period and 30 year IRR for ECMs, including incentive funding.

The double glazed windows (ECM2a) have a simple payback period of 2.8 years excluding any incentive funding, or 0.4 years including the BC Hydro NCP incentive. The triple glazed windows (ECM2b) have a simple payback period of 8 years excluding incentives, or 5.5 years including the NCP incentive, and an IRR of 18% over 30 years. The positive IRR means that over the life of the ECM, the incremental costs are fully covered and provide an additional benefit, of 18% for the triple glazing. This is a good number, given that borrowing costs are typically in the range of 3% to 5%. Though the wall insulation (ECM1) and air sealing (ECM3) are cost neutral, they still result in annual energy savings of $4,800 and $1,800, respectively. Overall, the enclosure ECMs (Package 1) combined have an estimated annual energy savings of $21,900, and an IRR of 37%.

The mechanical ECMs have longer payback periods since these are not taken as an incremental cost (i.e. the entire cost of the retrofit is counted against energy savings). ECM5 (in-suite HRVs) has a higher energy cost than the baseline due to the increase in electricity consumption (albeit improved indoor air quality). Although gas consumption is lower, the cost of electricity is higher and therefore overall annual energy costs increase. High efficiency fireplaces have a simple payback period of 6.6 years; if there was an incentive program to offset part of this cost, the payback period would be even more desirable. Note that gas fireplaces are controlled by occupants but paid for by the strata (common bill), creating a disconnect between use and billing. Replacing the make-up air unit has a simple payback period of 14.6 years; installing a high efficiency unit would only be financially feasible if the unit required replacement.

Based on this analysis, the wall insulation, window, and air sealing ECMs are all recommended for implementation as part of the building enclosure retrofit program. Triple glazed windows have a higher incremental cost and longer payback period than double glazed, though the 5.5 year payback period and 18% internal rate of return (IRR) are very reasonable and should be undertaken if funding permits. Replacing fireplaces with high efficiency units are also recommended. Although in-suite HRVs increase total energy costs, this measure may be required to provide acceptable indoor air quality following the enclosure air tightness improvements; this will be evaluated as part of this project. Replacing the make-up air unit is only recommended once the unit reaches the end of its service life.

These recommendations are based on climate and cost data for Vancouver. Similar recommendations would likely result for a building in other parts of Canada, however simulations should be performed for the climate and costs specific to a building's location in order to recommend ECMs.

2.6 Summary

The retrofit project was initially conceived to renew aging building enclosure components (including walls, windows, decks and roof), address localized building enclosure performance issues, improve the aesthetics and make the interior space more comfortable. The retrofit project presented an opportunity to reduce energy consumption at the building, using measures with little or no incremental cost above the planned retrofit budget. An energy analysis was completed using computer modeling to assess the potential savings and financial feasibility of building enclosure ECMs.

Five years of metered energy consumption data was obtained from BC Hydro and FortisBC for the retrofit building. The utility data was calendarized to align with monthly periods and weather normalized to represent data for a typical or average weather year to allow for comparison to simulated energy consumption. The annual energy consumption for the building is close to the average building energy consumption for south-western British Columbia determined in Parts 1 and 2 of this study and, therefore, the building is a good case-study that is relevant to many other buildings in BC and across Canada.

Energy modeling was performed using the program FAST, and modeled results were calibrated to align with metered energy consumption. Simulations were performed to assess the relative energy savings of building enclosure ECMs and a cost-payback analysis was completed to determine the financial feasibility of each measure. A later task will include energy modeling using additional energy simulation software tools to compare results from different simulation programs.

All of the building enclosure ECMs assessed in this study had payback periods of less than 6 years after incentive funding was considered, based on the incremental cost of the measures (before incentive funding, the enclosure ECM payback periods were less than 8 years). The wall insulation and air sealing ECMs could be completed at zero incremental cost to the retrofit budget and are therefore strongly recommended. The double glazed windows have a simple payback period of 0.4 years after the BC Hydro PowerSmart incentive and are therefore also recommended. The triple glazed windows have a simple payback period of 5.5 years, including the incentive funding, and are also recommended. Triple glazed windows would have additional benefits over double glazing, including improved thermal comfort (warmer surface temperatures) and reduced noise transmission. Replacing fireplaces with high efficiency units has a simple payback period of 6.6 years, which would be lower if there were an incentive program to assist with the cost of this measure.

An energy efficient retrofit project at the retrofit building would reduce annual operating costs and provide numerous other benefits. The retrofit would also improve the comfort of indoor spaces, upgrade the aesthetics of the building, and likely result in higher property value. Once the retrofit project was completed, measurement, verification and monitoring was performed to confirm the energy savings. Testing and monitoring was also undertaken to assess indoor air and environmental quality. Finally, while it is recognized that increased value may be an important aspect of an energy efficient retrofit project, this potential benefit may be assessed depending on available budgets for later parts of this study.

3 Design of Airflow and Indoor Environmental Quality Monitoring

This section describes the airflow and indoor environmental quality (IEQ) monitoring program conducted at the retrofit building.

3.1 Objective and Approach

A one year monitoring component of the retrofit project was implemented to quantify in-service performance including airflow and pressure patterns, thermal comfort, building operational characteristics, electricity consumption, and natural gas consumption. The quantification of these components of building operation allowed for evaluation of the following:

- Ventilation system performance
- Thermal comfort
- Impact of exterior environmental conditions on building operation and performance
- Fireplace usage
- Relationship between ventilation, thermal comfort, and energy consumption
- Impact of retrofit on electricity and natural gas energy consumption

While is not a primary goal of the study, monitoring was also implemented to evaluate indoor environmental quality using an indicator of indoor air quality (carbon dioxide concentration) which aided in assessment of the effectiveness of the ventilation system and allowed for comparisons with other measurements including energy consumption. This monitoring was completed both before and after the building enclosure retrofit so that the impact of the retrofit can be determined. This monitoring of the retrofit building was significantly more rigorous than that of typical energy studies as it allows for comparison of energy consumption data with detailed building operational characteristics to provide a more detailed understanding of how energy is being used, and consequently, of how energy consumption could potentially be reduced through changes in building design and operation.

To quantify these components of building operation a variety of indicators were measured using selected sensors installed at key locations. These indicators include:

- Interior temperatures
- Interior relative humidity levels
- Carbon Dioxide (CO_2) concentrations
- Pressure differences
    - Across building enclosure
    - Across interior separating elements

- Exterior conditions
  - Temperature
  - Relative humidity
  - Precipitation
  - Wind direction and speed
  - Solar radiation
  - Barometric pressure
- Fireplace on/off
- Makeup Air Unit (MAU) operation
  - On/off
  - Supply temperature
  - Supply relative humidity
  - Supply Carbon Dioxide (CO_2) concentration
- Energy consumption
  - Electricity consumption on suite-by-suite basis
  - Natural gas consumption with main building meter and separate sub-metering of the make-up air unit and domestic hot water boiler.

The majority of the sensor equipment was installed in July 2012 and the weather station was installed in September 2012, mid-way through the retrofit construction.

This report provides details on the measurement and monitoring performed at the retrofit building, excluding utility energy metering. Appendix B provides the energy measurement and verification (M&V) plan, following the International Performance Measurement and Verification Protocol (IPMVP Volume I EVO 10000-1:2012).

3.2 Monitoring Equipment Installation

3.2.1 Equipment Description

Wireless data acquisition units are being used to record sensor measurements throughout the building. Two different types of these units were used, the SMT-A2 and SMT-A3, both of which are supplied and manufactured by SMT Research Ltd. (SMT). These units were developed with input from RDH specifically for this project and were tested extensively by RDH prior to installation. The units can be located throughout the building to record data and then transmit the data wirelessly to an SMT BiG (Building Intelligence Gateway) which acts as a central location where the data can be stored and/or uploaded. The data for this project is uploaded from the BiGs to Building Analytics which is a secure internet accessible tool to log, view, and export data. Note that utility metered energy consumption data is not part of this process; utility metered data is obtained directly from the utilities, and is not uploaded to the internet or stored online.

The SMT-A2s and A3s were used in a variety of configurations as shown below in Figure 3.1 to Figure 3.5. Primarily the SMT-A3 configuration was used and mounted into the wall with a faceplate cover for aesthetics.

Figure 3.1 SMT-A3 unit with attached battery pack shown without faceplate. An LCD screen is provided to interact with the unit. Temperature and relative humidity sensors are located to the left of the LCD screen; the CO_2 sensor is round and white, and the pressure sensor is located on the back of the unit with a tube running out to a hole on the middle top of the right side.

Figure 3.2 SMT-A3 unit with attached battery pack shown with faceplate. Holes are provided in the face plate on the left side for the temperature and relative humidity sensors, and on the right side for one pressure tube. The other side of the pressure sensor is connected to a tube that is then routed to the appropriate pressure reference location.

Figure 3.3 SMT-A2 unit. An LCD screen is provided to interact with the unit. Temperature and relative humidity sensors are located within the unit, and ports are provided on the bottom of the unit to attach external sensors.

Figure 3.4 SMT-A3 unit installed in a waterproof enclosure for use outside. The SMT-A3 unit is contained in the box on the bottom, and the temperature, relative humidity, and CO_2 sensors are installed within the shroud on top of the box.

Figure 3.5 SMT-A3 floater unit in an outdoor waterproof case.

Figure 3.6 Exterior pressure tap with cover to protect the end of the tube from water.

The weather station was manufactured by Davis Instruments Corp. and configured to upload data to Building Analytics for ease of access to the data. The weather station and one of the two BiGs are shown in Figure 3.7 and Figure 3.8 respectively.

Figure 3.7 Weather station installed on roof of retrofit building to measure temperature, relative humidity, solar radiation, wind speed and direction, and barometric pressure.

Figure 3.8 One of two BiGs (laptop) located in an electrical closet to communicate with data acquisition units distributed throughout building. The weather station console and communications equipment (to access the internet) are also visible on the lower shelf.

Electricity consumption was monitored using a BC Hydro Smart Meter for each suite. Natural gas consumption was monitored using billing data from the main FortisBC gas meter as well as with monitoring equipment attached to submeters for the make-up air unit and domestic hot water boiler which provide hourly measurements of natural gas consumption.

Data acquisition unit, sensor, and weather station specifications are provided in Appendix C.

3.3 Monitoring Equipment Locations

Floor 3 and Floor 11 of the retrofit building were selected as representative floors and thus as primary testing and monitoring floors to allow for direct comparison of data. These floors were selected because they are typical floors near the top and near the bottom of the building and thus should provide a good representation of the typical floor in the building. Consistent with this approach, monitoring equipment was primarily installed on these floors per the monitoring equipment layouts provided in Figure 3.9 to Figure 3.16. Figure 3.17 schematically illustrates how the pressure sensors can all be referenced to each other because they “hop” from one zone to the next.

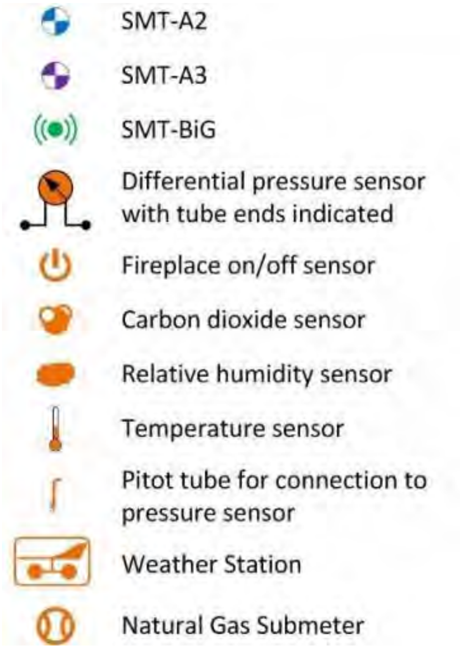


Figure 3.9 Legend of symbols used in subsequent sensor layouts

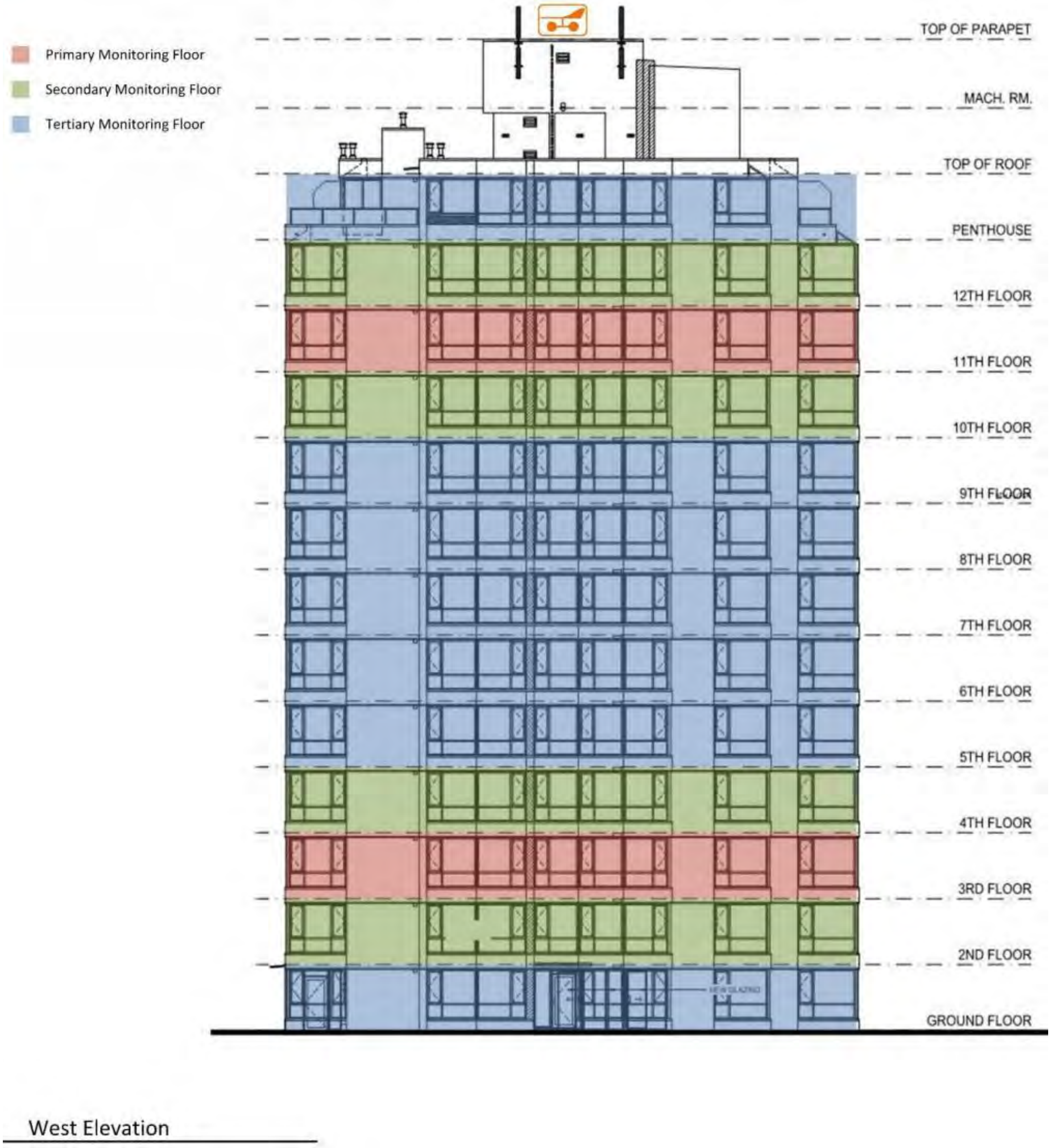


Figure 3.10 West elevation of retrofit building showing sensor layout and identification of monitoring floors.

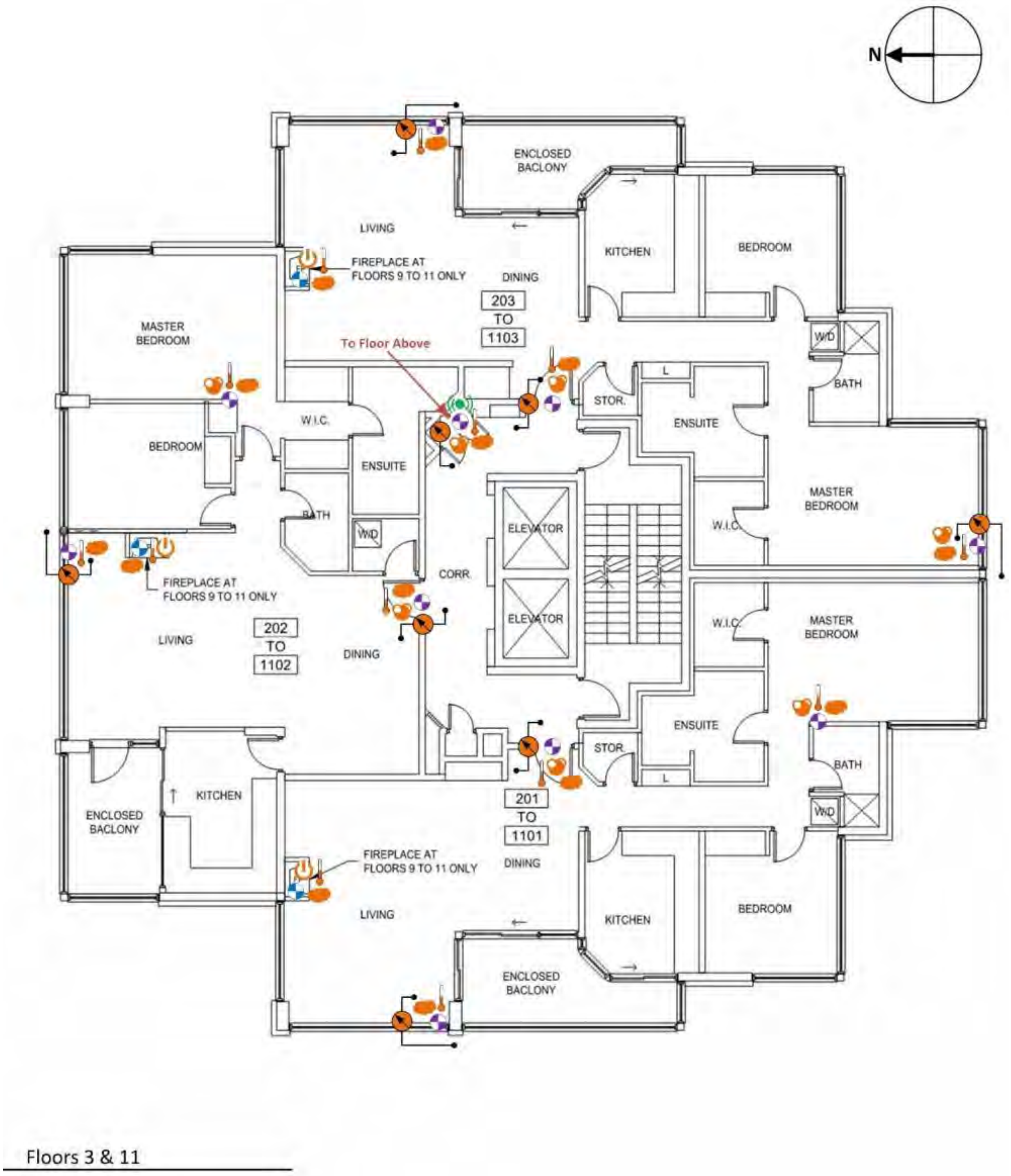


Figure 3.11 Primary Monitoring Floor Plan showing monitoring equipment layout

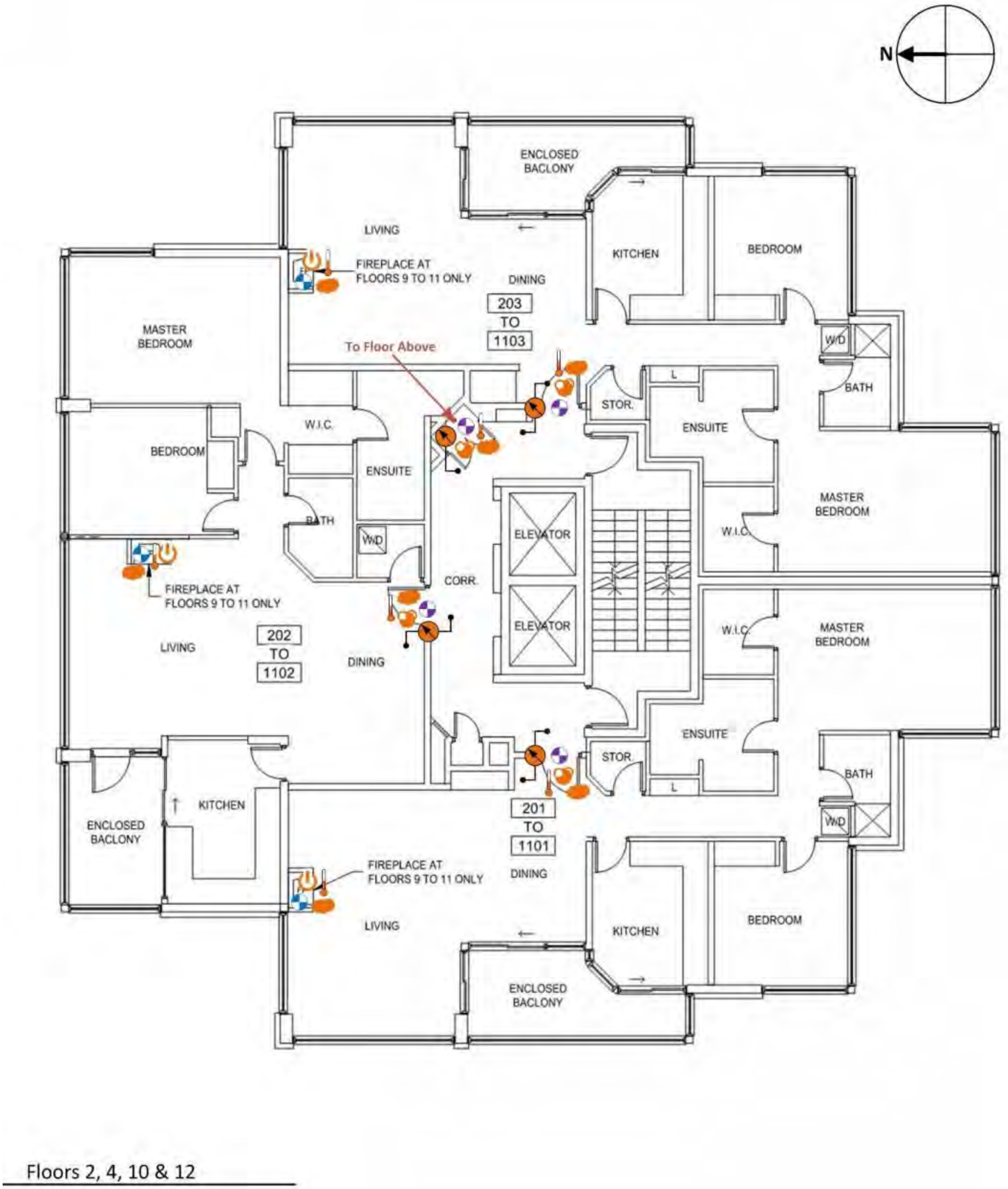


Figure 3.12 Secondary Monitoring Floor Plan showing monitoring equipment layout

Figure 3.13 Typical Tertiary Monitoring Floor Plan showing monitoring equipment layout

Figure 3.14 First Floor Plan showing monitoring equipment layout

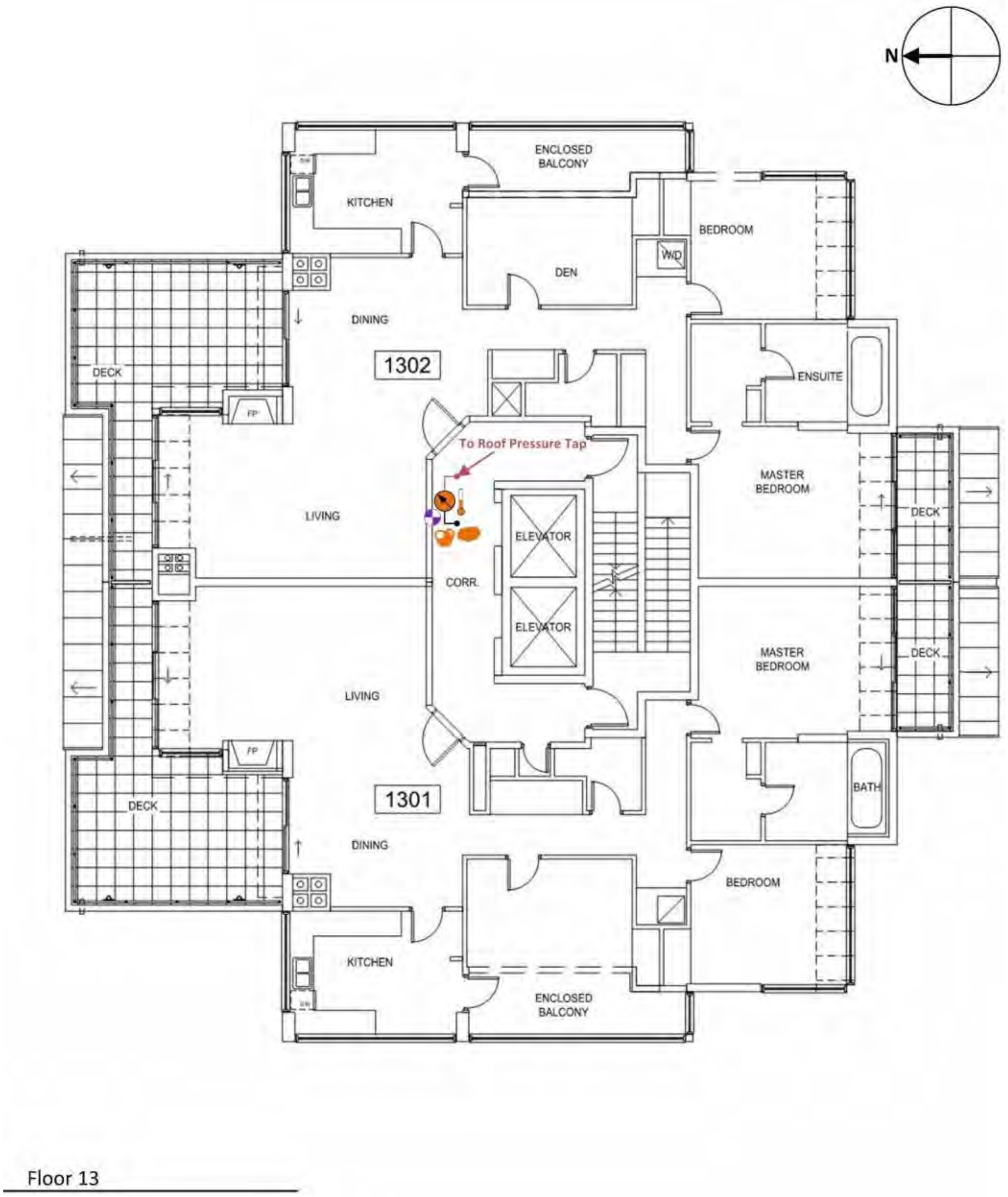


Figure 3.15 Thirteenth Floor Plan showing monitoring equipment layout.

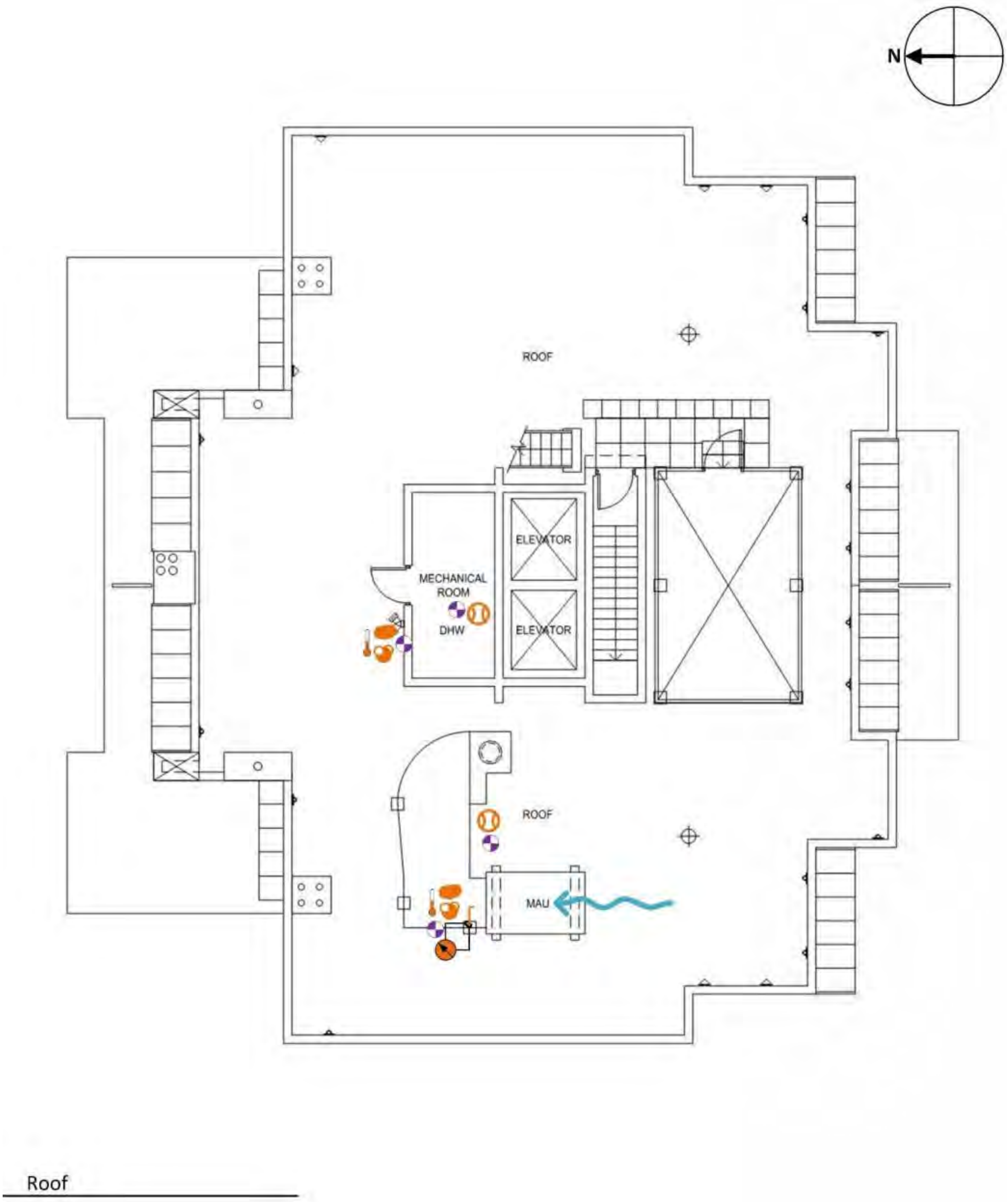


Figure 3.16 Roof Plan showing monitoring equipment layout

Figure 3.17 North-South cross-section showing schematic pressure sensor layout. The pressure sensors can all be referenced to each other since they "hop" from one zone to the next. (Note that not all pressure sensors are shown.)

Installed sensors are shown in Figure 3.18 and Figure 3.19.

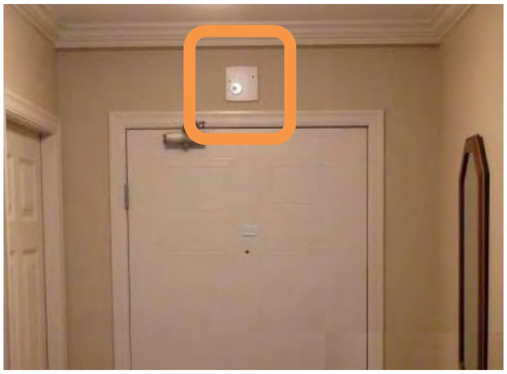


Figure 3.18 Typical SMT-A3 with faceplate installed above a suite entrance door. One pressure reference is installed to the front of the faceplate and the other is installed through the wall to the corridor to provide the pressure difference between the suite and the corridor.

Figure 3.19 Typical SMT-A2 installed under a fireplace. A temperature sensor is installed near the pilot light to provide an indicator of fireplace use.

Each sensor was given a unique name, which indicates its location and type. These are used when referencing sensor data. In addition to the data logger units and sensors identified in the drawings provided, three SMT-A2s and two waterproof SMT-A3s are being used as floater units to provide monitoring of specific locations of interest for shorter periods of time. A list of sensor names, types, and locations is provided in Appendix C.

A total of 62 data acquisition units with 216 sensors were installed and measurements were recorded simultaneously once per hour. The weather station recorded measurements every 5 minutes. More frequent measurements were taken as necessary.

Once these initial installations were completed, a period of system commissioning was undertaken. During the commissioning process a number of issues were identified including:

- Malfunctioning sensors
- Incorrect sensor calibration
- Data acquisition units not communicating with the BiG
- BiG errors leading to data loss
- BiG loss of internet connectivity
- Weather Station exporting data to Building Analytics incorrectly.

The majority of the commissioning work was completed by the end of September 2012, at which point all issues identified during commissioning had been rectified and the monitoring equipment was fully operational. Issues also occurred during the course of the monitoring project, and consistent review and maintenance of the monitoring system was required. The monitoring equipment system is manually checked to ensure correct functioning and the system was set to send alert e-mails if it failed to record data for a period of more than six hours and if a data logger unit has low batteries.

4 Pilot MURB Envelope Retrofit Process – Planning & Management Guidance for Stratas

This section describes the building enclosure retrofit project undertaken at the pilot building as a case study of a common renewals planning process to outline key decisions that need to be made through various stages of the project, including pre-construction, during construction, and post-construction. The retrofit process is discussed in general terms as it may apply to any project, with specific examples shown for the pilot building. Refer to the other sections of this report for more detailed and specific technical information and analysis on the retrofit measures.

4.1 Pre-construction Process

This section steps through the pre-construction phases of a building enclosure retrofit project from assessing the options to planning for the retrofit.

Initially, the Owners of the pilot project building needed input on a localized building enclosure issue, as part of their overall maintenance and renewals program. Considering the age of their complex, they decided to commission an overall building enclosure assessment of their complex to better establish the priorities, and to plan for efficiencies in maintaining their complex over the long-term. This assessment included the review of localized water ingress issues, condensation on windows and doors, drafts and cold spots, and other concerns.

The assessment included a visual review from the exterior of the building, water penetration resistance testing of windows, and exploratory openings. At the end of the condition assessment, the Owners were provided with the following three options:

- Option 1: Watershedding improvements. Watershedding improvements include things like replacing sealants, replacing flashings and other modest interventions to extend the life of existing building enclosure components. This recommendation was provided as a short term measure. Some further renewals work and ongoing maintenance work would have been required with this option.
- Option 2: Replace windows and watershedding improvements at walls. The window replacement was considered to be the best option for addressing condensation and improving thermal comfort, a significant concern identified by the Owners. While this recommendation would have resulted in improved performance compared to Option 1, ongoing maintenance and renewals costs were anticipated in the future compared to Option 3 below.
- Option 3: Replace windows and overclad walls. This was the preferred option to address performance issues, reduce future maintenance requirements, and reduce operation costs including energy bills.

For this retrofit project, the Owners decided to proceed with Option 3, replacing the windows and overcladding the walls. They selected this option because it would extend the service life of the building, address localized enclosure performance issues, improve the thermal comfort of the space, reduce energy consumption and reduce operating costs (both maintenance costs and energy costs). A significant factor was also the opportunity to upgrade the aesthetics of the building to give it a modern appearance, which could also increase the resale value of the building.

The pre-construction phase consisted of the following four steps:

1) Evaluating and defining the project needs or requirements.
2) Planning, designing and refining the project scope.
3) Preparing project documentation and contracts for the project.
4) Selecting the means of implementation and contractor(s) to do the work.

4.1.1 Evaluating and Defining the Project Needs

The condition assessment was used as the basis for defining the scope of the retrofit project. The condition assessment report included information such as what must be done (mandatory, such as the watershedding improvements to prevent water ingress), what should be done (optional/preventative, such as replacing the windows (frames and IGUs) which were nearing the end of their service life), and what could be done (upgrades, such as improving the aesthetics of the building and improving the thermal comfort of the spaces). The report also included preliminary budget estimates for the costs to complete each option and the estimated time frame to complete each option.

After receiving the condition assessment report, the Strata Council met with the consultants to ask questions and discuss the options further. The Strata Council decided to recommend the full retrofit project to the owners of the Strata Corporation. An information session was held with the full owner group where the owners were encouraged to ask questions and discuss the merits of the potential project including possible energy conservation measures. Next, a Special General Meeting was held to vote on the project. At this stage, the Owners approved a project which included the retrofit of the roof, walls, and windows. They selected this option for several reasons: it would extend the service life of the building, address localized enclosure performance issues, improve the thermal comfort of the space, and reduce operating costs (both maintenance costs and energy costs). A significant factor was also the opportunity to upgrade the aesthetics of the building to give it a modern appearance, which could also increase the resale value of the building. If the project was not done, the depreciation report would show significant maintenance costs coming up, which could deter potential buyers. By completing the retrofit project, the depreciation report shows the lower maintenance costs and a healthier financial outlook.

4.1.2 Planning, Designing and Refining the Project Scope

Once the Owners had elected to proceed with the retrofit project and general project scope, the consultant further defined the scope of the project and associated options. A design report was produced to describe the scope of work (what areas, assets, materials and components are included, and which are excluded), what new materials and components will be used, potential options associated with the work, impact of potential energy efficiency measures as part of a pilot project, and what the building will look like.

Several materials decisions were made at this stage. The options for replacement windows were presented. Double glazed aluminum frame windows typically would have the lowest initial cost but may not have alleviated cold surface temperatures and would yield less energy savings than a more efficient window. Double or triple glazed fibreglass frame windows typically cost more initially but result in higher energy savings each year and would also have warmer surface temperatures, improving the thermal comfort of the spaces. The decision was made to ask for prices for both aluminum and fibreglass frame windows, and both double and triple glazing, to further assess the costs associated with better insulated windows.

Cladding materials and colours were also selected at this stage. The consultant provided a design report with architectural renderings showing several colour schemes for the new building enclosure, on which the owners voted. Stucco and metal panel claddings were considered; metal panels are typically more expensive, but have a more modern appearance. The decision was made to proceed with stucco as the primary cladding type, but also ask for costing for metal panels to determine whether this option could fit within the budget.

Potential energy conservation measures that could be incorporated into the retrofit project were further assessed at this stage. The options were refined, and whole building energy modeling was performed to assess the potential energy savings of each measure. A financial analysis was performed to compare the initial investment to predicted annual savings to assist in deciding which measures to proceed with. Several financial metrics were shown, including simple payback period, return on investment, and internal rate of return. For details on this analysis refer to Section 2. At the pilot project, the measures that were investigated included wall insulation, energy efficient windows, air sealing, heat recovery ventilation, and replacing mechanical equipment with high efficiency units (domestic hot water boiler and make-up air unit).

4.1.3 Preparing Documentation and Contracts for the Project

Once the Owners decided on a program based on the design options presented, construction documents were developed based on this input to describe the work in a technical manner, including what specific materials are to be used, and how they are to be installed. Construction documents developed for this project included drawings (plans, elevations, and details) and specifications. The construction documents were used to obtain building permits from the municipality, to obtain pricing from contractors, and form part of the base contract with contractors. At this stage, a more detailed schedule was created. The project was scheduled to begin with mobilization in April and wrap up the following January for an anticipated duration of 10 months. Since the project would include scaffolding to access the exterior of the building and protect it from the weather, there was no seasonal limitation on when the work could be done.

As part of the preparation of the project documentation, the impact of the potential energy improvements were further considered as the documentation evolved. Specific details were considered so as to better ensure that the energy benefits would be realized. The predicted results of these measures were discussed with the owners and the project study partners.

4.1.4 Selecting a Construction Manager and Trades

Once the project had been defined and clearly articulated in construction documents, the next step was to identify and select contractors. In large projects where there are multiple trades involved, such as with this pilot project, there are typically two approaches that are considered to implementing the work: (1) general contractor and (2) construction management.

With a general contractor relationship, the Owners work with a consultant to prepare contract documents and either administer a tender process with multiple contractors or negotiate a price with one company, the general contractor. The strata will sign one contract with the general contractor. The general contractor will then sign sub-contracts with other trades contractors. When construction begins, the consultant administers the contract, including reviewing and approving submittals, changes to the contract and monthly payments. The consultant will also periodically visit the site to review samples of the work completed. The general contractor is responsible for coordinating activities on site and for ensuring the work conforms with the construction documents.

In a construction managed approach, in addition to the consultant the strata hires a construction manager. The construction manager may be part of the consulting team, or a separate third party. The construction manager administers a tender process to different trade contractors. The strata will sign multiple contracts – one contract for each of the major trades categories (for example, roofing, painting, and scaffolding). Once construction begins, the construction manager has a full-time presence on site, typically a site manager. The construction manager schedules and co-ordinates day to day construction activities, including safety, similar to the services a general contractor would provide. In addition, they administer the trade contracts and provide cost control services, while working with the engineers and architects to optimize construction process on the Owners' behalf.

The Owners of the pilot project building elected to proceed with a construction managed approach in order to better realize potential efficiencies with this process.

4.2 Construction Process

This section covers the construction phases of a building enclosure retrofit project where the work is performed on-site. Once the tender has closed and the trades have been selected, the construction manager and trades mobilize at the building to implement the work. Mobilization is the process of preparing to start construction and includes arranging for trades contractors, ensuring key staff are available, ordering material, signing contracts with sub-trades, and setting up the workspace at the property. At the pilot project, mobilization included installing a temporary office and first aid room on the property, installing scaffolding and weather protection around the building, and installing safety fences around the property.

4.2.1 Summary of Building Enclosure Energy Efficiency Measures Implemented

The retrofit project included replacing the windows, overcladding the walls, and re-roofing. Though the project was primarily driven by factors unrelated to energy savings, several energy conservation measures were incorporated into the project. These included adding wall insulation, installing energy efficient replacement windows, and air sealing. The Owners initially elected to proceed with only the building enclosure measures, and to consider the mechanical measures following the enclosure project. Refer to Section 2 for further details on the measures that were considered.

Wall Insulation and New Cladding

The walls were insulated with 3.5 inches of mineral wool insulation at the exterior. A key component of this assembly was the use of fibreglass clips to attach the cladding outside of the insulation, to reduce thermal bridging and result in a better insulated wall assembly (refer to Section 2 for details). New cladding was installed, which consisted of a combination of stucco and metal panels. Figure 4.1, Figure 4.2 and Figure 4.3 show photos of the insulation and overcladding installation.

Figure 4.1 Fibreglass clips and z-girts are screwed to the exterior concrete walls.

Figure 4.2 Mineral wool insulation is installed between the clips, filling the voids.

Figure 4.3 Stucco (left) and metal panels (right) are installed over the insulation.

Energy Efficient Windows

The existing aluminum frame windows were removed, and new fibreglass frame windows were installed. The windows have triple glazing with two low-e coatings and argon gas fill. These windows were selected for their energy savings compared to code-minimum double glazed aluminum frame windows. Refer to Section 2 for further discussion on the various window selection options, energy savings and financial analysis.

In most high-rise buildings, aluminum frame windows are needed to meet code requirements for fire safety. Upon further discussion and review with a code consultant and the City of Vancouver, fibreglass was deemed to be an acceptable alternate in the proposed arrangements at the pilot project building.

The window installation was planned such that each unit's windows were changed within a single day, so that owners only needed to provide suite access on one day, with one additional follow-up visit needed to perform interior repairs (though this scheduling may not be possible on all projects). Water testing was performed on a sample of installed windows to ensure that the installation and window met water penetration resistance requirements. Figure 4.4 and Figure 4.5 show photos of the window installation and the water testing.

Figure 4.4 Installing the new triple glazed fiberglass frame windows.

Figure 4.5 Testing the new windows for water penetration resistance.

Air Sealing

The cast in place concrete walls at the existing building were relatively air tight; however, air leakage occurred through joints and penetrations, particularly at the windows. As a result, the design decision was made to utilize the existing concrete wall as the air barrier and backup water resistive barrier. In order to do so, liquid-applied membrane was typically installed at cracks and cold joints in this wall. Air-tight architectural details were developed for joints and interfaces at the building. The details at all windows, joints, and penetrations included continuous air barrier achieved through a combination of products including liquid applied membranes, self-adhered membrane, and sealant. Figure 4.6 shows examples of the air barrier installation at cracks, joints and penetrations.

Figure 4.6 Airtight detailing around vents (left) and partial installation of a liquid applied barrier over concrete cracks and cold joints (right).

4.2.2 Site Modifications and Field Review

A representative of the consulting firm completed field reviews throughout the construction phase. Field review is making periodic visits to the site to ensure conformance with the construction documents and building code. Field review is also necessary to confirm the progress of work. The consultant checked to make sure the correct products are used and are installed as described in the specifications and drawings. They also see how much work has been completed. At the pilot project, field reviews were completed approximately once per week.

Following each site visit, a site visit report is submitted to the construction manager, contractor, and Strata Council. These reports summarize the observations and recommended or required actions made during a site visit (field review), while the project is under construction. These reports are used by the contractor to address deficiencies, or to confirm work is completed correctly. They are also useful to track the progress of work and are an important communication tool to keep the Owners apprised of the construction progress.

Site modifications are always required as construction progresses due to varying site conditions or situations that could not be anticipated. At the pilot project, a challenge that was encountered was inconsistencies in the existing concrete walls and window openings. Once construction began, it was found that some of the concrete walls were significantly out of plane, and some of the window openings were not aligned vertically and horizontally. To address this situation the site manager arranged for laser guidelines to be installed so that all the trades could complete precise measurements of the actual building configuration. This was particularly important for the window manufacturer and installer as well as the metal panel installer. Each window opening had to be measured to confirm the window size that had to be manufactured (i.e. so that the window would fit in the smallest opening), and to manufacture metal panels that would fit the actual building dimensions.

4.2.3 Communicating with the Owner Groups

The team involved in this retrofit project was large; it included the trades people on site, the residents, owners, various employees of the consulting firm, and the strata management firm. Good communication between all parties was key to achieving a successful retrofit project. There are several important communication tools that were used to achieve this, including consultant reports, meetings, correspondence, and notices.

Consultants issue a variety of formal reports during the pre-construction, construction, and post-construction stages of the project, each of which accomplishes a different task. Several types of reports have already been discussed, including the condition assessment report, the design report, and site visit reports.

In person meetings allow for effective face to face communication and allow participants to better ask questions and discuss options. Often, small meetings can be a useful tool for quickly resolving issues. Larger meetings can be useful for sharing information amongst a large group of people. For all meetings, meeting minutes are an important record of the items that were discussed and any decisions that were made. At the pilot project, weekly meetings were on site with the consultants, site manager and trades. Periodic meetings were also held with the Owners' and occupants group.

Throughout the project, electronic correspondence is used to ask and answer questions, make decisions, and send informational updates. Reports and letters of all types are shared through electronic mail between professionals such as consultants, contractors, and strata management firms. Electronic correspondence was an important tool throughout the pilot project to answer questions, coordinate meetings, and advise of progress.

Regular notices were also sent to owners to keep them informed on a variety of issues, such as the following:

- To advise when work will be beginning in a general area.
- To advise that suite access will be needed.
- To notify residents if there are limitations or changes to the use of the building (for example, temporary water or power disconnection, or limitations on access to balconies).
- To request residents do something to facilitate the work, such as moving furniture, or closing windows.
- To notify residents of safety concerns or issues.
- To notify of upcoming activities that might make large amounts of noise.
- To notify when work is complete.

The intent of these notices is to keep owners informed about what is happening that directly affects them. Notices might be issued by the contractor, strata corporation (typically via a strata manager), or by the consultant. Each notice should clearly state the purpose and provide appropriate contact information for questions.

4.3 Beyond Retrofits

This section covers important considerations following the retrofit project. Maintenance is all the regular activities needed to keep assets in good condition. Maintenance activities were a key consideration of the design of the project. Following the building enclosure retrofit project, the implementation of a maintenance program began. This involved the preparation of a building enclosure maintenance manual to assist the Owners in maintaining the assets that were renewed. A Maintenance Manual consists of instructions, rules and guidelines for performing particular maintenance tasks. This document answers the question “how do we take care of what we own?”

The renewed assets should also be incorporated into the building’s Maintenance Plan. The maintenance plan is a document that states when specific maintenance activities should be completed. This document answers the question “when do we have to do maintenance?” A Maintenance Plan is often presented as a checklist of activities.

Beyond regular maintenance, there may be other items to address following the retrofit project. Changing the building enclosure may impact other building systems, such as the mechanical system, and may create the need for additional work. The consultant should identify and discuss these items with the Owners’ during the pre-construction stages. In the case of the pilot project building, the airtightness improvements will result in less natural ventilation through leaks in the building enclosure. It was found that the mechanical ventilation system did not provide adequate fresh air to some of the suites. This can be addressed in a variety of ways, such as increasing the delivery of outdoor air or by adding continuous exhaust fans or more energy efficient Heat Recover Ventilation (HRV) units. The need to address ventilation, following the enclosure retrofit project, was discussed with the owners during the pre-construction stages; the Owners elected to address this, following the completion of the project, once the specific airflow within and through the building was better known, rather than attempting to address it as part of the building enclosure project.

In addition to ventilation upgrades, mechanical retrofits could have been incorporated into the project, such as replacement of the make-up air unit. In this case, the Owners elected to wait for the completion of the project to address mechanical retrofits so that the indoor air quality could be assessed following the upgrade. For example, if Heat Recovery Ventilators (HRVs) are to be installed in each suite, a much smaller make-up air unit could be purchased to replace the existing unit that is reaching the end of its service life. In other cases, it may make sense to plan for mechanical retrofits at the same time as the enclosure retrofit. An interdisciplinary team of consultants can help assess the merits of these approaches in the planning stages.

A new depreciation report was also completed following the project, as this report is updated once every three years. By completing a full retrofit project with high quality systems, the building performs like a new building, and reduced maintenance and repair costs are shown in the depreciation report. The depreciation report now shows a very positive financial outlook, particularly compared to many existing buildings with work ahead. This could also improve resale value of the units, as the building now has a better financial outlook than many existing buildings that have not been retrofitted.

4.4 Summary of Key Points

The retrofit project at the pilot building was completed on time and within the planned budget. The owners are very happy with the new modern look of the building, the improved thermal comfort in their suites, significantly lower energy bills, and reduced maintenance costs. Throughout the project, a significant time commitment was required from a small group of owners (in this case, the Strata Council) to review and discuss the options, make decisions, and keep track of the construction progress. The larger group of owners and residents had to live with approximately 10 months of construction with inconveniences such as noise, blocked views, odors, and people entering their building and suites. Based on the experiences gained through this project, the following are key points to a successful energy efficient retrofit.

- → The pre-construction and planning stages are key to a successful project. The project should be well-defined, with complete construction documents developed for accurate and competitive pricing. Incomplete planning can lead to extras and cost overruns in the construction phase.
- → An energy study should be completed early in the design and planning stages for the project. This should include identifying all possible energy efficiency measures that could be incorporated into the project and whole building energy modeling to assess the potential energy savings.
- → Owners can live in their suites through the retrofit and it is possible to mitigate the intrusion to residents' daily life by keeping them aware of activities and operations, providing answers and feedback to questions and concerns, and designing projects so that work from the interior of the building is reduced. The impacts and inconveniences to the owners during construction will vary from project to project. At the pilot project, the owners experienced limited views due to scaffolding for approximately 10 months and sporadic noise during daytime hours (while work was done near their suite). The inconveniences were mitigated by only working during daytime hours and limiting the need for suite access to

one day for window installation, plus a few hours on a second day for interior repairs.

- Communication is critical to a successful project. Enclosure retrofit projects can involve numerous people and organizations, and good communication between owners, consultants, trades, and property managers is essential.
- Field modifications will always be required as varying site conditions are encountered through the construction process. Anticipation of potential refinements to accommodate these conditions and effective communication between all parties to resolve these conditions quickly and thoroughly is important.
- Following the retrofit project, maintenance planning should be undertaken to ensure the performance and expected service life of the new components is achieved. Other issues may need to be addressed, such as ventilation. These items can be planned for as part of the retrofit project, or can be addressed separately after project completion, but should be discussed with the owners during the planning stages. An interdisciplinary team is key to consider long term needs and how a project can be designed to facilitate these needs.

5 Airflow Monitoring and Analysis Post Enclosure Retrofit

This section describes the airflow and airtightness testing and measurements that were performed as part of this project.

5.1 Objective and Approach

The airflow testing component of this project was implemented to quantify the airtightness of interior compartmentalizing elements and of the exterior building enclosure, pre- and post-retrofit. Compartmentalizing elements, typically a combination of interior walls and doors, separate the interior of the building into zones (e.g. individual suites), which are relatively separated from each other with respect to airflow. Quantifying building airtightness characteristics will allow for analysis of how absolute airtightness, relative airtightness, and changes in airtightness can affect airflow and energy use in the case study multi-unit residential building (MURB).

Testing was also conducted to quantify airflow characteristics of the make-up air unit (MAU) and of bathroom exhaust fans in each suite. This testing allows for analysis of the effectiveness and efficiency of the ventilation strategy for the retrofit building and of the potential contribution to ducts without operating fans to air leakage.

The methodologies used for each type of testing for this phase of the project are described in the subsequent sections.

5.1.1 Bathroom Fan Testing Methodology

To test the bathroom fans, a single point was measured at a pressure difference of 25, 50, 75, and 100 Pa using the Retrotec Inc. (Retrotec) DU200 DucTester, flex-duct, and flow hood as shown in Figure 5.1. This apparatus allows for the application of a pressure difference across the fan and duct and the measurement of the airflow rate using the calibrated fan. This testing was initially conducted as part of building investigations not part of the scope of this project; however, the data collected from the tests that is applicable to the analysis of the enclosure airtightness testing results is provided in this report.

Figure 5.1 Retrotec DucTester being used to test a bathroom fan.

5.1.2 Make-Up Air Unit Testing Methodology

A similar apparatus to that used for the bathroom fan measurements was used to measure the intake airflow rate of the make-up air unit (MAU). Since the flow rate of the MAU is much higher than that of a bathroom fan, a larger Retrotec fan typically used for airtightness testing was used to measure the flow rate. It was connected to the MAU intake with a custom-made flex duct system as shown in Figure 5.2.

Figure 5.2 Custom made MAU testing apparatus with green flex-duct to attach Retrotec fan to the MAU intake.

With the MAU on, the Retrotec fan was then manually adjusted to compensate for the flow resistance added by the testing apparatus. Once compensated, the calibrated Retrotec fan was used to measure the flow rate through the MAU. As some fluctuation in the flow rate and back pressure was observed due to a slight breeze and possible changes in building operation, multiple (over 10) readings of the flow rate were taken and a correlation developed between flow rate and the back pressure added by the testing apparatus to determine the actual flow rate of the MAU.

The MAU supply flow rate to each corridor was also measured using a balometer, and a smoke pencil was used to confirm the flow direction as shown in Figure 5.3 and Figure 5.4.

Figure 5.3 Balometer being used to measure airflow supply rate to a corridor from the MAU.

Figure 5.4 A smoke pencil being used to check the airflow direction out of the MAU grille with the MAU off showing smoke flowing back into the MAU duct.

5.1.3 Suite and Floor Airtightness Testing Methodology

Unlike single detached houses, the interior space of MURBs is typically relatively compartmentalized which poses unique challenges with respect to airtightness testing. To fully understand the airtightness characteristics of a MURB, it is necessary to measure the airtightness of the exterior enclosure as well as the compartmentalizing elements which separate the suite from adjacent suites on the same floor, from suites above and below, and from the corridor. To measure each of these suites’ airtightness separately, a pressure neutralized fan depressurization/pressurization technique is necessary. This method is not described in any standardized test procedure, but the general approach is described in Finch et al (2009) and involves using additional test fans to sequentially neutralize pressure differences across compartmentalizing elements such that airflow through these elements can be eliminated.

Airtightness testing was conducted of the suites on the primary testing floors (floors 3 and 11) of the retrofit building using the pressure neutralized fan depressurization/pressurization technique. This method was used to determine the airtightness of the following:

- Suites on Floors 3 and 11: Pre- and post-rehabilitation airtightness of the floors, ceilings, partition walls to neighbouring suites on right, partition walls to neighbouring suite on left, walls to corridor, and the exterior enclosure
- Suites on Floors 1 and 13: Pre- and post-rehabilitation airtightness of the exterior enclosure
- Floor 1: Pre- and post-rehabilitation exterior enclosure
- Floor 13: Post-rehabilitation exterior enclosure

Figure 5.5 shows a schematic of the airtightness testing layout for pressurizing an -01 suite while pressure equalizing the floor above. Schematics for each step of testing an -01 suite are provided in Appendix E, and these steps are similar for -02 and -03 type suites. (-01, -02, and -03 suites refer to suites ending in these values respectively. For example, -01 suites would include 101, 201, 301, 401, etc.)

Figure 5.5 Airtightness testing layout for pressurization of an -01 suite while equalizing the floor above showing the direction or airflow between zones either through open doors to allow for free movement of air, or as forced into zones by the testing fans.

Pre-retrofit testing was generally performed with pressurization and depressurization to 10, 30, 50, and 60 Pa with readings taken, using a computer and associated software, as frequently as the equipment would allow (minimum 1 reading per second) for 10 seconds. Measurement of the bias pressure was taken before and after testing for 30 seconds. Post-retrofit testing followed the same procedure except that pressurization and depressurization was conducted at 20, 30, 50, and 60 Pa. The change to the lowest pressure was made because during analysis of the pre-retrofit tests it was noted that frequently the 10 Pa measurements displayed the most error, thus the pressure magnitude was increased with the aim of decreasing the error for the post-retrofit tests. Additionally, measurements were generally taken for 20 seconds for the post-retrofit testing because the bias pressure was observed to be more variable and the longer measurement period is intended to compensate. General images of the testing equipment and set-up are provided in Figure 5.6 and Figure 5.7.

Figure 5.6 Two fan-doors used for airtightness testing. The soft-door with fan installed in the entrance door of a test suite (right door) was used for the test zones as they are more airtight than the hard door units (left door) which were used for the pressure equalized zones where airtightness of the door fan is not as important. Tape was used to seal around the door when necessary.

Figure 5.7 Four Retrotec DM-2 gauges used for control of the fans and pressure measurements during the testing. The gauge for the test zone is connected to a laptop running Retrotec's FanTestic airtightness testing software to record data points.

Minor variations from this procedure occurred during testing to aid in maintaining pressure differences either at the lowest or highest pressure settings, to maintain fan operation within the available maximum fan or electrical power capacity, or due to tester error; however, these variations are not anticipated to significantly impact the quality or validity of the test results.

5.1.4 Corridor Airtightness Testing Methodology and Procedure

The airtightness testing methodology for the corridors is similar to that for the suites and floors. Pressure equalization was used to prevent and measure leakage to the floors above and below; then various openings from the corridor to adjacent zones were sequentially sealed and the airflow rates measured to determine the airflow associated with each opening. Schematics of the testing layout for each of the test steps are provided in Appendix E. Sealing of a typical suite door and of elevator doors are shown in Figure 5.8 and Figure 5.9.

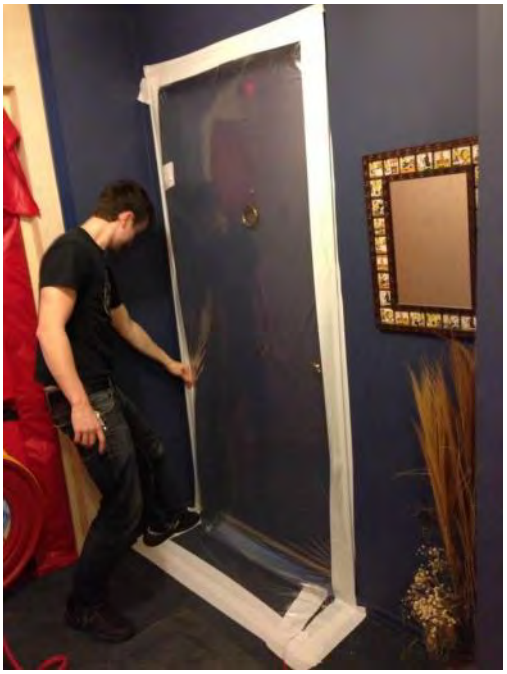


Figure 5.8 Typical suite entrance door sealed with a polyethylene sheet and tape to prevent airflow. By measuring the corridor air leakage with and without each this door sealed, the airflow rate through the door to the suite can be determined.

Figure 5.9 Typical sealing of elevator doors to eliminate airflow through the elevator doors to the shaft. A significant amount of corridor air leakage was found to be to the elevator shaft through these doors.

The potential airflow boundaries examined were:

- → Suite entrance doors (3 per floor)
- → Stairwell door
- → Elevator doors
- → Garbage chute room door
- → Electrical closet door
- → Floor above
- → Floor below

5.1.5 Airtightness Test Method Considerations

Pressure equalized airtightness testing allows for the measurement of airtightness of interior compartmentalizing elements and for the measurement of exterior enclosure airtightness in relatively compartmentalized buildings such as typical multi-unit residential buildings. The primary potential for errors in this method is in zone airflow bypasses. That is, when air can flow from one zone to another in such a way that it bypasses the pressure equalization. This can lead to errors in the air leakage measurements. Based on assessment of the retrofit building, this is not expected to create significant error for the suite airtightness testing as flow paths between floors, including vertical ducts, are limited. The potential for error of this type for the airtightness testing of the corridors is slightly higher as airflow can travel in the elevator shaft past the floors above and below. This potential source of error is discussed further in Section 5.4.1 and Section 5.4.3.

It is important to note that airtightness testing is performed at artificial pressure differentials that are significantly higher than typical in-service pressure differentials. Thus, while airtightness testing provides a good measurement of airflow path characteristics, when interpreting the data it is important to consider the actual in-service pressures, which will drive airflow.

5.2 Bathroom Fan Testing Results

The results of the bathroom fan testing are provided in Table 5.1. The average normalized airflow rate at 75 Pa for the sum of the two bathroom fans in each suite is 0.10 cfm/ft^2. The results of this testing are most relevant when discussed in conjunction with the suite airtightness testing results; consequently, discussion of the bathroom fan testing results is provided in Section 5.4.

TABLE 5.1 BATHROOM FAN TESTING RESULTS

Zone Type	Zone	Adjacent Zone	NAR$_{50}$ [cfm/ft^2]	NAR$_{75}$ [cfm/ft^2]
Typical Suite	**Suite 301**	**Main Bathroom**	0.07	0.08
		Ensuite Bathroom	0.07	0.09
		Sum of Bathroom Fans	0.13	0.17
	Suite 302	**Main Bathroom**	0.06	0.09
		Ensuite Bathroom	0.07	0.08
		Sum of Bathroom Fans	0.14	0.18
	Suite 303	**Main Bathroom**	0.11	0.13
		Ensuite Bathroom	0.06	0.08
		Sum of Bathroom Fans	0.117	0.22
	Suite 1101	**Main Bathroom**	0.06	0.08
		Ensuite Bathroom	0.05	0.06
		Sum of Bathroom Fans	0.11	0.14
	Suite 1102	**Main Bathroom**	0.06	0.07
		Ensuite Bathroom	0.05	0.07
		Sum of Bathroom Fans	0.11	0.14
	Suite 1103	**Main Bathroom**	0.05	0.07
		Ensuite Bathroom	0.06	0.08
		Sum of Bathroom Fans	0.11	0.15
1st Floor Suites	**Suite 101**	**Main Bathroom**	0.03	0.03
		Ensuite Bathroom	0.02	0.03
		Sum of Bathroom Fans	0.05	0.06
	Suite 102	**Main Bathroom**	0.03	0.04
		Ensuite Bathroom	0.02	0.03
		Sum of Bathroom Fans	0.05	0.07
13th Floor Suites	**Suite 1301**	**Main Bathroom**	0.02	0.02
		Ensuite Bathroom	0.02	0.02
		Sum of Bathroom Fans	0.04	0.05
	Suite 1302	**Main Bathroom**	0.02	0.03
		Ensuite Bathroom	0.02	0.03
		Sum of Bathroom Fans	0.05	0.06

*NAR$_X$ is the Normalized Airflow Rate at “x” Pa pressure differential.

5.3 Make-Up Air Unit Testing Results

Fifteen readings of the MAU flow rate and back pressure (resistance added by the testing apparatus) were made and the results are shown in Figure 5.10. (On the graph, negative back pressure means that the flow apparatus is restricting flow and a positive back pressure means that the flow apparatus is aiding flow.) A line was fit to these points and the flow rate (when there is no back pressure) was determined to be approximately 2900 cfm. Note that the range in flow rates is small in the context of the overall flow rate.

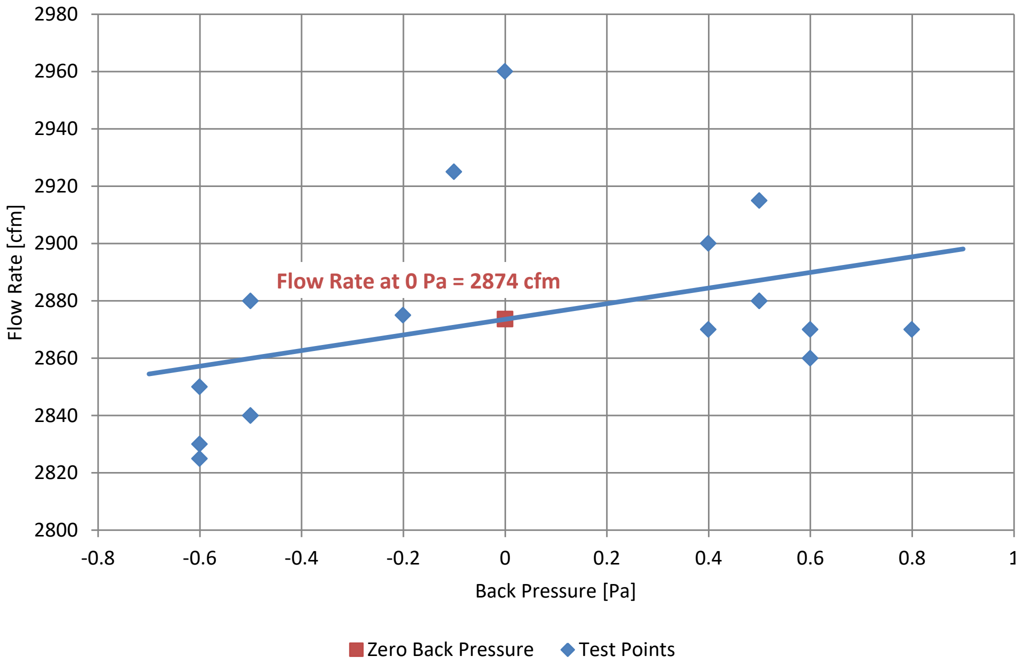


Figure 5.10 Graph of MAU Flow Rate versus back pressure showing the flow rate at no back pressure

The flow rate supplied to each floor with the MAU on was measured three separate times. The first was measured pre-retrofit during a period of 21˚C temperature, the second was post-retrofit during a period of 6˚C average temperature, and the third was during a period of 16˚C average temperature. The results of these measurements are shown in Figure 5.11.

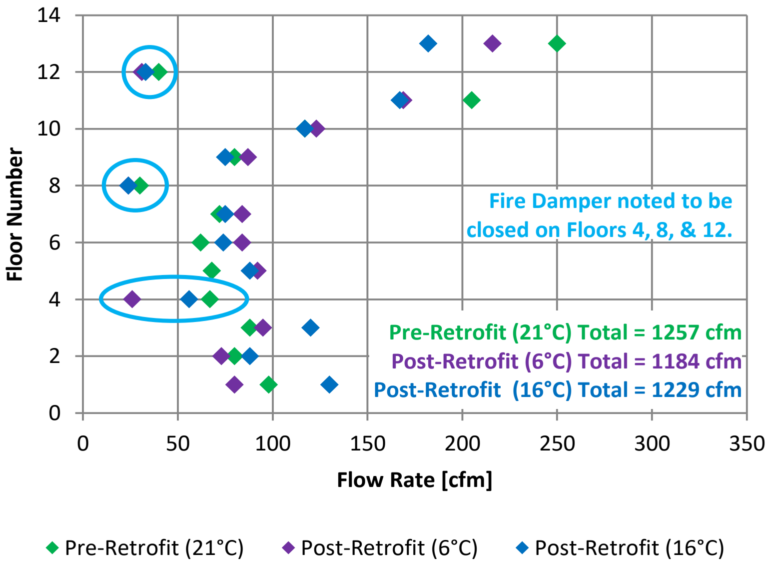


Figure 5.11 Graph of MAU supply flow rate to each corridor.

After these tests, the fire dampers on 4th, 8th, and 12th floors were noted to be closed. These dampers are intended to be open during normal operation, and having them unintentionally closed can significantly restrict the supply of air to those corridors. The effect of these closed dampers is discussed further in subsequent reports with respect to distribution of ventilation air. The sum of the flow rates supplied to the corridors for the post-retrofit case (when the MAU intake flow rate was measured) is 1184 cfm, which suggests a loss of 1690 cfm, or 59%, from the intake MAU flow rate.

5.4 Airtightness Testing Results

Airtightness testing was completed for the exterior enclosure, interior compartmentalizing elements, and corridors. The results of this testing are provided in the subsequent sections and a full table of testing results is provided in Appendix F.

5.4.1 Suite and Floor Exterior Enclosure

The exterior enclosure airtightness was measured pre- and post-retrofit as part of the pressure neutralized fan depressurization/pressurization procedure and the results for the suites are shown in Figure 5.12. The graph also shows the air leakage attributable to the bathroom fans based on the bathroom fans tests.

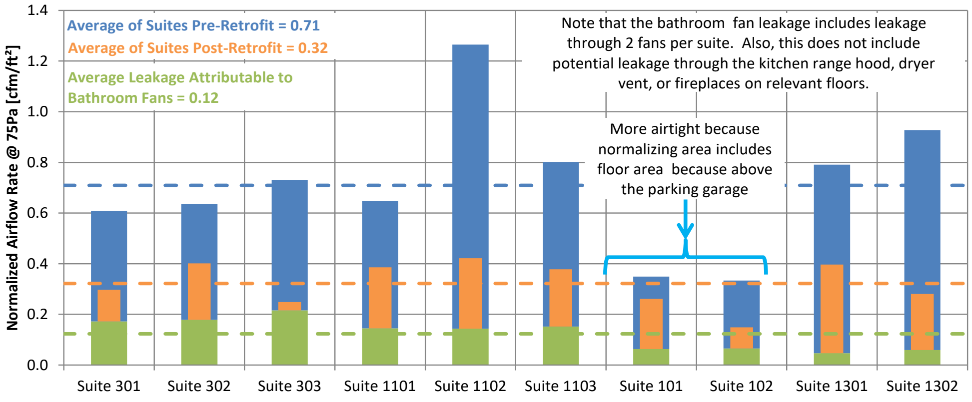


Figure 5.12 Graph showing results of enclosure airtightness testing of suites

Since a certain amount of the air leakage for each suite is attributable to the bathroom fans, this amount was removed from the total to obtain a better indication of the exterior enclosure only air leakage and these results are shown in Figure 5.13. It is important to note that these results do not account for leakage that likely occurs through ducting for kitchen range hoods and dryer vents as the airflow rate through these potential leakage locations was not measured separately. They also do not account for leakage through venting for fireplaces which are installed in suites on the 9th, 10th, 11th, 12th, and 13th floors. Leakage through these vents results in a limit on building enclosure airtightness.

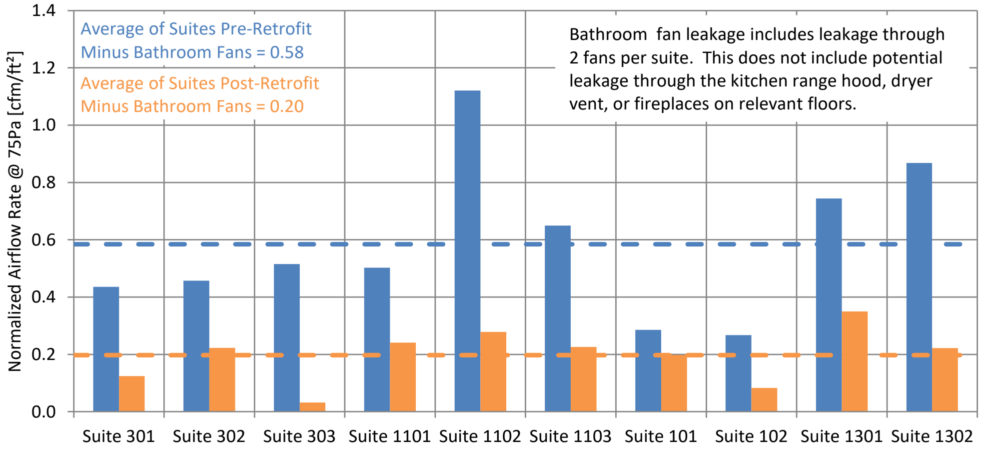


Figure 5.13 Graph showing results of enclosure airtightness testing of suites minus leakage attributable to bathroom fans.

As stated on the graphs, the average building enclosure airtightness pre- and post-retrofit is 0.71 cfm/ft² and 0.32 cfm/ft² respectively at 75 Pa, which is an improvement of 55%. When removing the amount of leakage attributable to the bathroom fans, the average airtightness of the building enclosure pre- and post-retrofit is 0.58 cfm/ft² and 0.20 cfm/ft² respectively, which is an improvement of 66%. These values are illustrated graphically in Figure 5.14.

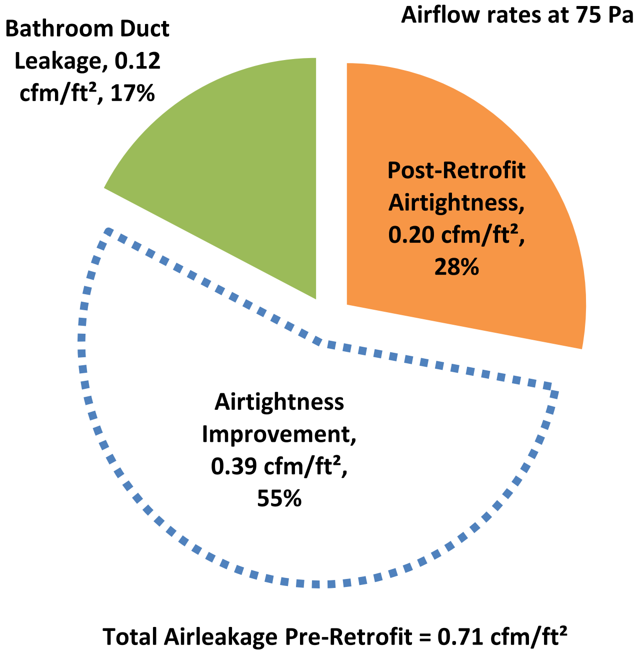


Figure 5.14 Chart showing airtightness improvement of exterior enclosure as a result of the retrofit.

Enclosure airtightness testing was also performed for entire floors at once on the 1st and 13th floors (bottom floor and top floor) since these floors are atypical. The normalized airflow rates at 75 Pa for the 1st floor pre- and post-retrofit respectively are 0.75 cfm/ft² and 0.47 cfm/ft², which is an improvement of 37%. Airtightness of the 13th floor was added during post-retrofit testing and is 1.03 cfm/ft² at 75 Pa.

The airtightness of the exterior enclosure of the corridors (and in the case of the first floor entranceway) were determined through subtraction of the suite airflow from the whole floor airflows for the 1st and 13th floors. The normalized airflow rates at 75 Pa for the 1st floor corridor (entranceway) pre- and post-retrofit respectively are 3.15 cfm/ft² and 1.97 cfm/ft², which is an improvement of 37%. Airtightness of the 13th floor corridor post-retrofit is 22.97 cfm/ft² at 75 Pa.

The airtightness values determined for the whole floor test and in particular for the corridors likely include a significant amount of airflow that occurred through the elevator shaft and bypasses pressure equalization measures. This would cause these numbers to be artificially higher (leakier) than is actually the case. That said, the higher leakage rate noted for the 1st and 13th floors are expected due to additional leakage at the bottom and top of the elevator to the exterior, leakage through the entranceway doors, and leakage through mechanical and plumbing penetrations at the 13th floor to mechanical rooms on the roof.

5.4.2 Suite Compartmentalizing Elements

The airtightness of suite compartmentalizing elements was measured as part of the suite pressure neutralized fan depressurization/pressurization testing and flow curves were developed as shown in Figure 5.15.

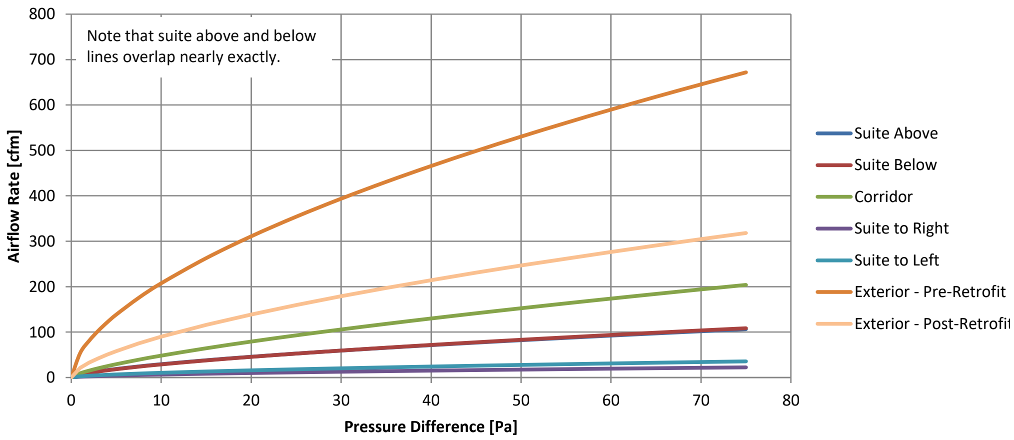


Figure 5.15 Graph showing flow curves for compartmentalizing elements and the exterior enclosure for average of typical suites. Note that the "Suite Above" and "Suite Below" curves overlap nearly exactly.

This same data is presented in a pie-chart in Figure 5.16 to illustrate the relative quantity of flow associated with each airflow boundary.

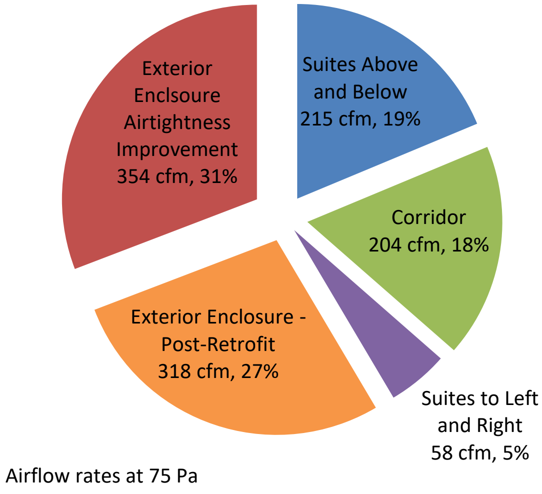


Figure 5.16 Chart showing proportion of airflow associated with each airflow boundary for average of typical suites.

The airflow data was then normalized using the area associated with each airflow boundary to illustrate the relative airtightness of each boundary and this is shown in Figure 5.17. It is important to note the difference between airtightness and actual airflow (i.e. a very large surface that is very airtight may allow more flow than a very small surface that is not very airtight).

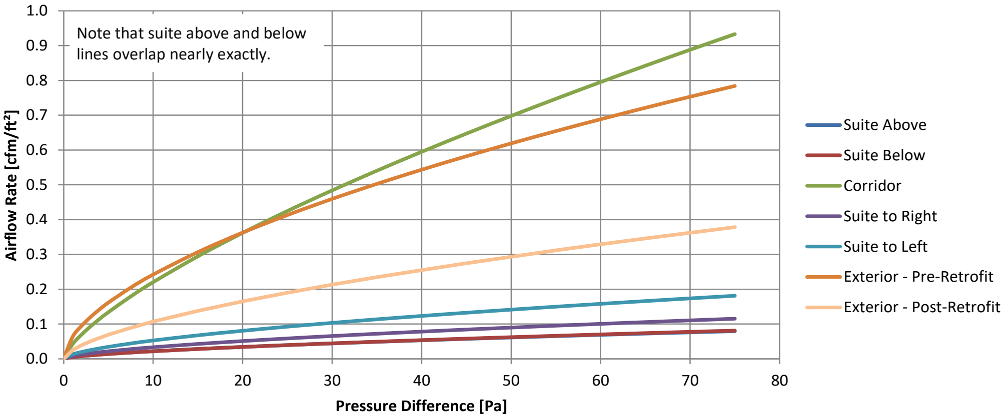


Figure 5.17 Graph showing normalized flow curves for compartmentalizing elements and the exterior enclosure of average of typical suites. Note that the "Suite Above" and "Suite Below" curves overlap nearly exactly.

5.4.3 Corridor Airtightness Testing

The airtightness of various components of corridors on the 3rd, 9th, and 11th floors were tested and the average of the results is shown in Figure 5.18.

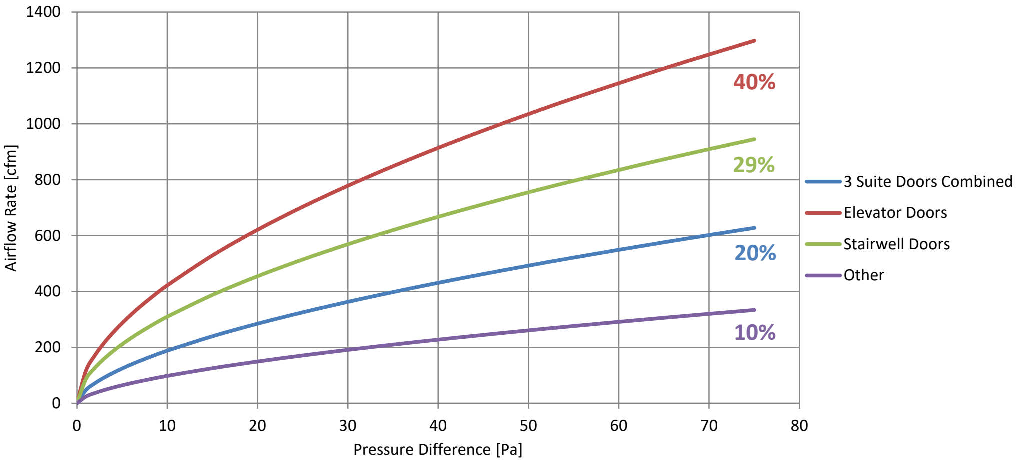
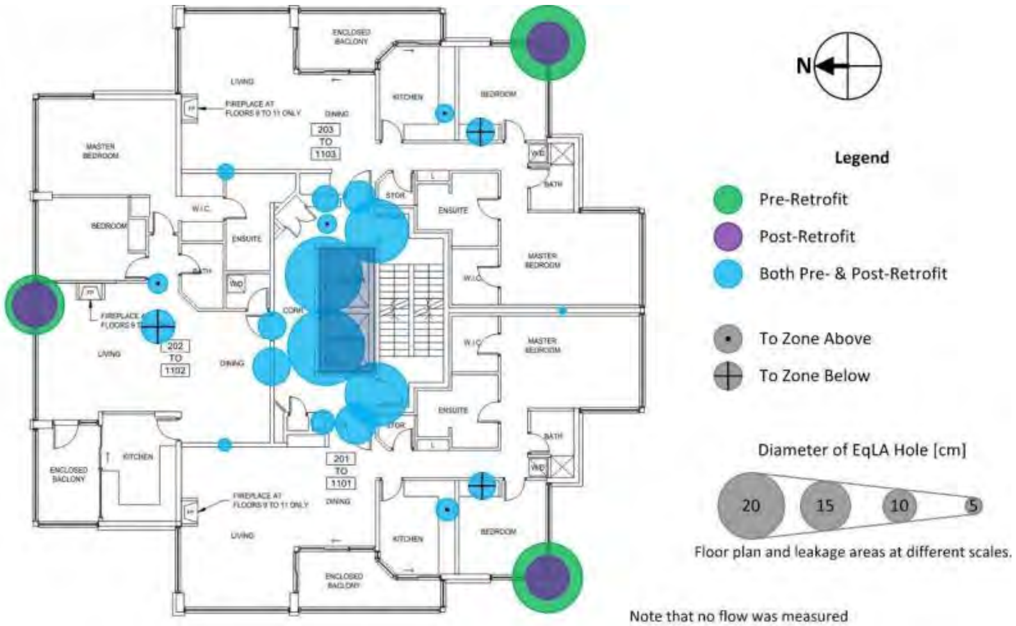


Figure 5.18 Graph showing airflow rates versus pressure differences of various components of the corridor compartmentalizing elements

Airflow denoted as “other” includes airflow to the floors above and below, to the electrical closet, and to the garbage chute room on each floor. There is the potential for double counting of leakage within these (i.e. air could flow through the electrical room to the floor above) and the quantities of flow are relatively small, so they have been put together to provide a better indication of relative airflow quantities. “Other” also includes airflow to the suites that travels unintentionally through the walls instead of under the entrance door. Notably, when the corridor is pressurized relative to adjacent zones, only approximately 20% of the air flows into the suites through the entrance doors.

There is also the potential for some bypass airflow in this test. Airflow through the elevator doors may be affected by pressure equalization of the floors above and below. Based on measurements to check the pressure differential across the elevator doors during testing, it is not felt that this effect is significant; however, this potential for error makes the corridor airtightness testing results more indicative than exact.

To provide a visual summary of the airtightness testing results of the corridors and the suites on the two primary test floors, Floor 3 and Floor 11, the equivalent leakage area has been calculated for each section of exterior enclosure and interior compartmentalizing elements; these are shown graphically in Figure 5.19 and Figure 5.20.



Note that no flow was measured from corridor to zone below.

Figure 5.19 Floor plan of Floor 3 showing the equivalent leakage areas of the measured suite exterior enclosures and interior compartmentalizing elements (Ricketts, 2013)

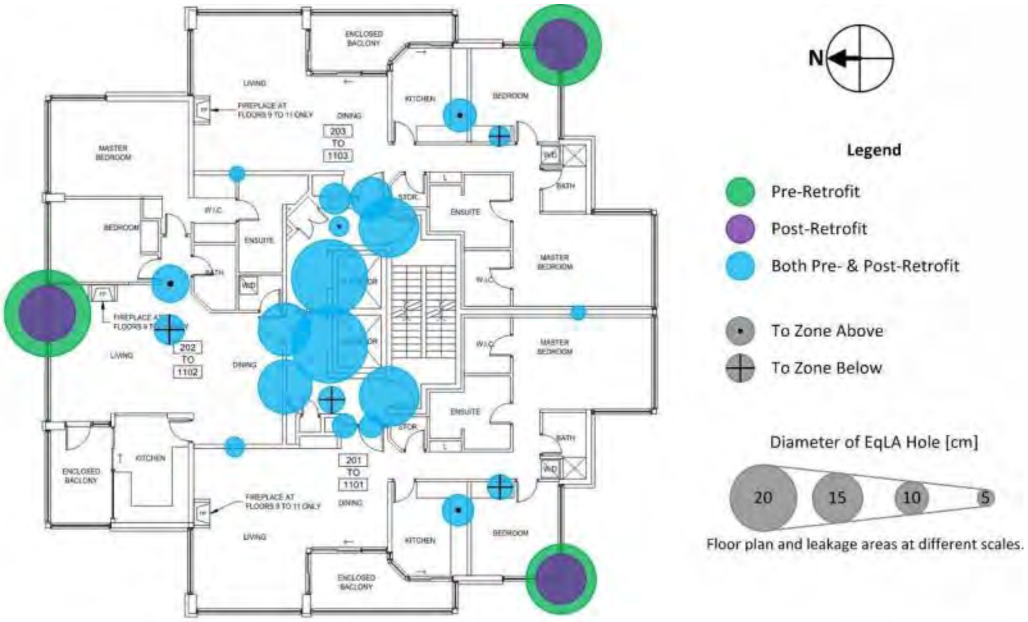


Figure 5.20 Floor plan of Floor 11 showing the equivalent leakage areas of the measured suite exterior enclosures and interior compartmentalizing elements (Ricketts, 2013)

6 Enclosure Retrofit Energy Utilization Impacts

This chapter provides the energy measurement and verification results following a one year monitoring period at the pilot building. The primary goal of this study is to measure the energy savings resulting from the building enclosure retrofit project, based on one year of metered gas and electricity data. Per the Measurement and Verification (M&V) plan created in the design stages (see Appendix B), the M&V methodology follows the International Performance Measurement and Verification Protocol (IPMVP) Option D – Calibrated Simulation.

This chapter is organized into the following sections:

- Section 6.1 Measurement and Verification Approach provides a brief overview of the approach that was outlined in the M&V plan.
- Section 6.2 Post Retrofit Metered Energy Consumption Data presents the metered data without any adjustments, and with weather normalization.
- Section 6.3 Energy Modeling Calibration Process describes the process of comparing metered data to modeled results and calibrating the model.
- Section 6.4 Total Measured Energy Savings through Calibrated Simulation summarizes the measured energy savings resulting from the retrofit.
- Section 6.5 Energy Savings of Individual ECMs presents the energy savings and financial analysis related to the windows ECM only.

Additional analysis is presented in Appendix G to gain further insight into the metered energy results, and to compare the measured energy savings to the savings that were predicted by the energy model.

6.1 Measurement and Verification Approach

Measurement and verification was performed for a period of one year (January to December 2013) following the completion of the retrofit. The IPMVP approach selected to perform M&V is Option D[8] – Calibrated Simulation, since this method allows for a better estimation of savings, attributable to particular energy end-uses, than an analysis of total building energy consumption. The measurement boundary is defined as the whole building energy consumption, including both gas and electricity. Using this method, an energy simulation is calibrated to the post-retrofit utility bills to determine energy savings. The M&V plan created during the design stages of the project is provided in Appendix B.

Metered energy consumption was obtained from the electricity and gas utilities, BC Hydro, and FortisBC. In the M&V plan, weather was identified as an independent variable that is expected to change regularly and impact energy use at the building. As such, the metered data was weather normalized following the same procedure as the pre-retrofit data, known as a routine adjustment.

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[8] Additional details on the four IPMVP options can be found in the IPMVP (Volume I EVO 10000-1:2012) Section 4.6 (page 17).

Other independent variables that may impact energy consumption include occupancy changes and occupant behavior changes. Tracking and measuring changes in occupant behaviour are beyond the scope of this project, but will be considered qualitatively in the M&V analysis. It is worth noting that the building is primarily occupied by mature residents without kids, some of whom are retired. Some of the residents take extended vacations away from home, particularly in the winter. Suites are all two bedroom units.

One possible non-routine adjustment was identified in the M&V plan; a new domestic hot water (DHW) boiler was installed part way through the retrofit work. The new unit that was installed has the same nominal efficiency as the previous unit, and so no adjustments were made to the modeling or data as a result of this change.

Once the one year period of data had been collected, the post-retrofit energy model was compared to the metered data and calibrated such that the model and metered data align. Section 6.2 provides the M&V results, showing the actual metered energy savings resulting from the retrofit.

The following points summarize key aspects of the M&V approach, as defined in the plan:

- Reporting Period: One year, January through December 2013.
- Energy data and independent variables: Energy data was obtained from BC Hydro and FortisBC, from the utility meters. Reporting period Heating Degree Day (HDD) values from Environment Canada were used to normalize the energy consumption to typical weather data (used in energy simulations). The M&V plan stated that weather data from the project site would be used; this was not done since the site weather station was only operating during and following the retrofit. As such, Environment Canada data was used for both pre- and post-retrofit analysis for consistency.
- Corrections made to observed data: The observed data was weather-normalized following the same procedure described in previous chapters for this project.
- Baseline non-routine adjustments: One possible non-routine adjustment was anticipated, being the DHW boiler that was replaced. However, since the new boiler has the same nominal efficiency as the existing boiler, no adjustments were made.

6.2 Post-Retrofit Metered Energy Consumption Data

Metered electricity and gas consumption was provided by BC Hydro and FortisBC. The data was weather normalized, following the same procedure used for the pre-retrofit energy consumption data described in Section 2. Figure 6.1 and Figure 6.2 show the metered gas and electricity consumption for the measurement period, as well as the consumption after weather normalizing. Actual consumption values as well as actual and average HDD values are provided in Appendix G.

The total metered consumption is 883 MWh, an Energy Use Intensity (EUI) of 176 kWh/m^2 without weather normalizing. The total weather normalized consumption is 918 MWh, an EUI of 181 kWh/m^2. The normalized value is higher than the metered data (before normalizing) as the measurement period had fewer heating degree days than the typical weather year.

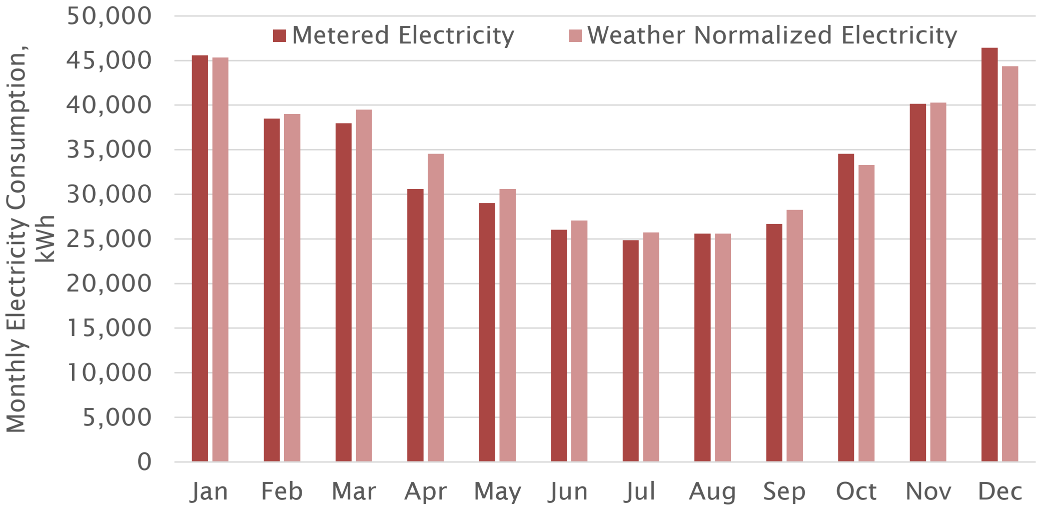

Figure 6.1 Monthly electricity consumption during the post-retrofit measurement period, with and without weather normalizing.

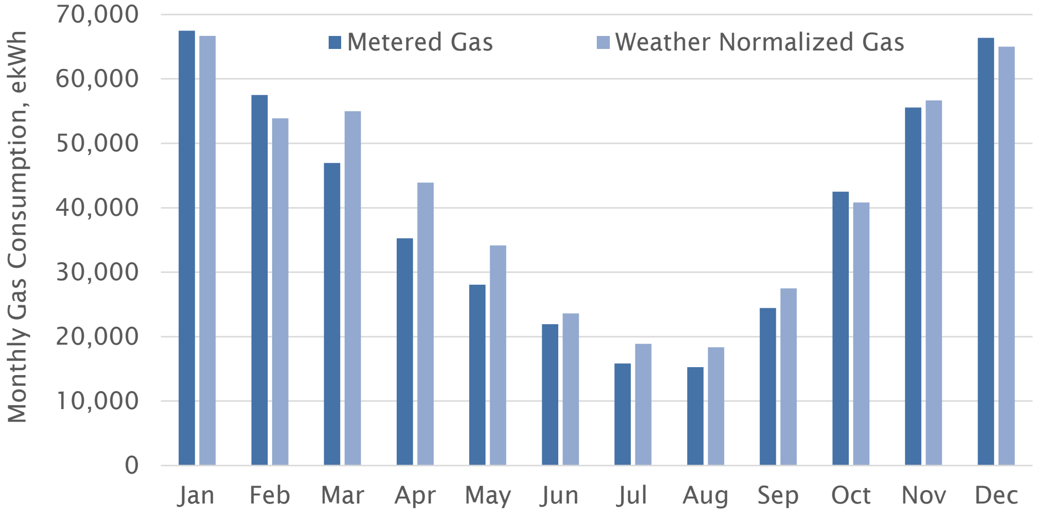

Figure 6.2 Monthly gas consumption during the post-retrofit measurement period, with and without weather normalizing.

6.3 Energy Modeling Calibration Process

The model calibration process was an important step in the research study as it helps to understand how effective and accurate the energy modeling tool was at predicting energy savings for the retrofit project. This section details the calibration process.

IPMVP Option D uses whole building energy modeling, where an energy simulation of the building is calibrated to align with metered consumption data. Energy modeling was performed using the program DesignBuilder, an interface for the EnergyPlus engine.

Gas Consumption

Calibrating gas energy consumption was done by comparing the modeled post-retrofit consumption results to the weather-normalized metered consumption. Calibrations are informed by examining summer consumption versus seasonal (winter) consumption.

Summer consumption typically informs the baseline, in this case domestic hot water consumption, as there should be little or no heating energy during this period. Seasonal consumption informs heating energy (make-up air and fireplaces in this case).

Comparing the modeled and metered gas consumption data showed higher metered gas consumption in the summer months, and lower metered gas consumption in the winter months. As such, two input changes were required to calibrate gas.

- → Increase summer gas consumption. Following the assumption that there is no fireplace or make-up air heating energy consumption in the summer, this would require an increase in DHW consumption. Since the increase is relatively low (7% and 8% difference in July and August, respectively), it could be attributed to inaccuracies in the weather normalizing and modeling processes. To calibrate the model so that modeled consumption closely reflects metered data, the DHW consumption rate was increased.
- → Decrease gas consumption in winter and shoulder months. This is likely due to a reduction in fireplace use following the retrofit, consistent with discussions with the owners that they use fireplaces less often. This change was not modeled in the original design model as it was dependant on occupant behaviour. To calibrate the model, the monthly fireplace use schedule was adjusted month-by-month to calibrate the gas data to the metered data.

Figure 6.3 shows the metered (weather normalized), uncalibrated model, and calibrated model gas consumption. Following the calibration, the modeled monthly consumption is within 2% difference of the metered data. Gas consumption by end-use will be further investigated once sub-metered gas data is available.

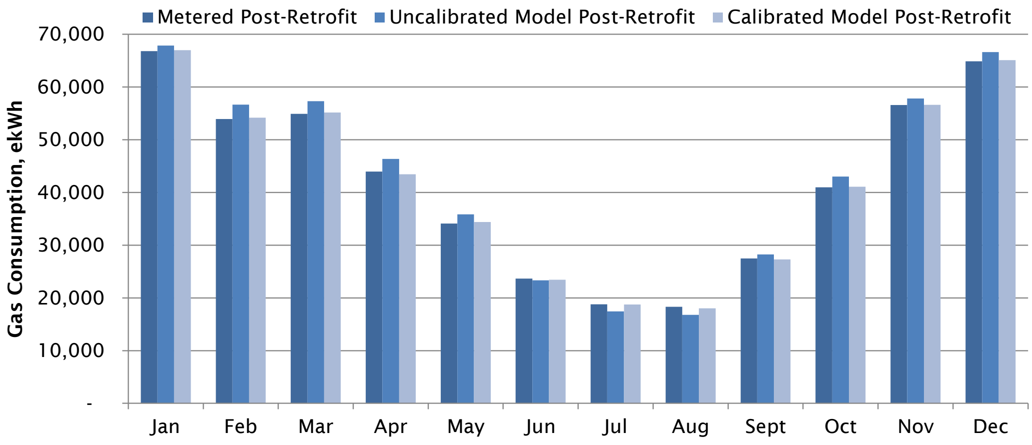

Figure 6.3 Metered, uncalibrated model and calibrated model post-retrofit gas consumption (DHW, fireplaces, make-up air heating), ekWh.

Electricity Consumption

As with the gas calibration, electricity consumption is also calibrated by examining baseline (summer) versus seasonal (heating) consumption.

Comparing the post-retrofit modeled and metered electricity consumption data showed lower metered electricity consumption in the summer months and higher metered electricity consumption in the winter months.

The data shows that summer electricity consumption decreased following the retrofit. Summer electricity is typically attributed to lighting and miscellaneous loads, following the assumption that there is little to no heating energy in the summer. As such, a standard approach to calibrate the model would be to decrease lighting or plug loads so that summer consumption aligns with the metered data. However, there were no known changes in baseline electricity consumption that could explain the metered decrease in summer electricity following the retrofit. It is possible that prior to the retrofit there was some electric baseboard heating energy in the summer, possibly due to owners who kept their thermostat setpoints high throughout the year. Thermostats set as high as 26˚C were observed prior to and during the retrofit period.

Pre-retrofit summer electrical baseboard heating energy would explain the post-retrofit metered decrease in summer electricity consumption. It is not possible to know with certainty the change in energy consumption by end-use without extensive sub-metering that is beyond the scope of this project. However, to test this "summer heating" theory, the pre-retrofit model was re-calibrated with a higher temperature setpoint (23.5˚C). This reflects the fact that some owners keep their thermostats at higher setpoints, and results in summer heating energy in the model. To calibrate the model, miscellaneous electrical (plug) loads were decreased. In addition, a heating load was applied to all suite areas to simulate heat from the make-up air unit that enters the suites in the pre-retrofit model.

Once these changes were applied to the pre-retrofit model, the post-retrofit model much more closely reflected the metered post-retrofit consumption. To calibrate the post-retrofit model, the make-up air heat load was removed. After this change, the post-retrofit model was within 5% difference monthly of the metered energy consumption and less than 1% difference annually. This calibration is noteworthy as it may reflect changing airflow patterns within the building following the retrofit; this should be further investigated together with the airflow testing results.

Figure 6.4 shows the metered (weather normalized), uncalibrated model, and calibrated model electricity consumption, using the revised pre-retrofit model to develop the post-retrofit model.

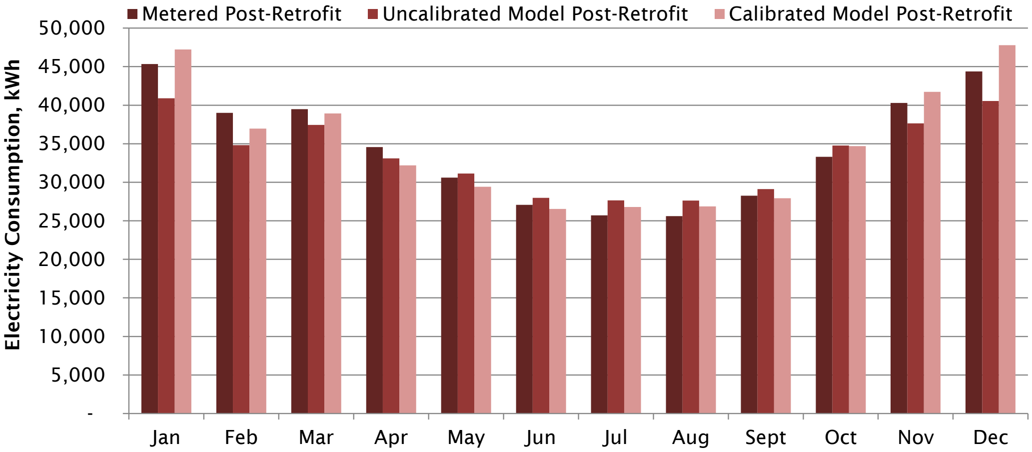

Figure 6.4 Metered, uncalibrated model and calibrated model post-retrofit electricity consumption, kWh.

Table 6.1 shows the energy savings predicted by the original model (including a calibrated post-retrofit model) and the revised models that include pre-retrofit summer electric baseboard heating.

With both modeling approaches, the electricity savings were lower than predicted. In the first approach, the electric baseboard savings are understated since the summer electricity reduction is attributed to other end-uses (e.g. reduction in plug load energy), though total electricity savings are close to modeled savings. In the second (revised) models, all electricity savings are attributed to the electric baseboards and the measured electric baseboard savings of 63% is closer to modeled savings of 68%. The difference between the total savings using the two methods is likely due to modeling error.

The key result in this exercise is the total energy savings, which was determined through building-level metering and is therefore reliably known. The variability in energy consumption or savings by end-use (i.e. electric baseboard energy savings) is estimated through modeling, since it is not feasible to sub-meter all electric baseboards. This value is an estimation and is influenced by several factors, in particular occupant behaviour. Other possible explanations for the decrease in summer electricity could be owners using their lights less following the retrofit, or owners using air conditioning units less following the retrofit (the replacement windows have a lower solar heat gain coefficient). An occupant survey should be conducted to further investigate these effects.

TABLE 6.1 UNCALIBRATED AND CALIBRATED MODEL ENERGY SAVINGS COMPARED TO PRE-RETROFIT MODEL, EKWH SAVINGS AND % SAVINGS

	Electric Baseboard Heating	Total Electricity	Total Gas	Total Energy
Original Model (minimal summer electric baseboard heating)				
Uncalibrated Model (Predicted) Savings	213,000 [89%]	213,000 [37%]	0 [0%]	213,000 [20%]
Calibrated Model Savings	135,200 [57%]	187,700 [32%]	12,900 [2%]	200,600 [18%]
Revised Model (re-calibrated to include pre-retrofit summer heating)				
Revised Uncalibrated Model Savings	215,500 [68%]	215,500 [35%]	0 [0%]	215,500 [19%]
Revised Calibrated Model Savings	201,100 [63%]	201,100 [33%]	12,900 [2%]	214,000 [19%]

6.4 Total Measured Energy Savings through Calibrated Simulation

The calibrated models give insight into energy savings by end-use, which can help to evaluate individual ECMs. However, regardless of which calibration method is used, the total savings resulting from the project can be assessed as a whole from either model.

Figure 6.5, Figure 6.6 and Figure 6.7 show the calibrated pre- and post-retrofit energy models for electricity, gas, and total energy, respectively, showing final measured energy savings at the study building. As explained above, the electricity plot (Figure 6.5) shows a drop in summer electricity consumption, suggesting that either the baseline (lighting and miscellaneous) energy use changed, or there was some summer electric baseboard use that dropped following the retrofit. The gas plot (Figure 6.6) shows a greater drop in gas consumption during the winter and shoulder season months, suggesting that owners are using their fireplaces less during these months in particular.

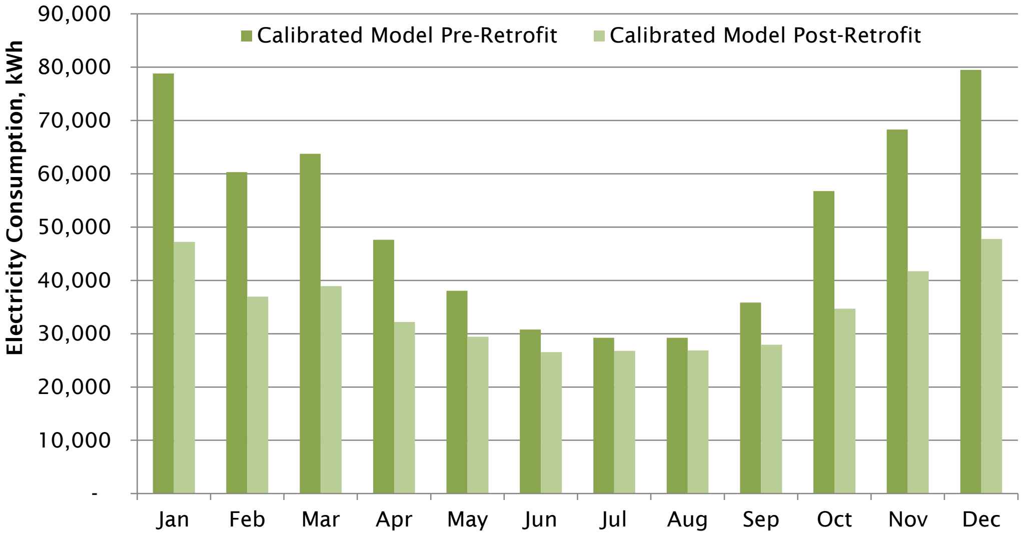

Figure 6.5 Calibrated model pre- and post-retrofit electricity consumption (suite and common areas), kWh.

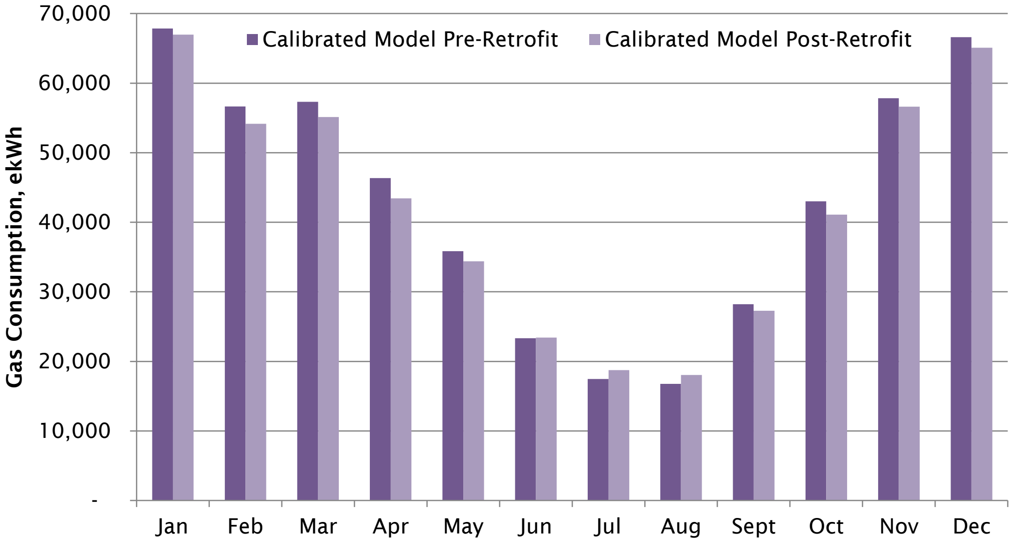

Figure 6.6 Calibrated model pre- and post-retrofit gas consumption, ekWh.

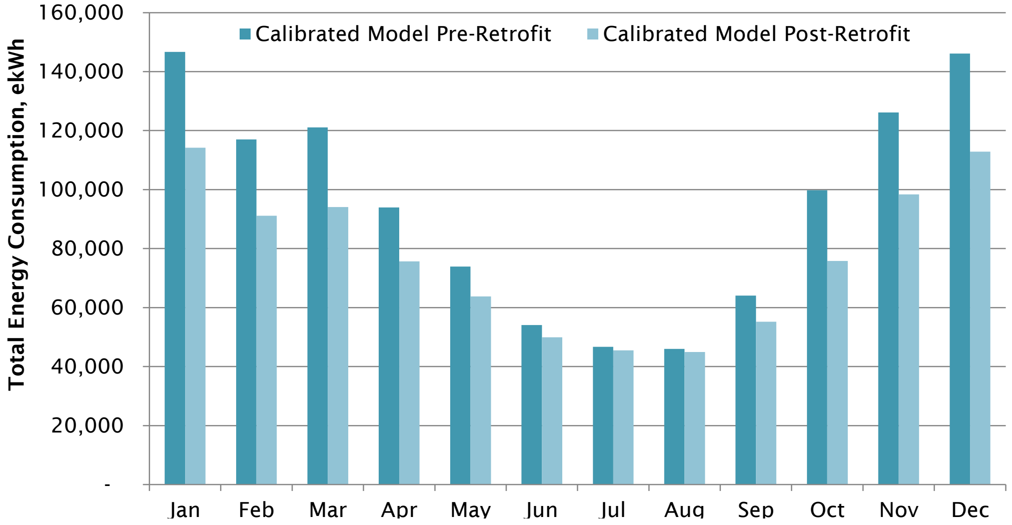

Figure 6.7 Calibrated model pre- and post-retrofit total energy consumption, ekWh.

Table 6.2 shows the total energy consumption and savings resulting from the retrofit. Overall, the measured energy savings at the study building are 214,000 ekWh per year, an EUI of 43 kWh/m^2 and overall 19% reduction in total energy consumption. The revised modeling is used to obtain this kWh savings since it had less percent difference compared to the metered data than the original modeling.

Using gas and electricity prices for Vancouver, BC as of January 2014, this results in an annual savings of $23,000 at the building, or $630 average per suite. These savings reflect a typical weather year; actual annual savings will vary depending on heating needs.

TABLE 6.2 PRE- AND POST-RETROFIT ENERGY CONSUMPTION FROM CALIBRATED MODELING (USING REVISED MODELS)

	Pre-Retrofit	**Post-Retrofit**	**Savings**	
Electricity, kWh	618,200	417,100	201,100	33%
Gas, ekWh	517,300	504,400	12,900	2%
Total, ekWh	1,135,500	921,500	214,000	19%

6.5 Energy Savings of Individual ECMs

The savings attributable to each of the three individual ECMs cannot be measured or metered directly since they all result in a reduction of space heating energy. However, the savings attributable to individual measures can be estimated using the calibrated model.

To estimate savings of individual ECMs, measures are first simulated individually. The sum of the individual savings is greater than the savings from the bundled simulation. Therefore, the percent contribution of each measure to the total sum is calculated and the weightings are applied to the total savings from the bundle simulation.

TABLE 6.3 ESTIMATED SAVINGS OF INDIVIUAL ECMS

	Percent of Total Savings	Electric Baseboard Heating Savings, kWh
Insulated Walls	34%	68,000
Windows	49%	98,600
Airtightness	17%	34,500

TABLE 6.3 ESTIMATED SAVINGS OF INDIVIUAL ECMS		
Total Savings	**100%**	**201,100**

By comparison, the total annual electricity savings estimated in the original BC Hydro incentive energy study (covering the windows ECM only) was 91,800 kWh (which used a window U-value of U-0.17). It is our understanding that savings used to calculate the incentive amount were lowered following the change to U-0.20 windows. This analysis indicates that the expected savings for BC Hydro's Commercial New Construction incentive for the window component of the project were exceeded.

The incremental cost of the windows compared to code-minimum windows was priced at \$88,100, or \$60,000 including the BC Hydro incentive. To calculate payback period, the same utility rates used in the original study are used, current as of April 2013. These are \$8.66/GJ for gas[9], and for electricity a stepped rate of \$0.069/kWh for the first 1,350 kWh in a two-month billing period (or 22.2 kWh per day) and \$0.1034 above 1,350 kWh in a billing period[10]. These rates are exclusive of tax and fixed fee charges. The current financial analysis does not account for increasing energy prices; if this was incorporated, payback periods would be lower (therefore the current analysis is conservative).

Based on this, total annual savings from the project are \$21,000. Attributing 49% to windows gives a savings of \$10,400 per year. This yields an incremental payback period of 8 years, or 6 years including the incentive funding. Note this is based on measured savings and does not consider the fact that code-minimum windows would have resulted in small savings, whereas the incremental cost used is the cost difference from code minimum.

The cost savings was also calculated using 2014 rates for comparison. This yields an annual savings of \$23,000 due to the increase in both gas and electricity prices since the original study was completed. These prices yield a payback period for the windows of 8 years, or 5 years including the incentive funding.

Payback periods were not calculated for the airtightness and insulation retrofit measures as these were included in the project for durability and moisture control; as such, no incremental cost was assigned. The low-conductivity cladding attachment was an energy upgrade, but was cost-neutral to traditional metal girts.

6.6 Summary

Overall, the measurement and verification showed a measured, weather normalized energy savings of 214,000 ekWh, an EUI reduction of 43 ekWh/m^2 (building EUI was reduced from 226 kWh/m^2 to 183 kWh/m^2). This is comprised of 201,100 kWh electricity savings and 12,900 ekWh gas savings. The savings expected through BC Hydro's Commercial New Construction incentive program for the window replacement component of the project were achieved.

Energy savings by end use based on the calibrated energy modeling estimates a 63% savings in electric baseboard heating energy was achieved through the retrofit. The

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[9] FortisBC Lower Mainland Rate 2, commercial with consumption less than 2000 GJ annually, April 2013, with carbon tax of \$1.50/GJ

[10] BC Hydro residential rates, April 2013

energy savings by end use cannot be known with certainty without electrical sub-metering, which is beyond the scope of this project.

7 Indoor Air Quality Measurements and Testing

This section provides a summary of the monitoring and testing of the ventilation system at the case study building. In particular, the results of the building monitoring and of the tracer gas testing are discussed. An in depth and extensive review of this aspect of the monitoring and testing is provided in *A Field Study of Airflow in a High-Rise Multi-Unit Residential Building*[11].

7.1 Introduction

Airflow into, out of, and within buildings is a fundamental factor of building design and operation, as building airflow patterns impact occupant health and comfort, building durability, and energy consumption. The height, typical inclusion of operable windows, and compartmentalized nature of high-rise multi-unit residential buildings makes them both unique and complex, and to efficiently and effectively ventilate these types of buildings, an understanding of airflow within and through them is required. This understanding should include consideration of the driving forces of airflow and their interaction with the physical building including the building enclosure and interior compartmentalizing elements. While significant work has been conducted to understand airflows in houses and commercial buildings, multi-unit residential buildings pose unique challenges and are less well understood.

Corridor pressurization based ventilation systems are pervasively used to ventilate mid- to high-rise multi-unit residential buildings in Canada and the United States. This system incorporates a centralized outdoor-air unit that provides conditioned ventilation air to the corridor on each floor. The supply of this air is intended to pressurize the corridors relative to the adjacent suites and, in doing so, to provide ventilation air to the suites via door undercuts. The air is intended to then exit the building through leakage paths in the building enclosure or through operation of local exhaust fans in the bathrooms and kitchen. This system is intended to provide ventilation air to suites, and to control and dilute air contaminants.

Despite common anecdotal accounts of poor performance, and supporting research, the use of this ventilation system in high-rise multi-unit residential buildings is pervasive. Performance complaints include high humidity levels, sound transfer, and poor air quality caused by the migration of odours and vehicle exhaust.

To evaluate the performance of the ventilation system and its interaction with other drivers of airflow at the case study building, an experimental program was developed and implemented.

7.2 Methodology

The installation of building monitoring equipment and the airtightness testing of the case study are described in Chapter 3 and Chapter 5 respectively. In addition to this,

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[11] Ricketts, L. (2014) *A Field Study of Airflow in a High-Rise Multi-Unit Residential Building. UWSpace. http://hdl.handle.net/10012/8190*

perfluorocarbon tracer (PFT) gas testing was also used to directly measure airflow rates between zones of the building.

Perfluorocarbon Tracer Gas Testing

Perfluorocarbon tracer gas (PFT) testing was implemented at the case study building to directly measured time averaged airflows between zones of the building, as well as exfiltration and infiltration.

The objective of the PFT testing was to measure in-service airflows at the case study building. The airflows measured include:

- Airflow between corridors and suites
- Airflow between adjacent suites on the same floor, and on floors above and below
- Airflow from the parking garage to suites and corridors

The testing also provides qualitative results regarding the distribution of ventilation air from the make-up air unit and the flow of air from the parking garage into the occupied spaces of the building.

To measure the airflow between zones, PFT testing was conducted which provides time-averaged flow rates. The PFT test method used was developed by Brookhaven National Laboratory and uses seven distinct perfluorocarbon tracers. These tracers are released into the air and then absorbed by capillary absorption tube samplers (CATS). The laboratory is then able to determine the how much of the tracer the CATS absorbed. Using these absorbed volumes and the known release rates of the PFTs, the airflow between zones can be determined. The PFT equipment and processing of the CATS samplers was provided by Brookhaven National Laboratory through Meadowbrook Partners Inc. (MPI). Figure 7.1 shows the PFT sources and Figure 7.2 shows a typical CATS used for this testing.

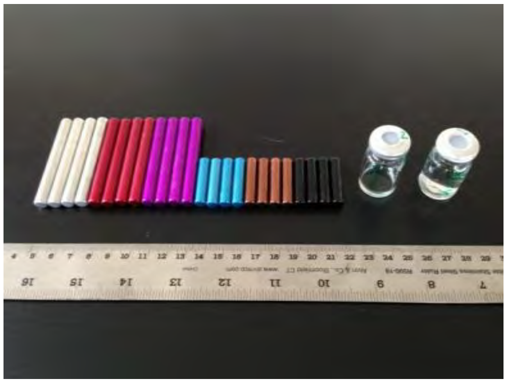


Figure 7.1 PFT sources used at the case study building. Each colour is a different PFT tracer and the glass vials are “mega” sources of a distinct PFT used in the MAU.

Figure 7.2 Typical CATS used for PFT testing at the case study building

This type of airflow measurement was selected because it provided for the ability to measure multiple airflows between zones during the same test period, and because it provided a time averaged measurement which is generally of the most interest with respect to airflow in buildings for indoor air quality, energy, and comfort considerations.

Consistent with the approach used in other components of the testing and measurement program, PFT testing focused on the primary test floors of the case study building. A unique tracer was also released in both the rooftop MAU and the parking garage so that airflow from these sources to zones of the building could be determined. Due to the limited number of PFTs available, some of the tracers were used in two locations within the building as suggested by MPI. Based on their previous experience with this type of testing, a separation of 3 floors between repeated tracers is typically sufficient to limit interference of the two source locations. (Based on the testing at the case study building, this assumption was subsequently found to be true.) Also, again due to the limited number of PFTs available, on each of the primary test floors a particular suite was identified as the primary test suite and tracers were installed in the suites above and below these suites. Suites 302 and 1103 were selected as the primary test suites. A CATS was installed in each suite on the primary test floors and the floors above and below the test floors, as well as in the corridor on each level of the building, in the MAU supply airflow duct (downstream of the PFT source), in the elevator lobby at the parking garage level. Three CATS were installed in the parking garage due to its large volume.

The layout of PFTs and CATS on Floor 11 is provided in Figure 7.3. Two sources of the same type were used in each tagged suite to provide a sufficiently high release rate of the tracers to achieve measurable concentrations and to evenly distribute the tracers within the suites.

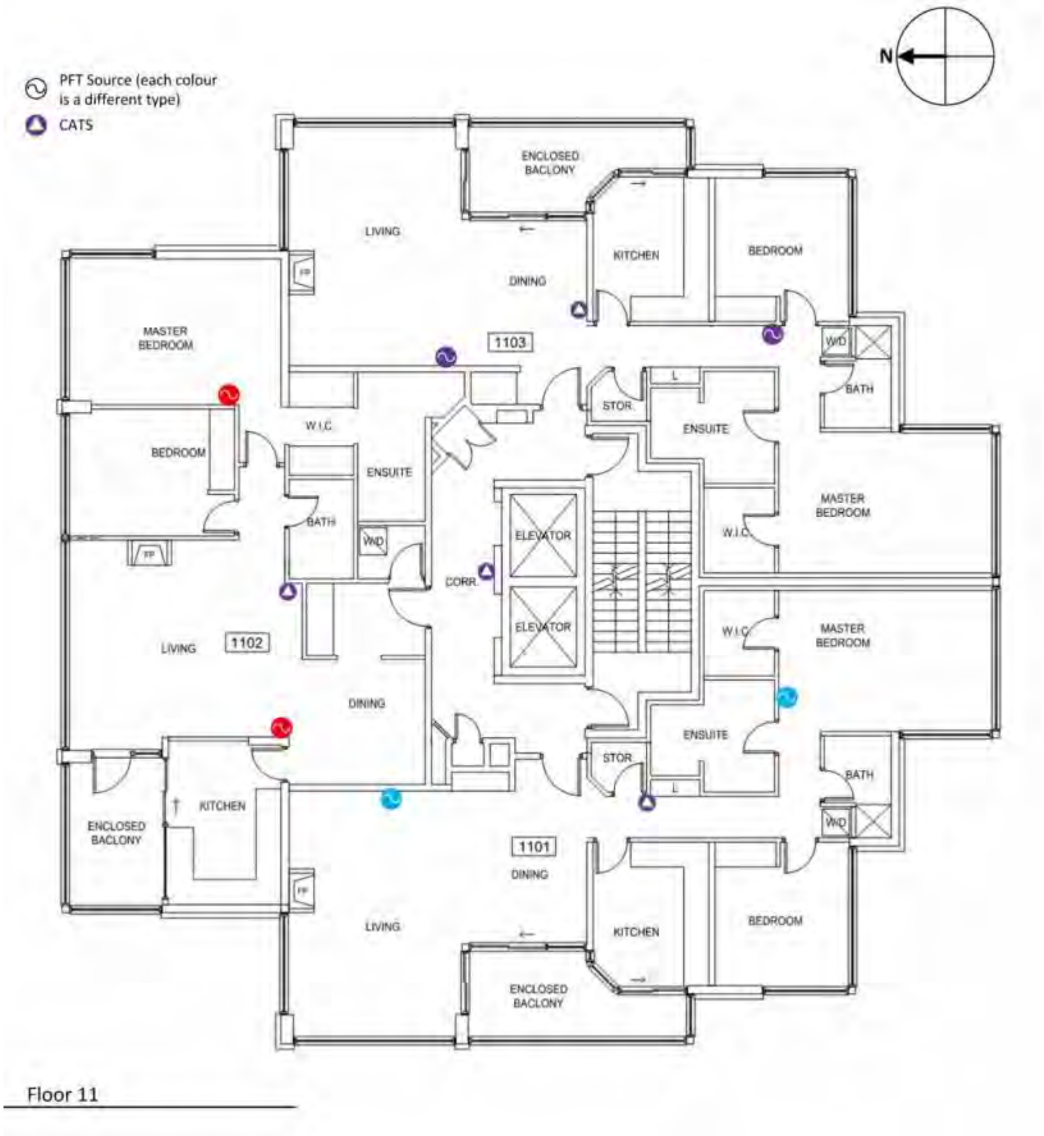


Figure 7.3 Layout of PFT testing equipment on Floor 11 of the case study building

7.3 PFT Testing Results

The PFT testing was conducted for a period of one week from April 10th, 2013 to April 17th, 2013 to capture the weekly occupancy pattern typical of a residential building. The duration of the test was also intended to average the effects of open windows, high and low wind speeds, intermittent operation of exhaust fans, et cetera. For reference, the average exterior temperature during this period was 8°C and the average wind speed was 3.3 m/s. The total air flow rates into the suites as determined by the PFT testing are provided in Figure 7.4.

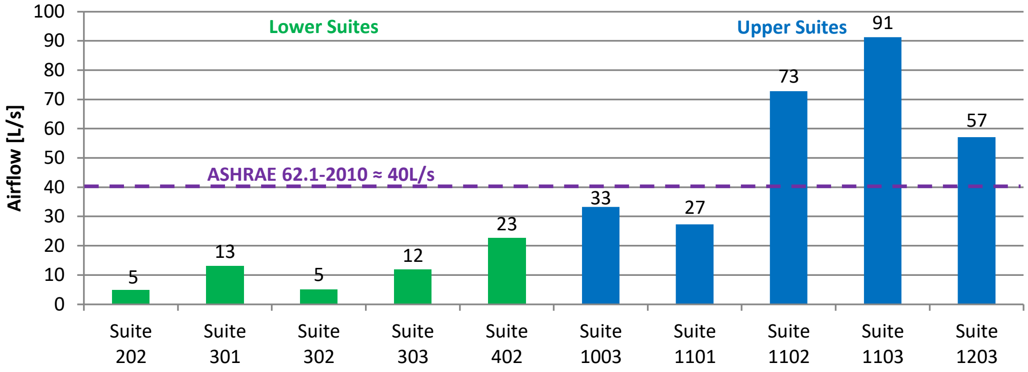


Figure 7.4 Chart showing the total airflow rate from all sources into each of the measured suites

Figure 7.4 indicates that there is an order of magnitude variation in the ventilation rates of the suites at the case study building. Typically, upper suites are more ventilated than lower suites, and most suites are either over- or under-ventilated compared to modern ventilation standards (ASHRAE 62.1-2010). The cause of this variation is discussed in subsequent sections.

Figure 7.5 and Figure 7.6 the airflow rates to and from adjacent zones for six suites at the case study building as measured as part of the PFT testing.

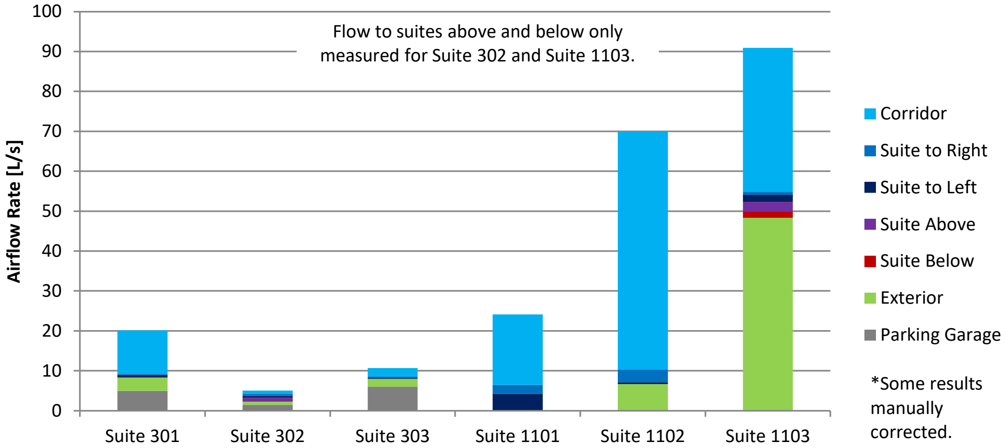


Figure 7.5 Airflow rate and source of airflow into suites for six suites at the case study building

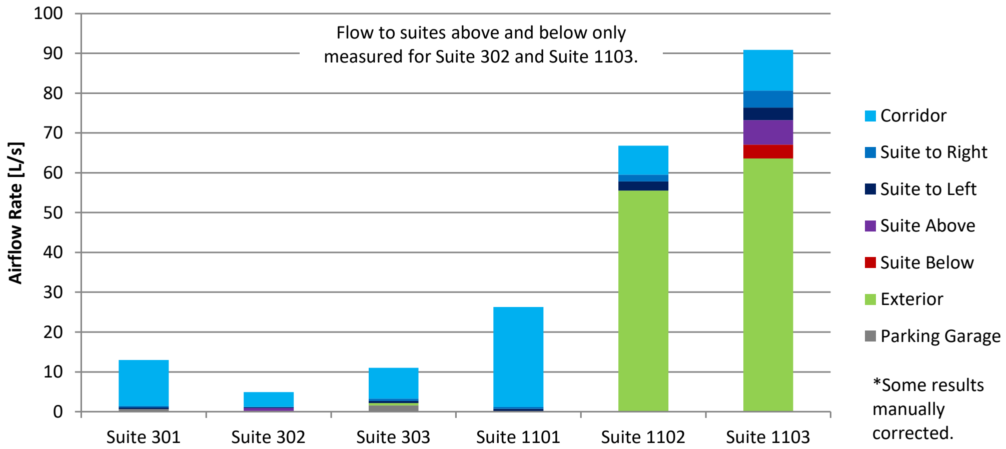


Figure 7.6 Airflow rate and source of airflow out of suites for six suites at the case study building

Consistent with Figure 7.4, Figure 7.5 and Figure 7.6 show significantly higher airflow rates into and out of the upper suites compared to the lower suites. Generally, this is due to higher airflow rates into the suite from the corridor (ventilation) and higher airflow rates out of the suites to the exterior. This finding is consistent with stack effect which would tend to cause exfiltration at the top of the building from the corridor through the suites to the exterior. This may also be caused by proximity to the make-up air unit and increased magnitude of wind on upper floors.

It is also apparent that the lower suites (Suite 301, Suite 302, and Suite 303) receive a significant proportion of the airflow into the suites from the parking garage. Parking garages can have relatively high concentrations of contaminates including particulates, carbon monoxide, and various hydrocarbons from vehicle exhaust; consequently, airflow from the parking garage to occupied spaces of the building is a significant indoor air quality and health concern.

To illustrate the distribution of air from the make-up air unit (MAU) and parking garage into the building, Figure 7.7 and Figure 7.8 show the quantity of tracer measured each zone for the tracer released in the MAU intake and for the tracer released in the parking garage. Note that the concentration of the tracer released in the parking garage was measured to be higher in Suite 302 than in the parking garage which is impossible and likely indicates that this CATS was unintentionally contaminated.

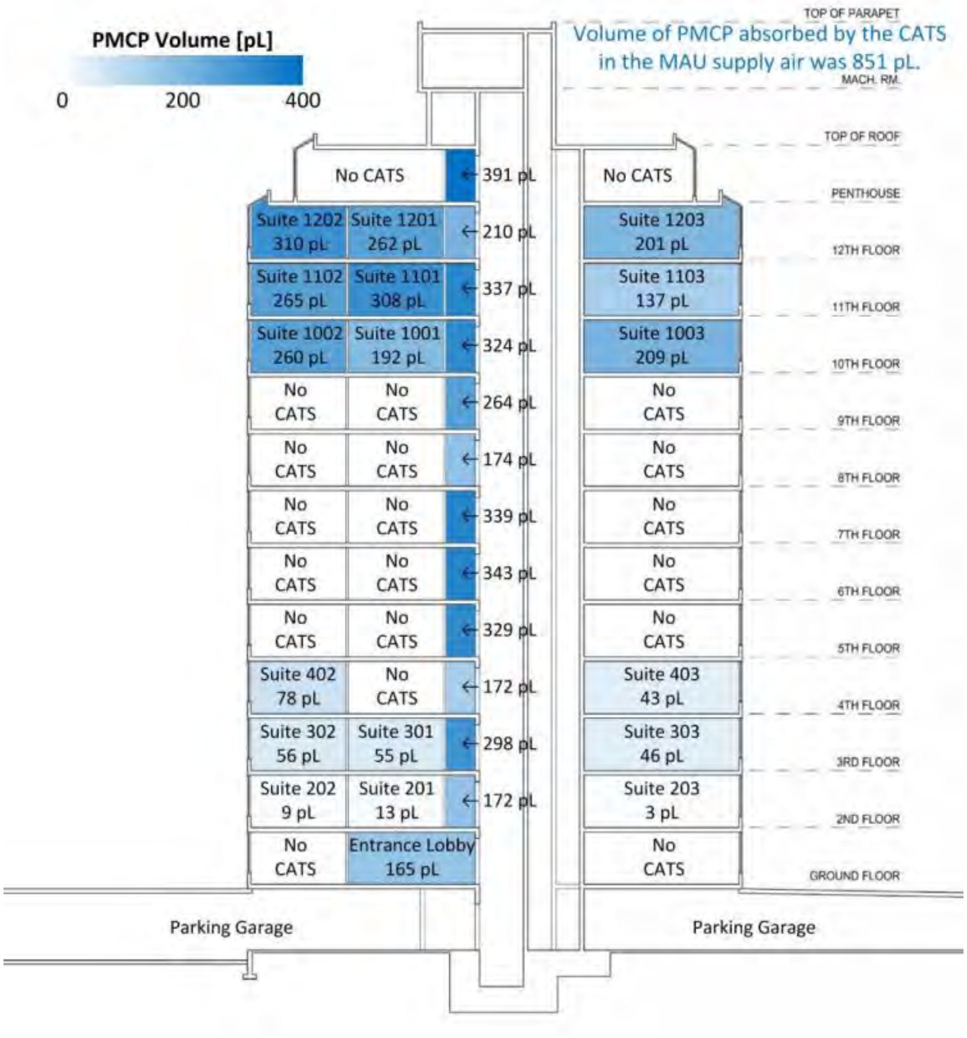


Figure 7.7 Schematic cross-sections of the case study building showing the amount of tracer released in the MAU air intake that was measured in each zone

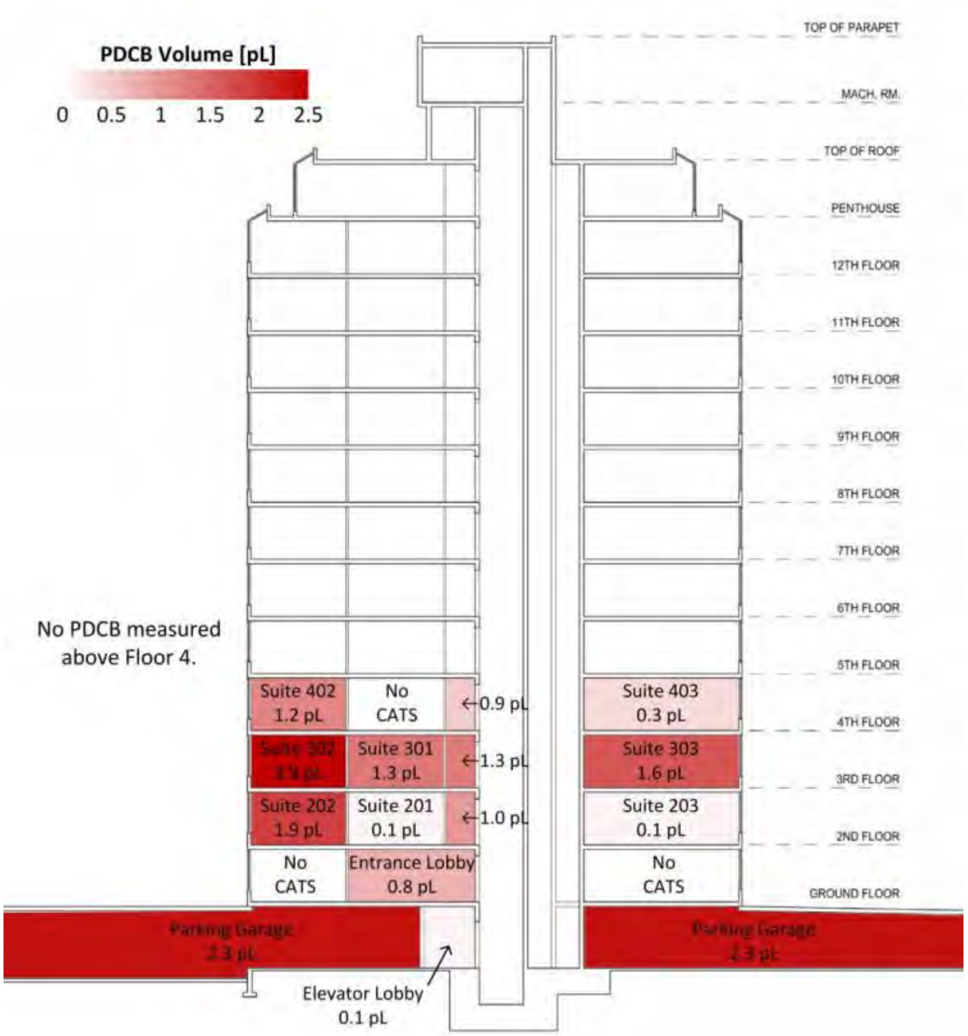


Figure 7.8 Schematic cross-sections of the case study building showing the amount of tracer released in the parking garage air intake that was measured in each zone

Overall, the PFT testing at the case study building found that typically the upper suites are over-ventilated and the lower suites are under-ventilated compared to modern ventilation standards, and that there is an order of magnitude variation in the ventilation rates. These findings indicate that the corridor pressurization ventilation system at this building is not effectively or efficiently ventilating the suites. The cause of these airflow patterns is discussed in more detail in subsequent sections.

7.4 Pressure Monitoring Results

To understand the causes of the poor performance of corridor pressurization based ventilation systems, and subsequently to design alternative systems to provide better ventilation and airflow control, an understanding of the pressure regime at the building is required. Pressure differences are created by wind, stack effect, and mechanical ventilation systems which collectively will be referred to as the driving forces of airflow. The impact of these driving forces is illustrated schematically in Figure 7.9.

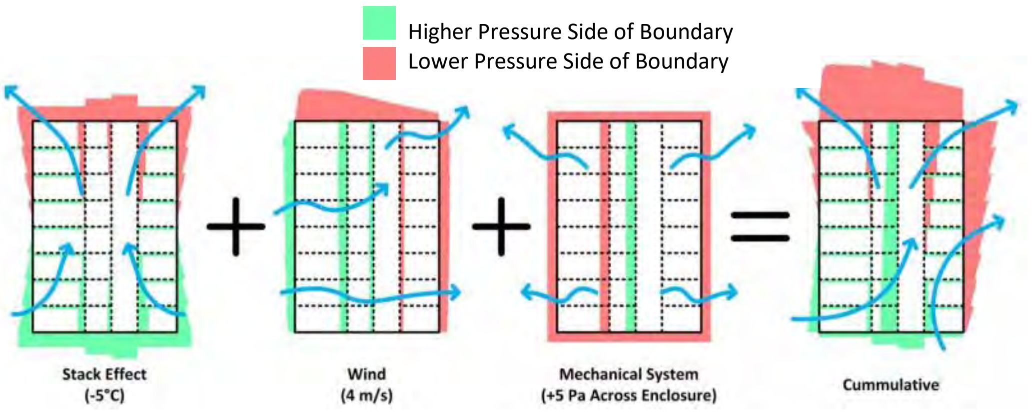


Figure 7.9 Schematic cumulative effect of driving forces of airflow on a tall building

These pressure differences drive airflow within and through buildings and can be developed across both the exterior enclosure and across interior compartmentalizing elements such as suite entrance doors, floors, and shaft walls. The airtightness of these elements resists airflow and alters the distribution of pressure differences within a building. Significant work has previously been completed in this area; a complete review of relevant literature is provided in Ricketts (2014). At the case study building, pressure differences were measured as part of the monitoring program.

One pressure measurement of interest is the difference in pressure from the interior corridor to the suites. This pressure difference is shown for a one year period in Figure 7.10.

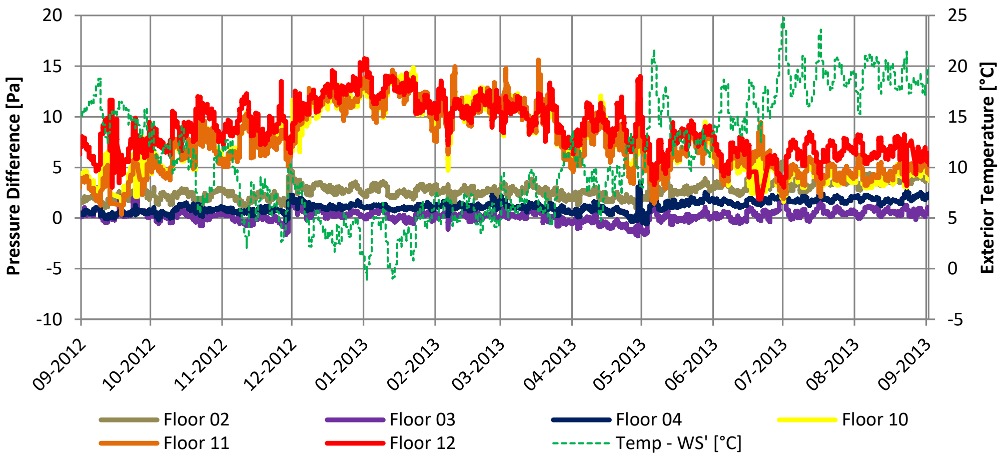


Figure 7.10 Graph showing the average pressure difference from the corridors to the adjacent suites for six floors at the case study building (positive indicates corridor is higher pressure than adjacent suites)

Figure 7.10 shows that on upper floors the pressure of the corridor increases relative to the adjacent suites during colder periods of the year; while on lower floors there is little to no variation. This finding is consistent with stack effect combined with mechanical pressurization (pressurization offsets the stack-effect induced inward-acting pressures at the bottom). Importantly the variation in the pressure on upper floors is approximately 10 to 15 Pa, and other measurements determined that the MAU pressurizes the corridor by approximately 5 to 10 Pa. Because these pressure differences are of similar magnitude and acting in the same location, it is likely that stack effect significantly affects ventilation rates within the case study building and is a major cause of the measured airflow patterns. Based on these measurements, stack effect has a relatively large impact on the building pressure regime despite the relatively moderate climate of Vancouver, BC.

Figure 7.11 shows the stack effect gradient measured across building elements. The stack effect gradient refers to the difference in pressure differences at two locations divided by the vertical difference between the two locations. Using this metric allows for comparison of the proportion of the theoretical development of stack pressure that acts on different parts of the building.

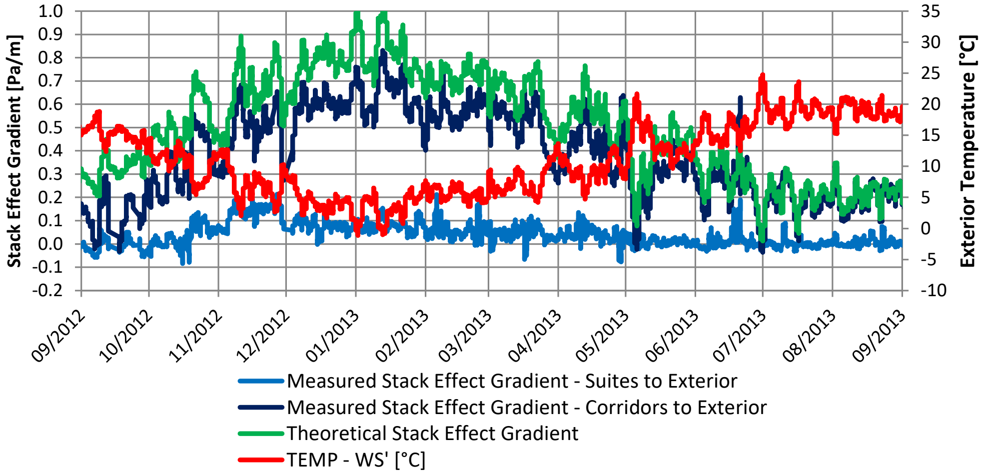


Figure 7.11 Measured and theoretical (calculated from measured indoor-outdoor temperature difference) stack effect gradients at the case study building

Figure 7.11 shows that the measured pressure differences are consistent with the pressure differences predicted by theory and demonstrate increasing pressure difference (i.e. stack effect gradient) during colder periods. Furthermore, the figure shows only a small amount of the pressure difference created by stack effect acts across the exterior enclosure; however, a very large portion of the theoretical stack effect pressure difference acts across the corridor to suite pressure boundary. During a period when the neutral pressure plane location was consistent, from December 1, 2012 to Mar 31, 2013, 9% of the pressure difference due to stack effect acted across the exterior enclosure, and 69% acted across the corridor to suite boundary. This finding is likely due to the opening of operable windows significantly reducing the in-service airtightness of the building enclosure and consequently transferring pressure differences created by stack effect to the most airtight element, which in this case is the walls and doors between the corridors and the suites. This finding has direct implications for the performance of the pressurized corridor based ventilation system, and is an example of how naturally occurring pressure differences can significantly affect interior pressure difference and airflows, and consequently impact the performance of the mechanical ventilation system. This distribution of pressure differences due to stack effect is illustrated graphically in Figure 7.12. The neutral pressure plane (NPP) for the building was determined to be at approximately the middle of the third floor.

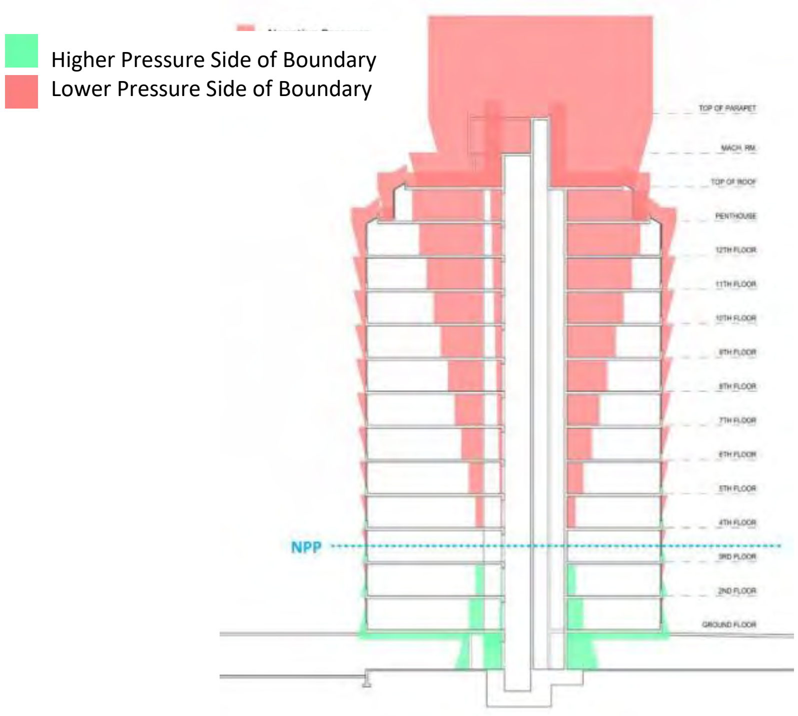


Figure 7.12 Measured and theoretical (calculated from measured indoor-outdoor temperature difference) stack effect gradients at the case study building

Wind is another cause of pressure differences at buildings, and as one would expect, it was found to create the peak pressure differences across the building enclosure at the case study building; however, typically these pressures acted for relatively short time periods. Wind also created the peak pressure differences across interior elements which could cause transfer of air contaminates between adjacent suites. A plot showing an instance when wind created relatively high pressure differences across the compartmentalizing elements of a suite is shown in Figure 7.13 as an example. Note that “ED” refers to the “Entrance Door” of the suite and indicates that these are measurements of the pressure difference from the suites to the corridor. In this case, the suites are the reference pressure for each measurement, thus a positive measurement indicates higher pressure in the corridor than in the adjoining suite.

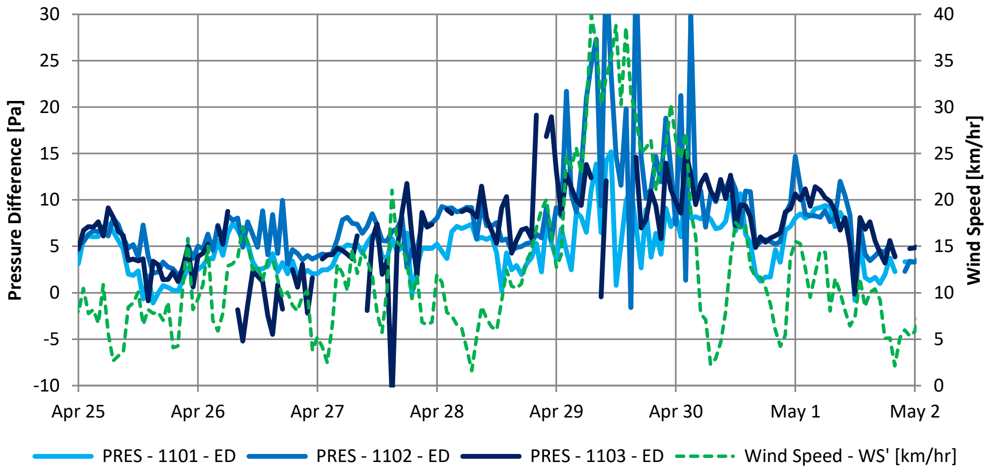


Figure 7.13 An instance of relatively strong winds significantly increased the pressure in the corridor relative to the pressure in Suite 1102. (Note that "ED" refers to the "Entrance Door" of the suite and indicates that these are measurements of the pressure difference from the suites to the corridor. Positive pressure measurements indicate higher pressure in the corridor than in the adjacent suite.)

7.5 Indoor Air Quality Monitoring Results

Indoor air quality (IAQ) is a critical factor in determining the health and comfort of building occupants. Exposure to poor air quality has been shown to have detrimental health impacts through numerous studies which has resulted in exposure recommendations and limits for a number of pollutants (EPA 2008, Government of Canada 2015, WHO 2010). Symptoms of exposure to indoor air pollution can include cognitive decline, fatigue, eye, nose, and throat irritation, headaches, dizziness, respiratory disease, heart disease, and cancer. Satish et al. (2012) showed moderate declines in cognitive performance with exposure to CO_2 concentrations of 1,000ppm and significant declines at concentrations of 2,500ppm compared to baseline testing at 600ppm. A follow-up study (Allen et al 2015) controlling both CO_2 and total volatile organic compound (TVOC) concentration in a simulated office environment confirmed that increases in CO_2 concentration reduced cognitive function. In addition, the study found that a 500µg/m^3 increase in TVOC exposure was associated with a further 18% decline in cognitive function. Intervention studies of CO_2 reductions on student testing showed improved results for concentration changes from 1,300ppm to 900ppm (Wargocki and Wyon 2007). Exposure to elevated bedroom CO_2 concentrations have also been shown to result in decreased perceived and measured sleep quality and to cause reductions in next day performance using intervention studies in college dormitories (Strom-Telsen et al. 2015).

Temperature and relative humidity are also key parameters in determining the quality of the indoor environment. Relative humidity indicates the percentage of moisture in the air compared to the saturation moisture content of air at that temperature. The human comfort range for relative humidity strongly depends on the individual and the surroundings but should generally be maintained by the HVAC system to within the range of 30-60% (ASHRAE 2013, Lstiburek 2002). Relative humidity levels below 30% may result in irritation whereas higher relative humidity levels may cause feelings of discomfort. The relative humidity within a building may also contribute to health risks due to moisture problems. Excessive moisture in in the air will condense on surfaces with temperature below the dew point temperature of the surrounding air. Dampness in the indoor environment has been identified as a hazard to human health by the WHO due to the prevalence for promoting biological growth (WHO 2009). Moisture on surfaces can promote mold and fungal growth within a building leading to exposure and health impacts. Moisture and dampness in homes are correlated with significant increases in respiratory symptoms such as coughing and wheezing (Fisk et al. 2007) as well as increases in the occurrence of Bronchitis and respiratory infections (Fisk et al. 2010).

The building ventilation system is used to control the build-up of pollutants within the indoor air and consequently measurement of indicators of indoor air and environmental quality provide an measure of ventilation system efficacy.

Carbon Dioxide Concentration

The average CO_2 concentration within suites on each of the floors in this study was compared to determine variations in indoor air quality. The percentage of time that the average CO_2 concentration within suites on each of the study floors exceeds a given threshold is shown in Figure 7.14. The results show a clear differentiation between suites on the lower floors and the upper floors. The average concentration in suites on Floors 2, 3, and 4 exceeds a 1,100ppm threshold (in line with ASHRAE 62.1 ventilation design) 82%, 87%, and 42% of the time respectively, compared to 0%, 1%, and 0% for floors 10, 11, and 12, respectively. Additionally, the CO_2 concentration in suites on floors 2 and 3 is often more than 2,000ppm. The average CO_2 concentration on the floors is indicated at the 50% line and again highlights significant disparity between the suites within the building. The residents in suites on lower floors are exposed to significantly higher average concentrations of CO_2. The highest average concentration on a floor within the building (Floor 3, 1,550ppm) is approximately 2.4x higher than the lowest average concentration on a floor (Floor 10, 640ppm). The differences in CO_2 concentration are consistent with differences in airflow measurements as determined by the PFT testing. A reduction in ventilation rate is consistent with elevated CO_2 concentrations while occupants are present and is likely a significant contributing factor for the measured disparity.

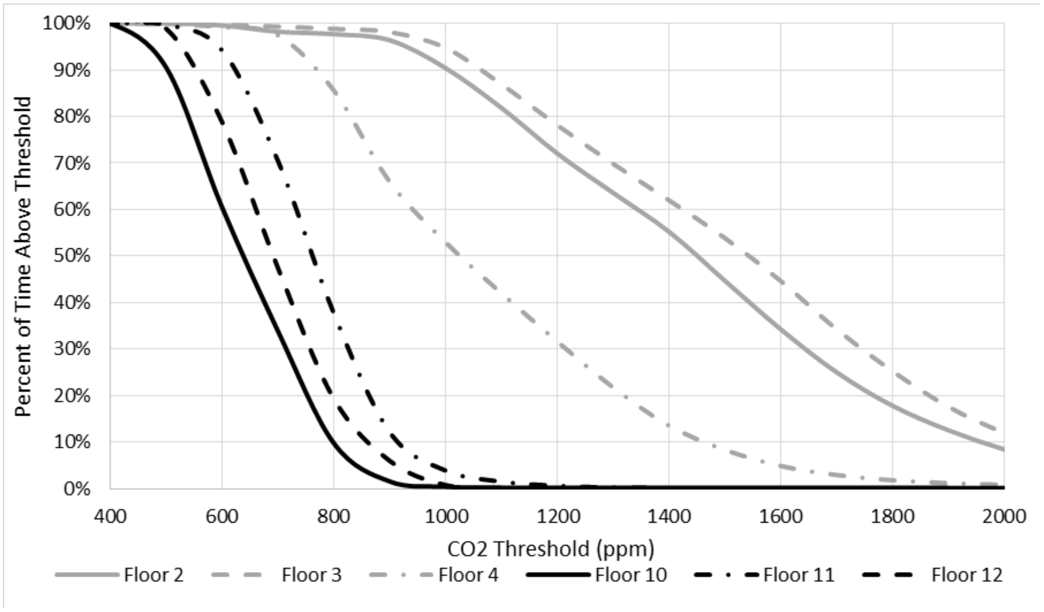


Figure 7.14 Percent of time average CO_2 exceeds a threshold by floor

The average CO_2 concentration was compared for temporal variations throughout the year. The monthly average in suites of each floor are shown in Figure 7.15. CO_2 concentrations were found to be lower for all suites during summer months (May through August) compared to the winter months (Jan. to Mar. and Nov. to Dec.). The CO_2 concentration shows only a slight variation throughout the year in suites on the upper floors compared with significant variation for suites on the lower floors. This results in the difference in average CO_2 concentrations between lower and upper floors being smaller in the summer month (average of 950ppm and 610ppm for floors 2-4 and floors 10-12, respectively) compared to the winter (average of 1,685ppm and 815ppm for floors 2-4 and floors 10-12, respectively). A potential reason for this seasonal variation is the observed opening of windows in the summer months to provide cooling to the space or to address perceived stuffiness through natural ventilation. This natural ventilation increase can supplement the mechanical ventilation airflow rates in to the suites (on all floors) and would have a larger impact on the potentially underventilated suites on floors 2-4. Reduced stack effect influence on mechanically induced corridor-to-suite pressure differences in the summer (smaller temperature difference) is likely also contributes significantly to this seasonal variation.

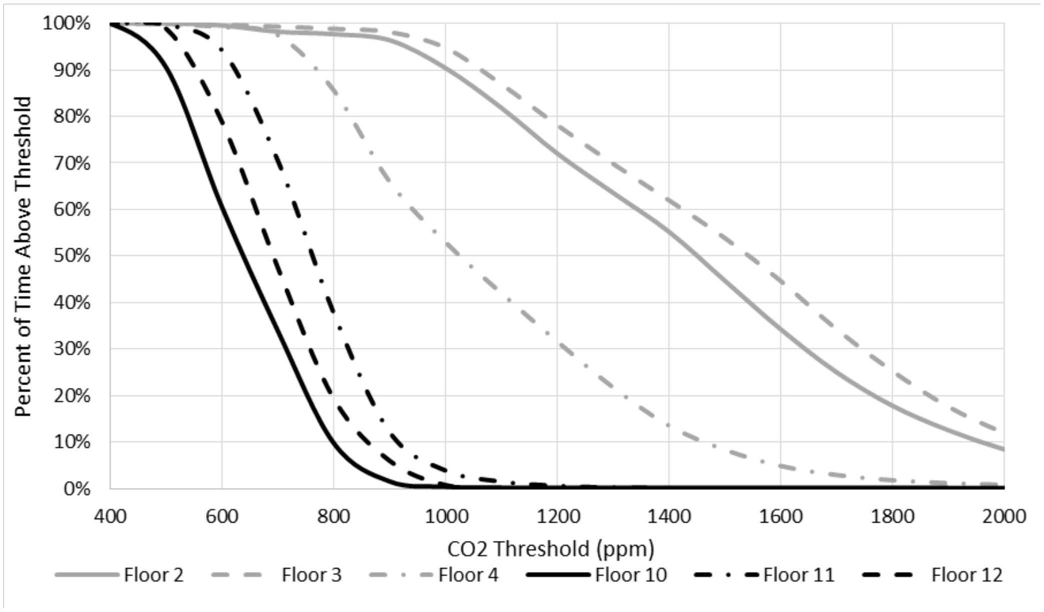


Figure 7.15 Average monthly CO_2 concentration in suites on each floor

Temperature, Relative Humidity, & Dewpoint Temperature

The percent of time that the temperature and relative humidity within suites on each floor of the building exceeds a specified value is shown in Figure 7.16 and Figure 7.17, respectively. The temperature within the building varies between 21˚C and 26˚C which is typical for indoor set-point conditions. The indoor temperature profile varies with month of the year, with July being approximately 2˚C warmer than in winter months (data not shown). There is no consistent distinction in the temperature measurements between the suites on different floors although the upper floors have a slightly greater fraction of time with temperatures above 24˚C. The space heating is provided by electric baseboards controlled by thermostats in the suites and is largely decoupled from the ventilation. This allows for the occupants to control temperature to their desired comfort levels irrespective of the potential challenges with the ventilation airflow rates.

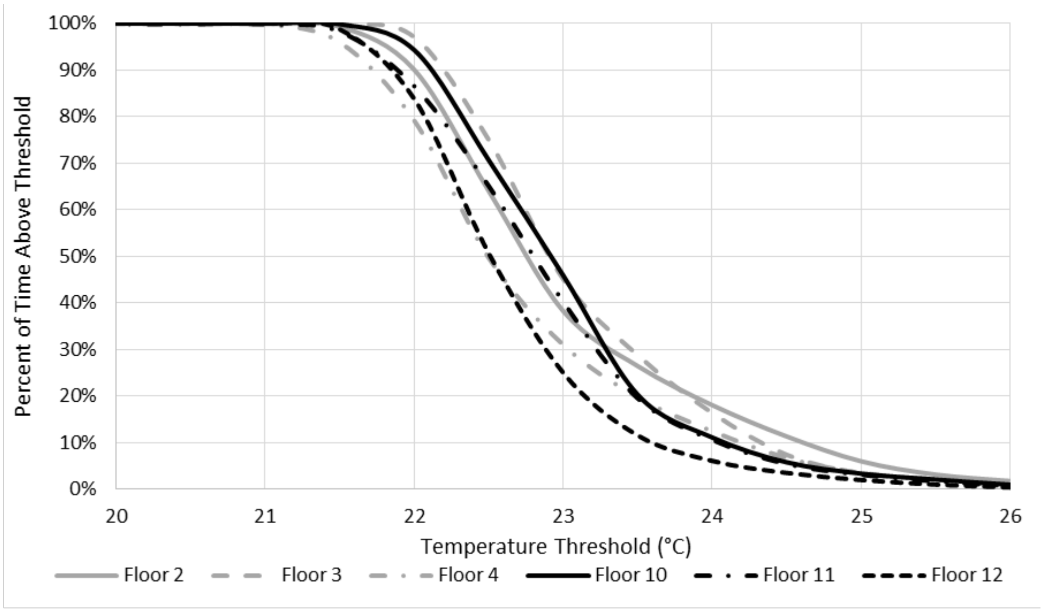


Figure 7.16 Percent of time average temperature exceeds a threshold by floor

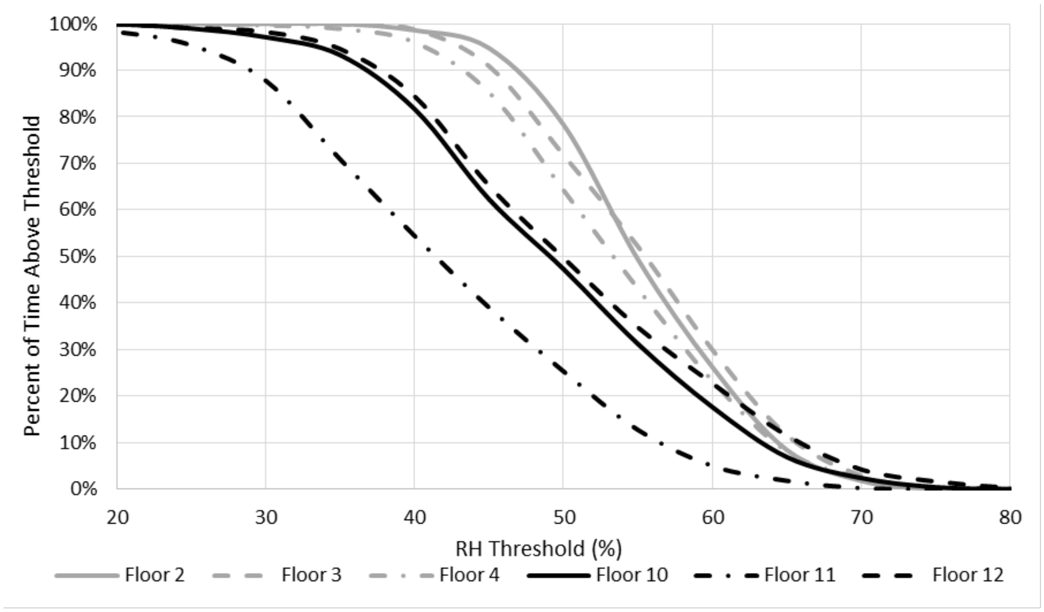


Figure 7.17 Percent of time average relative humidity exceeds a threshold by floor

Comparison of the relative humidity measurements (Figure 7.17) shows a distinct difference between suites on the lower floors versus the upper floors, similar to the CO_2 measurements above. The relative humidity throughout the building is seldom above 70% indicating that extremely humid conditions are generally avoided. Very dry conditions are also rare throughout the building. These results are consistent with anecdotal observations of typical multi-family buildings in the Pacific Northwest where air conditioning and space dehumidification are rare. Although the relative humidity measurements are typically within the desired design range on all floors the RH on lower floors is generally higher than those on upper floors. The average RH is approximately

55% on floors 2, 3, and 4 compared to 42%-50% on floors 10, 11, and 12. The results on Floor 11 are skewed by a resident who indicates that they maintain open windows year-round in their suite which is atypical operation. Consistently higher relative humidity within a space can lead to potential issues with biological growth (such as mold), health complications (such as respiratory illness), as well as thermal discomfort. Although the measurements are typically within design range the percentage of time that residents on the lower floors are exposed to elevated relative humidity can potentially be problematic. If 60% is used as the upper threshold for acceptable relative humidity (ASHRAE 2013), the lower suites exceed these conditions 23-30% of the time compared to 5-23% of the time in suites on upper floors.

The dewpoint temperature was calculated in each space using the dry bulb temperature and relative humidity measurements. Figure 7.18 presents the percent of time that the average dewpoint temperature on each floor of the study building exceeded the indicated threshold during the heating season (Jan.-Mar., Oct.-Dec.). Figure 7.19 shows the average monthly dewpoint temperature on each floor. An interior dewpoint temperatures of >10˚C is often associated with an increased risk of condensation. The average dewpoint temperature on the lower floors was 11-13˚C compared to 6-9˚C on the upper floors. Lower floors also had much greater frequency of high dewpoint temperature measurements. The dewpoint temperature exceeded 15˚C on lower floors between 5-16% of the time compared to <1% on the upper floors. The high frequency of elevated dewpoint temperature during the heating season presents a risk for condensation on colder surfaces.

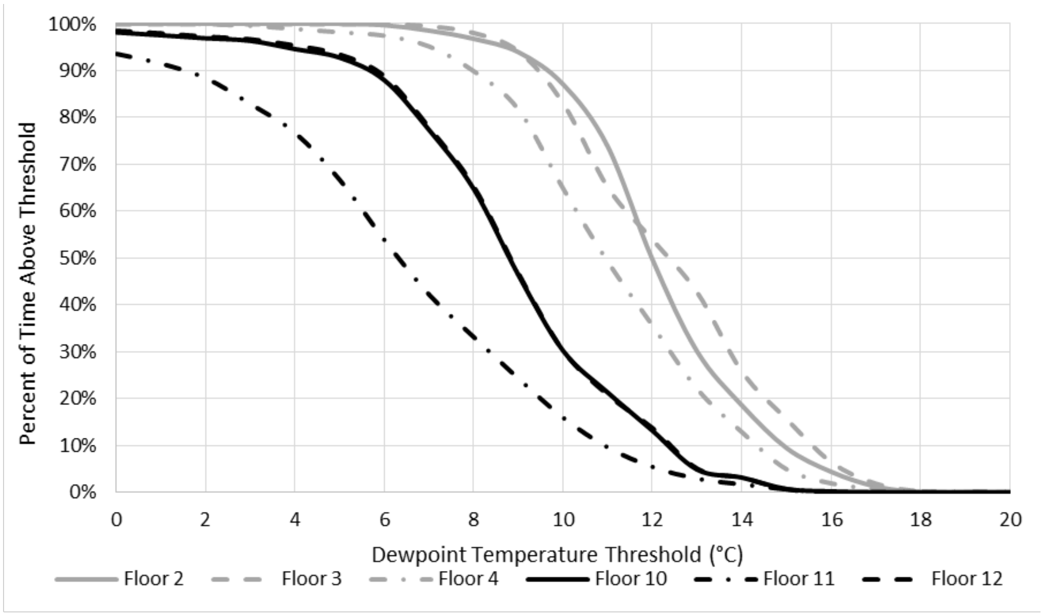


Figure 7.18 Percent of time average dewpoint temperature exceeds a threshold by floor during the heating season (Jan.- Mar. and Oct.-Dec.)

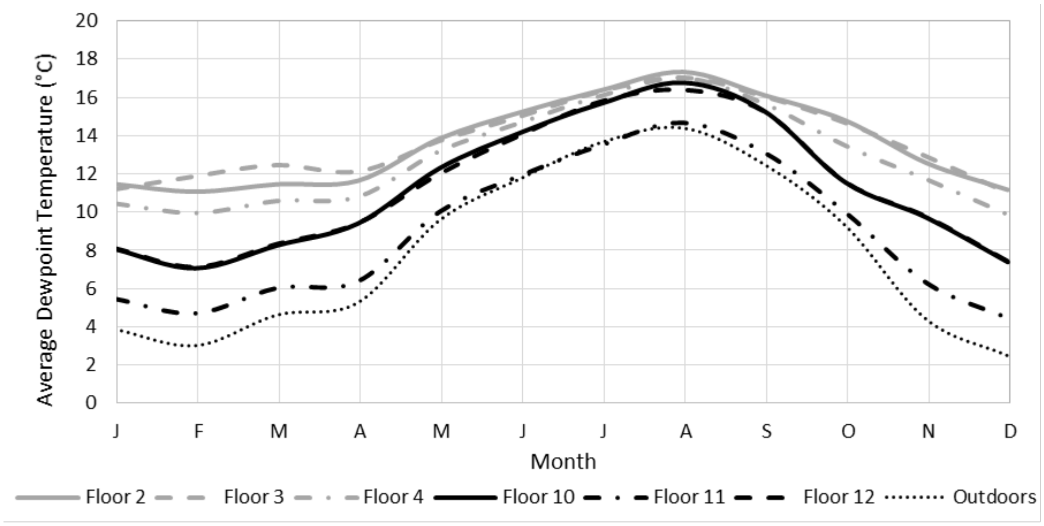


Figure 7.19 Average monthly dewpoint temperature in suites on each floor

Importantly, no change in the performance of the mechanical ventilation system was noted as a result of the building enclosure retrofit. While increased airtightness of the building enclosure is sometimes theorized to impact ventilation system performance, a combination of poor pre-retrofit ventilation system performance and open operable windows reducing effective building enclosure airtightness likely negated any potential impact.

7.6 Summary

The airflow measurement results at the case study building lead to numerous important conclusions. Primarily these results indicate a significantly uneven distribution of ventilation air to the corridors and suites of the building. Lower suites receive orders of magnitude less ventilation air from the MAU and also have less air exchange with the outdoors. Numerous suites receive small fractions of modern ventilation requirements primarily because the majority of the ventilation air brought in to the building by the make-up air unit does not directly reach the suites and is unevenly distributed.

Furthermore, the ventilation system is not adequately controlling the migration of air contaminants within the building. While minimal flows were measured between suites, the potential for transfer of air contaminants exists. Flow of air from the parking garage in to the building, however, was measured to be significant and poses a risk for the transfer of harmful contaminants into occupied spaces of the building.

The poor measured performance of the ventilation system manifests in indoor air and environmental challenges. The CO_2 concentration in suites on the lower floors of the building were considerably higher than in suites on the upper floors and were often in excess of the design values typical for ASHRAE 62.1 (1,100ppm). The dewpoint temperature during the heating season was approximately 10-12˚C on the lower floors and on the lower floors than on upper floors, which could be a concern for potential condensation and mold growth issues. This difference in carbon dioxide and relative humidity levels (with no appreciable difference in drybulb temperature) is consistent with the measured difference in ventilation airflow rates to the suites on different floors.

The challenges with indoor air quality and provision of fresh air to suites on lower floors in apartment buildings with pressurized corridor ventilation systems is likely a common challenge in buildings constructed with this common mechanical system design and would likely be more severe in locations with more extreme climate conditions. Methods with the potential to improve indoor air quality within these buildings include focused retro-commissioning to adjust and rebalance the ventilation system, delivery of ventilation air directly from the make-up air unit to the suites using a ducted system, or compartmentalization of individual suites with dedicated ventilation through in-suite heat recovery ventilators. Recent changes in ventilation code interpretations, understanding of ventilation (at least in part as a result of the work done for this study), and energy efficiency standards have moved the industry towards alternative ventilation strategies in new buildings including direct mechanical supply of ventilation air to occupied spaces and also frequently incorporating heat recovery. The applicability of these solutions to new construction and retrofit projects should be the focus of future research efforts.

8 Summary of Key Findings & Commentary

Key findings and commentary from this deep building enclosure energy retrofit demonstration and verification project are provided below.

→ **Energy and Greenhouse Gas Emissions Reduction Opportunity**

A significant opportunity exists to reduce the energy consumption and associated greenhouse gas emissions of existing multi-unit residential buildings through the implementation of energy conservation measures as part of already planned renewals work. Given the extent of the existing building stock as compared to the rate of new construction, reducing the energy consumption and greenhouse gas emissions of existing buildings should form a fundamental part of achieving overall energy conservation and greenhouse gas emission targeted reductions for buildings. It is worth noting that the relative balance of energy savings and greenhouse gas emission reductions will depend on the heating and mechanical system fuel types.

→ **Integration of Energy Conservation Measures with Enclosure Renewals**

Energy conservation measures can be implemented as part of on-going major renewals work at a relatively minimal incremental cost. This method of implementing energy conservation measures as part of renewals work likely represents the most cost effective opportunity to reduce energy consumption and associated greenhouse gas emissions of existing building. At the case study building, the implemented energy conservations measures all had predicted simple payback of less than 8 years without incentives (6 years with the incentive) which is substantially less than the expected service life of the installed components.

→ **Execution of Major Enclosure Renewals**

Major enclosure renewals work such as that undertaken at the case study building often requires significant investment and effort. Thorough project planning and an experienced and knowledgeable design, construction, and management team can greatly streamline this process as well as reduce cost and risks to the building owners.

→ **Relative Impact of Energy Conservation Measures**

The relative impact of different energy conservation measures should be determined on a case-by-case basis. However, for typical mid- to high-rise multi-unit residential buildings with relatively large amount of glazing, replacement of aging and poorly performing fenestration assemblies with improved energy efficient options is often one of the greatest performance improvement opportunities over the service life of the building. The building enclosure renewal process also provides a significant opportunity to improve airtightness of the building.

→ **Reliability & Predictability of Enclosure Energy Conservation Measures**

Building enclosure related energy conservation measures such as increased insulation, thermally efficient windows, and improved airtightness provide a reliable and predictable means for reducing building energy consumption. Energy modeling for the case study building was able to accurately predict the savings as a result of these measures. Measurement, verification, and monitoring of the actual building performance provided valuable feedback on the actual performance to allow for the calibration of the models, for use in both the study building and to inform future projects.

→ **Ancillary Benefits of Energy Conservation Measures**

Energy conservation measures and, in particular, building enclosure related measures often provide a variety of ancillary benefits in addition to energy consumption and greenhouse gas emission reductions. These benefits include improved durability, thermal comfort, and acoustic comfort. Post-retrofit discussion with the owners have indicated the strong importance of these ancillary benefits and, in many cases, should be considered as primary benefits.

→ **Owner Engagement**

Major building enclosure renewals are a necessary part of the service life of a building to maintain performance; however, this type of work is often expensive and invasive. Strong engagement and buy-in of the building owner group in the renewal design and implementation process is required for to achieve success.

→ **Ventilation System Effectiveness, Efficiency, and Opportunity**

Corridor pressurization based ventilation systems have historically been pervasively used in multi-unit resident buildings; however, the efficiency and efficacy of these systems in mid- to high-rise buildings is typically poor. As a result, opportunities exist to further reduce the energy consumption and greenhouse gas emission of multi-unit residential buildings through the implementation of ventilation system retrofits. An optimal retrofit approach would likely include compartmentalization of the suites and recovery of heat from exhaust air, and in addition to the potential energy savings, also has the potential to significantly improve indoor air quality. Further research is required in this area.

Appendix A

Section 2 – Additional Analysis

Weather Normalized Energy Data

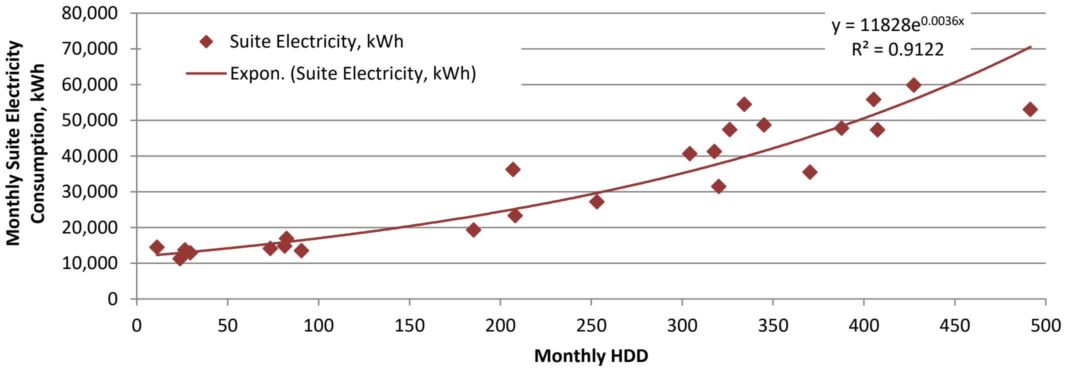


Figure A.1 Monthly suite electricity consumption versus heating degree days (HDD).

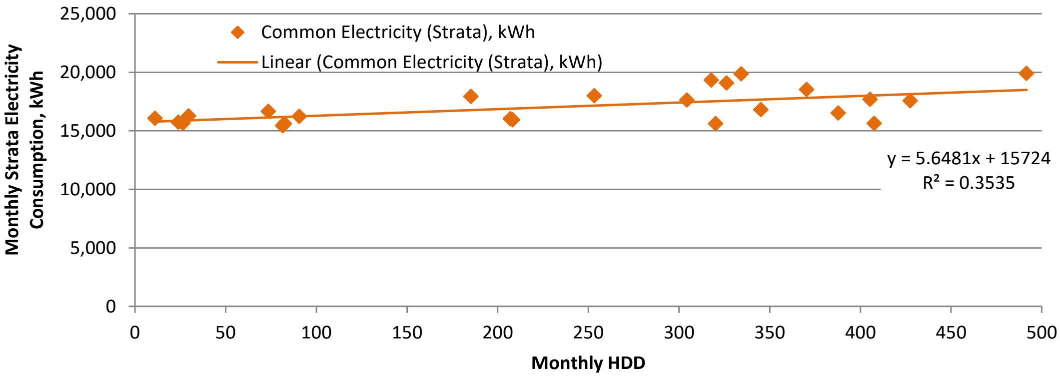


Figure A.2 Monthly common electricity consumption versus heating degree days (HDD).

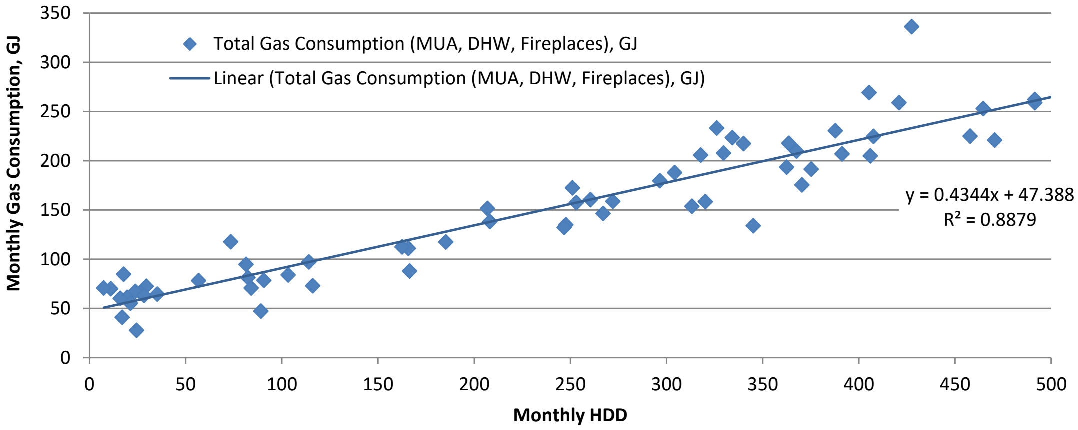


Figure A.3 Monthly gas consumption versus heating degree days (HDD).

Energy Model Inputs

Table A.1 shows the architectural inputs for the energy model of the retrofit building. Floor areas, enclosure areas, and window percentages were calculated through area takeoffs. Overall effective wall, roof, and window R- and U-values were estimated based on the field review and architectural drawings of the building assemblies. The infiltration rate was estimated at an average of 0.15 cfm per square foot of enclosure area at 5 Pa, since the existing building air tightness testing had not been completed at the initial time of modeling. This value will be confirmed through whole building air tightness testing.

TABLE A.1 ARCHITECTURAL INPUTS FOR THE RETROFIT BUILDING ENERGY MODEL

	Baseline	ECM	Units
Total Floor Area	54,082		ft²
Percent Area for Common Space	11%		
Number of Suites	37		
Number of Storeys (above grade)	13		
Height of Average Storey	8.7		ft
Orientation from North	0		°
Gross Exposed Wall Area, Wall 1	8,312		ft²
Gross Exposed Wall Area, Wall 2	8,312		ft²
Gross Exposed Wall Area, Wall 3	8,312		ft²
Gross Exposed Wall Area, Wall 4	8,312		ft²
Window Percentage, Wall 1	51%		
Window Percentage, Wall 2	51%		
Window Percentage, Wall 3	51%		
Window Percentage, Wall 4	51%		
Infiltration Rate (0.15 cfm/sf)	0.643	0.322	ACH
Overall Roof R-Value	9.5		°F-ft²-hr/Btu
Overall Wall R-Value	4.0	16.1	°F-ft²-hr/Btu
Overall Window U-Value	0.55	0.28, 0.17	Btu/°F-ft²-hr
Window Solar Heat Gain Coefficient	0.40		

Table A.2 shows the mechanical inputs for the energy model of the retrofit building. Equipment efficiencies and outdoor airflow rate were determined from equipment labels. It should be noted that the actual equipment operating efficiencies and airflow rates may not be per the labels; however, these values are used as inputs to the energy model since actual performance is not known. Several of the mechanical inputs were not known and were calibrated to the metered energy consumption, including set-point temperatures (suite and make-up air), fireplace load, and domestic hot water consumption. These values are difficult to predict for residential buildings due to variations with different occupants, but through calibrating the model to metered energy consumption a good approximation can be obtained.

TABLE A.2 MECHANICAL INPUTS FOR THE RETROFITS BUILDING ENERGY MODEL			
	Baseline	ECM	Units
System Type	No Direct Mechanical Ventilation / Central MAU (pressurized corridors for ventilation)	Minimum MAU for corridor pressurization, in-suite HRVs	
Ventilation			
Outside Air per sf of total floor area (suites and common)	0.061*	0.024	cfm/ft²
Overall Static Pressure	1.0		in. of water
Make-up Air Supply Temperature	68*		°F
Make-up Air Unit Heating Efficiency	80%		
Make-up Air Unit Type	Single Stage		
In-Suite Space Heating			
Space Heating Equipment	Electric Resistance		
Baseboard Capacity	5.0*		Btu/ft²
Fireplaces	Yes (floors 9, 10, 11, 12, 13 for a total of 14 fireplaces)		
Fireplace Diversified Load	1,200*		MBtuh
Fireplace Efficiency	40	80	%
Auxiliaries			
Fan Efficiency	50%*		
Domestic Hot Water			
Source	Fossil Fuel		
Heater Type	Modulating		
Supply Temperature	140		°F
Equipment Efficiency	82%	92%	
Avg. Daily Peak Flow Rate	2.9*		gpm
Space Conditions			
Heating Temperature Setpoint (Day)	68*		°F
Heating Temperature Setback (Night)	68*		°F

*Inputs adjusted by calibrating model to metered data.

Table A.3 shows the electrical inputs for the retrofit building, including lighting, plug loads and miscellaneous equipment. These values are difficult to predict for residential buildings due to occupant behaviour, but were calibrated to align with metered energy consumption to obtain a good approximation.

TABLE A.3 ELECTRICAL INPUTS FOR THE RETROFIT BUILDING ENERGY MODEL		
Common Area Lighting Power Density	0.32*	W/ft²
Suite Lighting Power Density	0.81*	W/ft²
Plug Load Power Density	0.50*	W/ft²
Peak Average Hourly Elevator Load	32.0*	kW
Exterior Lighting & Miscellaneous Loads	14.5*	kW

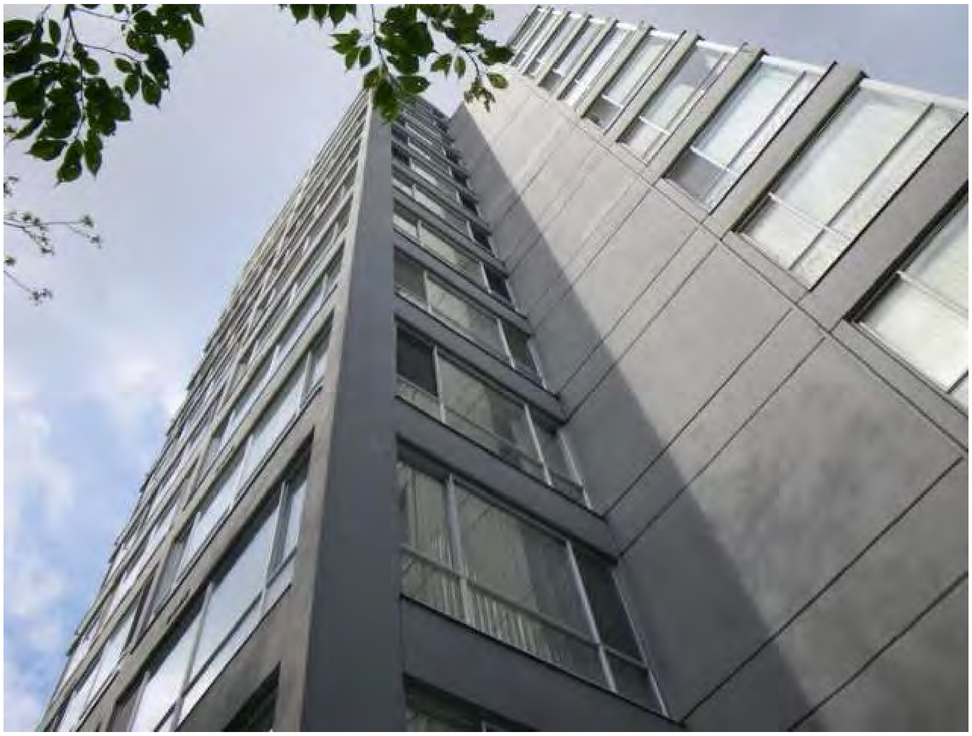
*Inputs adjusted by calibrating model to metered data.

Appendix B

Section 3 - Measurement and Verification Plan

Measurement and Verification Plan

Energy Efficiency in Mid- to High-Rise Residential Buildings



CLIENT Study Partners

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PROJECT # 3033.30

DATE July 23, 2013

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1. Background

1.1. Project Background

The Belmont is a 13 storey multi-unit residential building located in Vancouver, BC, built in 1986.

The principal wall type is a cast-in-place concrete wall with interior rigid insulation. There are also several small areas of steel stud walls with stucco cladding at the roof and ground floor levels. The existing wall assembly has an overall effective R-value of R-4. The typical window assembly is a non-thermally broken, aluminum window wall assembly. The glazing is typically double paned insulated glazing units (IGU's), and operable vents are typically sliding style. The windows have a U-value of approximately U-0.55. The primary roof at the Belmont is a low-slope membrane roof with rigid insulation, with an R-value of approximately R-10.

The building is heated by electric baseboards within the suites. Fourteen gas fireplaces are located within the suites at the top floors of the building. Ventilation air is heated at a gas-fired rooftop make-up air unit and provided to the central corridors, using the pressurized corridor approach. Intermittent, occupant controlled exhaust fans are present in the bathrooms and kitchens of the suites. The building does not have a central mechanical cooling system.

A building enclosure renewals project is currently underway at The Belmont. The initial goal of the project was to correct water ingress related issues. Additional Energy Conservation Measures (ECMs) were incorporated into the renewals work to also improve the energy efficiency of the building.

The ECMs in the current renewals project include the following:

1. Add exterior insulation to walls
2. Replace windows with triple glazed, fibreglass frame windows
3. Improve air tightness

Additional mechanical ECMs may be added to the project at a later phase, subject to further retrofit project funding. A second plan will be developed at this time to outline Measurement and Verification (M&V) for these ECMs.

The existing building energy consumption at The Belmont was analyzed through energy modeling calibrated to metered data provided by the utilities. Energy savings of the ECMs were predicted using the calibrated energy model. Savings will be confirmed through measurement and verification as outlined in this plan.

As part of the work being undertaken at the retrofit building, testing and monitoring is being performed in addition to energy monitoring, primarily related to airflow. The focus of this M&V plan is on confirming energy savings, and therefore the additional airflow testing is outside the scope of this plan and is not discussed. Please refer to Report 2 for monitoring and verification protocols for airflow and other related testing.

2. Measurement and Verification Plan

2.1. Energy Conservation Measures (ECM) Intent

Three ECMs are being implemented at the retrofit building as part of the first phase of building enclosure renewals:

1. Add exterior insulation to walls
2. Replace windows with triple glazed, fibreglass frame windows
3. Improve air tightness

The goal of the three ECMs is to reduce heating energy consumption at the retrofit building. This will be primarily seen in a reduction of the electric baseboard heating energy. The ECMs may also impact the gas fireplaces and gas-fired make-up air unit energy; however, such savings cannot be reliably known and are therefore not included in the energy modeling.

Operational Verification is defined in the IPMVP (Volume I EVO 10000-1:2012) as "Verification that the ECMs are installed and operating properly and have the potential to generate savings." At the retrofit building, Operational Verification of the building enclosure ECMs will be completed by periodic field review throughout the construction process, to ensure that all ECMs are completed correctly to realize the full energy savings potential. Site Visit Reports will document the construction progress and any deficiencies observed or corrections needed, to be signed off by the trades. Site visits are conducted as needed, but generally about once per week.

Aside from the enclosure ECMs, the Domestic Hot Water (DHW) boiler at the retrofit building was recently replaced. This may affect the baseline energy consumption, and will need to be considered in the M&V analysis. Other than this, no changes to the baseline are anticipated.

2.2. Selected IPMVP Option and Measurement Boundary

Four M&V options are defined in the IPMVP (Volume I EVO 10000-1:2012). Option D – Calibrated Simulation will be used to determine savings at the retrofit building. This method is similar to Option C – Whole Facility, however it also allows for the estimation of savings attributable to each ECM. For this project, Option D will assist in better examining the space heat savings and other end-use impacts. To perform Option D, an hourly energy simulation will be calibrated to monthly utility bills.

The measurement boundary is defined as the whole building energy consumption, both gas and electricity. No interactive effects beyond the measurement boundary are anticipated.

2.3. Baseline: Period, Energy and Conditions

The baseline energy consumption will be determined through metered gas and electricity provided by the utilities. The baseline period will be from 2006 to 2011. Data will be normalized based on Heating Degree Days (HDDs) to obtain data for a typical or average weather year, for comparison to the energy simulation output and the post retrofit period.

a) Baseline Period: 2006 to 2011, normalized based on Heating Degree Days (HDD) to determine an average weather year.

b) Baseline energy consumption: Table 2.1 shows the weather normalized baseline energy consumption at the retrofit building. Detailed calculations showing the derivation of this data will be provided in the M&V report. For an example of this process performed for other buildings, please refer to "Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia" (RDH 2011).

Table 2.1 Normalized Baseline Energy Consumption for the retrofit building

	Suite Electricity [kWh]	Common Electricity [kWh]	Gas [GJ]
Jan	62,920	18,618	247
Feb	39,936	16,514	204
Mar	45,507	18,110	208
Apr	31,851	17,084	169
May	23,976	17,104	130
June	16,014	16,006	86
July	13,674	16,223	63
Aug	13,430	16,195	60
Sept	18,428	16,226	103
Oct	29,972	17,455	157
Nov	46,149	17,666	213
Dec	59,828	18,539	241
Total	**401,685**	**205,740**	**1,904**

c) Independent Variable data: An Independent Variable is defined in the IPMVP as “A parameter that is expected to change regularly and have a measurable impact on the energy use of a system or facility.” The primary independent variable at the retrofit building is weather, primarily outdoor temperature. HDD values from the building weather station will be used to normalize energy data. The weather station has been set up on the roof of the building to record temperature, relative humidity, wind speed and direction, precipitation, and solar radiation.

Other Independent Variables that may impact energy consumption include occupancy changes and occupant behaviour. Tracking changes in occupant behaviour are beyond the scope of this project. However, minor changes from a small number of units will be averaged over the energy consumption of the whole building, and should not have a significant impact on the results.

d) Static factors: All baseline conditions (model inputs) will be documented in the M&V report. This information will include occupancy type, density and periods, operating conditions assumptions, building enclosure parameters, mechanical system parameters, and any other inputs or assumptions. Since the retrofit building is a multi-unit residential building, many of the energy end-uses are run by individual suite owners and therefore cannot be reliably known (e.g. owners may have different heating setpoints, and may change the setpoint randomly). However assumptions can be made regarding typical practice, and are generally reliable when the computer model is calibrated to actual energy use. These assumptions will be documented in the M&V report.

2.4. Reporting Period

The reporting period will be one year from the completion of the building enclosure ECM work. This will provide a long enough period to ensure the building is performing as intended, and to confirm annual savings are in line with the modeled savings.

2.5. Basis for Adjustment

Two types of adjustments are defined in the IPMVP: routine adjustments and non-routine adjustments. Routine adjustments are adjustments for any energy-governing factors that are expected to change routinely during the reporting period (i.e. independent variables), such as weather. Non-routine adjustments are adjustments for energy-governing factors which are not usually expected to change (i.e. static factors).

For the enclosure ECMs at the retrofit building, both routine and non-routine adjustments will be required. A routine adjustment will be made to account for weather variations. Both the baseline and reporting period energy consumption data will be adjusted or normalized based on the measured HDDs. A mathematical correlation of HDDs versus energy consumption will be developed, and this will be applied to normalize the data to a standard weather year set of monthly HDD values. This process is described in more detail in “Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia” (RDH 2011).

A non-routine adjustment to the baseline energy consumption may be required for Domestic Hot Water since the boiler was replaced in 2012 with a new unit; the new unit has the same nominal efficiency as the existing unit, however the new unit may operate more efficiently. Although this change will have little or no impact on space heating energy consumption, which is the target of the ECMs, it will still impact overall building energy consumption and therefore should be considered as an adjustment to the baseline. This non-routine adjustment will be investigated through a calibrated hourly energy simulation.

To that effect, savings will be reported as “Normalized Savings”, as opposed to “Avoided Energy Use”. Normalized Savings are defined as “The reduction in energy use or cost that occurred in the reporting period, relative to what would have occurred if the facility had been equipped and operated as it was in the baseline period but under a normal set of conditions.” In this case, the normal set of conditions is a typical or average weather year.

2.6. Analysis Procedure

The analysis procedure will be as follows:

1. Perform routine adjustment to baseline period energy consumption for weather (HDDs) and non-routine adjustment for new DHW boiler to determine baseline energy consumption.
2. Perform routine adjustment to reporting period energy consumption for weather (HDDs).
3. Subtract baseline energy minus reporting period energy to determine normalized savings.

The primary independent variable is weather, and this analysis will be valid over weather variations due to the HDD adjustment. Other possible independent variables identified include occupancy and occupant behaviour; however, these are not anticipated to change significantly in the reporting period.

2.7. Energy Prices

The energy prices initially used to evaluate savings of the ECMs were based on 2013 prices in Vancouver, BC. The prices used were $7.16/GJ for gas and a stepped electricity rate of $0.069/kWh up to 1,350 kWh, and $0.1034/kWh above 1,350 kWh per billing period. Energy prices change regularly, and so updated or current values may be used in the M&V analysis to re-assess the effectiveness of the ECMs and review or update payback, subject to changes in rates. Also, respected forecasts of future energy prices may be incorporated into the financial analysis. However, the same prices will always be used to compare baseline and reporting period energy consumption for a particular analysis; in other words, when comparing the baseline and post-retrofit energy costs, a single set of energy prices will be selected for the comparison. Prices for analysis will be determined in consultation with the project steering committee.

Residential rates do not have a demand charge in British Columbia, and therefore demand savings will not be included in this analysis.

2.8. Meter Specifications

Metering at the retrofit building is accomplished through several utility meters. Overall building gas consumption is metered on one meter for the whole building by FortisBC. Electricity is metered separately for each suite by BC Hydro, however suite electricity is reported as an aggregate of all suites to protect the privacy of individual owners. In addition, common area electricity consumption is also metered separately by BC Hydro, which includes the parkade, corridors, main entrance lobby and outdoor lighting (on one meter).

2.9. Monitoring Responsibilities

Utility meter data is recorded and reported by FortisBC and BC Hydro, and will be used for the M&V process. Additional weather station data is taken hourly by the data collection equipment, and data is uploaded daily to a database through the sensor supplier (SMT Analytics).

2.10. Expected Accuracy

The IPMVP defines three ways in which errors occur: modeling, sampling, and measurement.

The modeling undertaken as part of the M&V process is whole building energy modeling that simulates hourly energy consumption over a typical weather year. This tool is widely used to evaluate and assess building energy consumption. Calibrating the energy model to the baseline energy consumption and reporting period energy consumption further reduces modeling error.

Sampling error is minimized by measuring the whole building energy consumption over the period of an entire year.

Measurement error occurs due to the accuracy and precision of sensors and metering equipment. Utility meter data is very accurate since this data is used for billing purposes; federal regulations from Measurement Canada require that all meters in service in Canada are within a 1% accuracy tolerance[1]. The precision of the weather station data has been reviewed and is well within the range needed for M&V at the retrofit building. The data sheet is attached for reference. Should any data be lost, interpolations will be used.

A detailed statistical analysis of the accuracy and precision of energy savings at the retrofit building is beyond the scope of this project.

2.11. Budget

The M&V work and savings determination is included in the overall consulting budget for the energy study of the retrofit building, as part of the larger research and pilot project.

2.12. Report Format

A complete M&V report will be prepared and included as part of the final project report of the ECMs and other research work being completed at the retrofit building. The report will include the requirements stated in Chapter 6 of the IPMVP (Volume I EVO 10000-1:2012). The proposed format of the report will be submitted to the Power Smart M&V Department for review and approval. The report will be reviewed with the owners of the retrofit building.

2.13. Quality Assurance

The M&V report will be reviewed by senior engineers at RDH for quality assurance. In addition, the report will be reviewed by the Steering Committee, and comments received will be incorporated into the report. The report will also be reviewed by the Power Smart M&V Department and by FortisBC, and will be modified in accordance with their directives. The owners will have an opportunity to review and comment on the draft report before a final version is completed.

2.14. Simulation Software

The calibrated simulation method will be used for the M&V analysis at the retrofit building. The software program to be used is DesignBuilder Version 3, since this is an hourly energy simulation program that uses the EnergyPlus engine, a common energy simulation tool. Input and output data will be provided as part of the M&V report. Input data will include an indication of which parameters were measured and which where estimated. An explanation of the calibration of the baseline model to the baseline energy consumption data will be provided. For an example of this process completed for other buildings, please refer to the report "Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia" (RDH 2011).

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[1] BC Hydro, http://www.bchydro.com/news/conservation/2011/smart_meter_facts.html

Appendix C

Section 3 - Monitoring Equipment List

Name	SMT Node Ref. #	Location	Sensors
0201 - ED	8012	Suite 201 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
0202 - ED	8029	Suite 202 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
0203 - ED	8021	Suite 203 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
0200 - CO	8004	Corridor 02	Temperature, Relative Humidity, CO2, Pressure to Corridor Above
0301 - ED	8016	Suite 301 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
0301 - LR	8011	Suite 301 - Living Room	Temperature, Relative Humidity, Pressure to Exterior
0301 - MBR	8032	Suite 301 - Master Bedroom	Temperature, Relative Humidity, CO2
0302 - ED	8023	Suite 302 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
0302 - LR	8030	Suite 302 - Living Room	Temperature, Relative Humidity, Pressure to Exterior
0302 - MBR	8041	Suite 302 - Master Bedroom	Temperature, Relative Humidity, CO2
0303 - ED	8037	Suite 303 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
0303 - LR	8042	Suite 303 - Living Room	Temperature, Relative Humidity, CO2, Pressure to Exterior
0303 - MBR	8040	Suite 303 - Master Bedroom	Temperature, Relative Humidity, CO2, Pressure to Exterior
0300 - CO	8009	Corridor 03	Temperature, Relative Humidity, CO2, Pressure to Corridor Above
0401 - ED	8031	Suite 401 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
0402 - ED	8036	Suite 402 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
0403 - ED	8006	Suite 403 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
0400 - CO	8020	Corridor 04	Temperature, Relative Humidity, CO2, Pressure to Corridor Above
0500 - CO	8035	Corridor 05	Temperature, Relative Humidity, CO2, Pressure to Corridor Above
0600 - CO	8038	Corridor 06	Temperature, Relative Humidity, CO2, Pressure to Corridor Above
0700 - CO	8008	Corridor 07	Temperature, Relative Humidity, CO2, Pressure to Corridor Above
0800 - CO	8024	Corridor 08	Temperature, Relative Humidity, CO2, Pressure to Corridor Above
0900 - CO	8007	Corridor 09	Temperature, Relative Humidity, CO2, Pressure to Corridor Above
1001 - ED	8000	Suite 1001 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
1001 - FIRE	5133	Suite 1001 - Fireplace	Temperature, Relative Humidity, Fireplace On/Off
1002 - ED	8001	Suite 1002 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
1002 - FIRE	5126	Suite 1002 - Fireplace	Temperature, Relative Humidity, Fireplace On/Off
1003 - ED	8025	Suite 1003 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
1003 - FIRE	5113	Suite 1003 - Fireplace	Temperature, Relative Humidity, Fireplace On/Off
1000 - CO	8010	Corridor 10	Temperature, Relative Humidity, CO2, Pressure to Corridor Above
1101 - ED	8002	Suite 1101 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
1101 - LR	8018	Suite 1101 - Living Room	Temperature, Relative Humidity, Pressure to Exterior
1101 - MBR	8034	Suite 1101 - Master Bedroom	Temperature, Relative Humidity, CO2
1101 - FIRE	5127	Suite 1101 - Fireplace	Temperature, Relative Humidity, Fireplace On/Off
1102 - ED	8019	Suite 1102 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
1102 - LR	8043	Suite 1102 - Living Room	Temperature, Relative Humidity, Pressure to Exterior
1102 - MBR	8033	Suite 1102 - Master Bedroom	Temperature, Relative Humidity, CO2
1102 - FIRE	5117	Suite 1102 - Fireplace	Temperature, Relative Humidity, Fireplace On/Off
1103 - ED	8027	Suite 1103 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
1103 - LR	8014	Suite 1103 - Living Room	Temperature, Relative Humidity, Pressure to Exterior
1103 - MBR	8039	Suite 1103 - Master Bedroom	Temperature, Relative Humidity, CO2, Pressure to Exterior
1103 - FIRE	5138	Suite 1103 - Fireplace	Temperature, Relative Humidity, Fireplace On/Off
1100 - CO	8017	Corridor 11	Temperature, Relative Humidity, CO2, Pressure to Corridor Above
1201 - ED	8015	Suite 1201 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
1201 - FIRE	5149	Suite 1201 - Fireplace	Temperature, Relative Humidity, Fireplace On/Off
1202 - ED	8028	Suite 1202 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
1202 - FIRE	5119	Suite 1202 - Fireplace	Temperature, Relative Humidity, Fireplace On/Off
1203 - ED	8005	Suite 1203 - Near Entrance Door	Temperature, Relative Humidity, CO2, Pressure to Corridor
1203 - FIRE	5132	Suite 1203 - Fireplace	Temperature, Relative Humidity, Fireplace On/Off
1200 - CO	8026	Corridor 12	Temperature, Relative Humidity, CO2, Pressure to Corridor Above
1300 - CO	8022	Corridor 13	Temperature, Relative Humidity, CO2, Pressure to Roof
ROOF	8059	On Mechanical Penthouse Wall	Temperature, Relative Humidity, CO2
GROUND	8076	On Wall near Front Entrance	Temperature, Relative Humidity, CO2
MAU	8073	Inside Make Up Air Unit	Temperature, Relative Humidity, CO2 , Pressure (MAU Operation)
GAS MAU	5146	Attached to gas submeter for MAU	Gas pulse meter recording
GAS DHW	5263	Attached to gas submeter for MAU	Gas pulse meter recording
FLOAT01 - A2	5114	Elevator Mechanical Room	Temperature, Relative Humidity
FLOAT02 - A2	5115	Mail Room	Temperature, Relative Humidity
FLOAT03 - A2	5116	Parkade - Near Vehicle Ramp	Temperature, Relative Humidity
FLOAT04 - A2	5139	Parkade - Near Elevator Entrance	Temperature, Relative Humidity
FLOAT05	8101	Top of Fire Exit Stairs	Temperature, Temperature, Relative Humidity, CO2 , Pressure to exterior
FLOAT06	8100	Elevator Mechanical Room	Temperature, Temperature, Relative Humidity, CO2 , Pressure to exterior
WS	n/a	On roof of mechanical penthouse	Weather Station (Temperature, Relative Humidity, Precipitation, Wind Direction, Wind Speed, Solar Radiation, Barometric Pressure)

Sensor Type	Type
CO_2	COZIR 5000PPM
Pressure	All Sensor 0.25" DS 0032
SMT-A2 & SMT-A3 Built-in Temperature	Cantherm MF58
SMT-A2 & SMT-A3 Built-in Relative Humidity	Honeywell HIH-4000-001
Fireplace ON/OFF (Temperature) & Temperature	Cantherm MF52 Thermistor
Temperature and Relative Humidity	Measurement Specialties HTM25X0LF
Weather Station	Davis Vantage Pro2 with Solar Radiation Sensor

Appendix D

Section 3 - Monitoring Equipment Specifications

Amplified Very Low Pressure Sensors

AMPLIFIED Pressure Sensors

Features

- 0.25 and 0.50 In H2O Pressure Ranges
- Ratiometric 4V Output
- Temperature Compensated
- Calibrated Zero and Span

Applications

- Medical Breathing
- HVAC

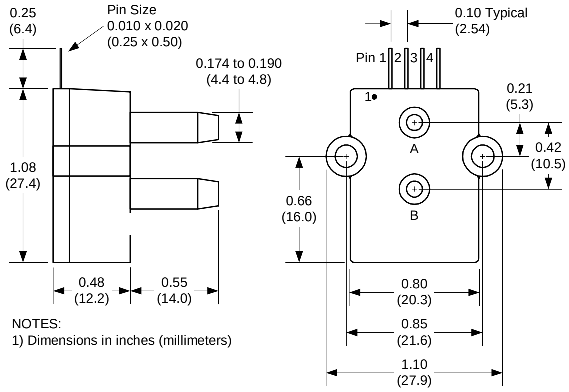
General Description (generic product)

The Amplified line of low pressure sensors is based upon a proprietary technology to reduce all output offset or common mode errors. This model provides a ratiometric 4-volt output with superior output offset characteristics. Output offset errors due to change in temperature, stability to warm-up, stability to long time period, and position sensitivity are all significantly reduced when compared to conventional compensation methods. In addition the sensor utilizes a silicon, micromachined, stress concentration enhanced structure to provide a very linear output to measured pressure.

These calibrated and temperature compensated sensors give an accurate and stable output over a wide temperature range. This series is intended for use with non-corrosive, non-ionic working fluids such as air, dry gases and the like.

The output of the device is ratiometric to the supply voltage over a supply voltage range of 4.5 to 5.5 volts.

Physical Dimensions



NOTES:
1) Dimensions in inches (millimeters)

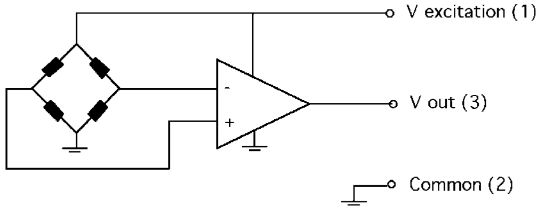
pin 1: Vsupply

pin 2: Common

pin 3: Voutput

pin 4: do not connect

Equivalent Circuit



Pressure Sensor Ratings

Supply Voltage, Vs	+4.5 to +5.5 Vdc
Common-mode pressure	-10 to +10 psig
Lead Temperature, max (soldering 2-4 sec.)	250°C

Environmental Specifications

Temperature Ranges

Compensated	5 to 50° C
Operating	-25 to 85° C
Storage	-40 to 125° C
Humidity Limits	0 to 95% RH (non condensing)

Performance Characteristics for: 0.25 INCH-D-4V

Parameter, note 1	Minimum	Nominal	Maximum	Units
Operating Range, differential pressure		±0.25		"H2O
Output Span, note 5	±1.80	±2.0	±2.20	volt
Offset Voltage @ zero differential pressure	2.00	2.25	2.50	volt
Offset Temperature Shift (5°C-50°C), note 2			±50	mvolt
Offset Warm-up Shift, note 3		±20	±50	mvolt
Offset Position Sensitivity (±1g)		±40	±100	mvolt
Offset Long Term Drift (one year)		±20	±50	mvolt
Linearity, hysteresis error, note 4		0.05	0.25	%fs
Span Shift (5°C-50°C), note 2			±4	%span

Performance Characteristics for: 0.5 INCH-G-4V

Parameter, note 1	Minimum	Nominal	Maximum	Units
Operating Range, gage pressure		0.5		"H2O
Output Span, note 5	3.80	4.0	4.20	volt
Offset Voltage @ zero gage pressure	0.10	0.25	0.40	volt
Offset Temperature Shift (5°C-50°C), note 2			±50	mvolt
Offset Warm-up Shift, note 3		±20	±50	mvolt
Offset Position Sensitivity (±1g)		±40	±100	mvolt
Offset Long Term Drift (one year)		±20	±50	mvolt
Linearity, hysteresis error, note 4		0.05	0.25	%fs
Span Shift (5°C-50°C), note 2			±4	%span

Specification Notes

note 1: All parameters are measured at 5.0 volt excitation, for the nominal full scale pressure and room temperature unless otherwise specified. **Pressure measurements are with positive pressure applied to Port B.**

note 2: Shift is relative to 25°C.

note 3: Shift is within the first hour of excitation applied to the device.

note 4: Measured at one-half full scale rated pressure using best straight line curve fit.

note 5: The voltage added to the offset voltage at full scale pressure. Nominally the output voltage range is 0.25 to 4.25 volts for minus to plus full scale pressure.

CANTHERM

Supplying high-quality bimetal and thermal sensor products.

MF52 Pearl-Shaped Precision NTC Thermistor for Temperature Measurement

The MF52 series of Pearl-Shaped NTC Thermistors is ethoxyline resin coated. The small size is made possible by new materials and manufacturing methods which provide the benefit of close tolerances and fast response. MF52 thermistors are available with 5 lead styles in standard or custom lengths.

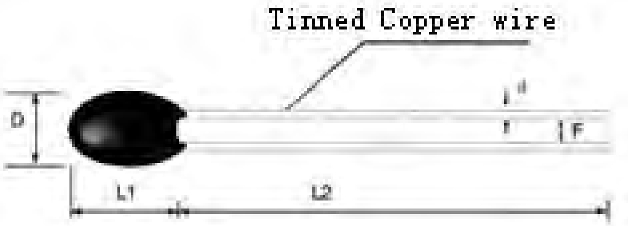
UL 1434
(File E240991)

Application

- Heating, Ventilation & Air Conditioning
- Temperature Regulation and Measurement
- Electronic Thermometers
- Liquid Level Sensing
- Automotive Electronics
- Medical Equipment and Apparatus
- Battery Packs and Portable Electronics

Characteristics

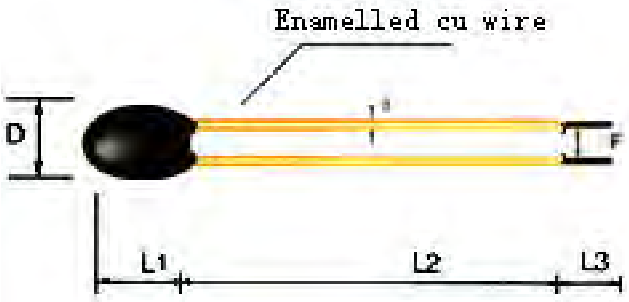
- Small Size and fast response
- Available tolerances: ±1%, ±2%, ±3% and ±5%
- Long-term Stability and Reliability
- Excellent Tolerance and Interchangeability
- Available in all popular resistance values
- Dissipation Constant ≥2.0mW/°C
- Time Constant of ≤7 seconds in still air
- Available in custom probes
- UL Listed E240991



Dimensions(mm)

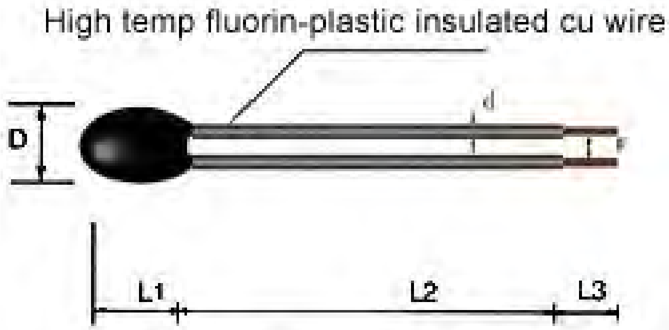
A: Tin. Ag. nickel plated cu wire

Code	D max	L_1 max	L_2 min	d +/- 0.05	F +/- 0.05
A1	2	3	25	0.3	2.0
A2	3	4	25	0.45	2.5



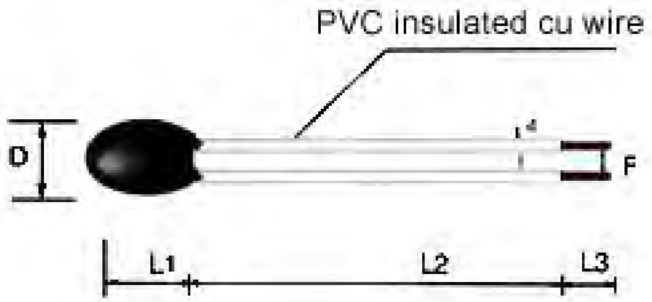
B: Enamelled cu wire

Code	D max	L_1 max	L_2 min	L_3 +/- 1	d +/- 0.05	F +/- 0.05
B1	2	3.5	Customer Specified	5	0.2	2.0
B2	3	4	Customer Specified	5	0.3	2.5



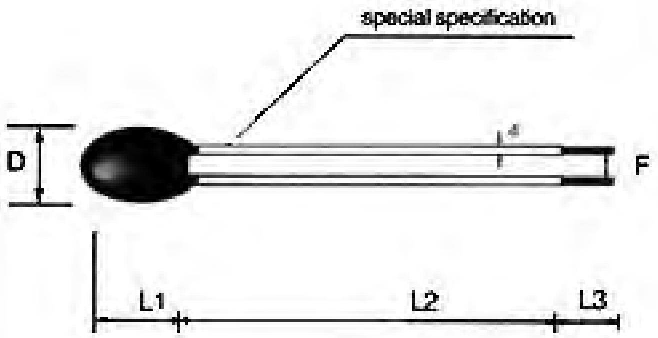
C: High temp fluorin-plastic wire

Code	D max	L_1 max	L_2 min	L_3+/- 1	d +/- 0.05	F +/- 0.05
C1	2	3.5	Customer Specified	5	0.4	2.0
C2	3	4	Customer Specified	5	0.5	2.5



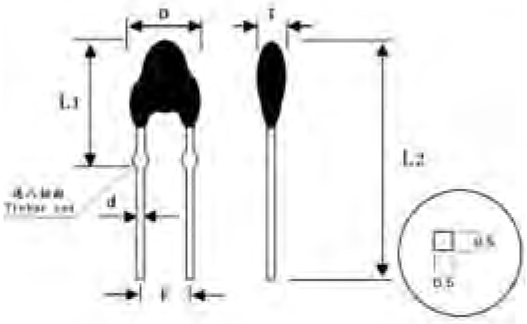
D: PVC wire

Code	D max	L_1 max	L_2 min	L_3+/-1	d +/- 0.05	F +/- 0.05
D1	2	3.5	Customer Specified	5	0.26	2.5
D2	3	4	Customer Specified	5	0.32	2.5



E: Lead and head according to specification

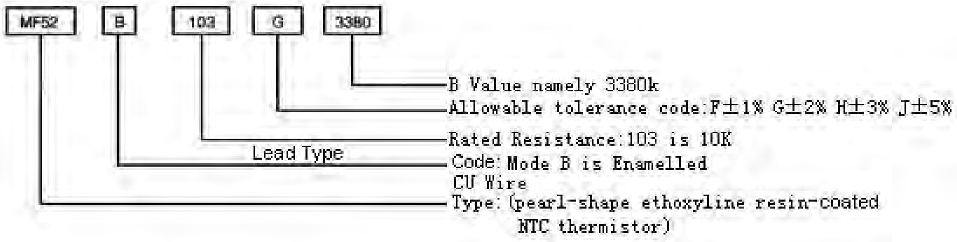
Code	D max	L_1 max	L_2 min	L_3+/- 1	d +/- 0.05	F +/- 0.05
E1	Customer Specified	Customer Specified	Customer Specified	5	Customer Specified	2.5
E2	Customer Specified	Customer Specified	Customer Specified	5	Customer Specified	2.5



F: Tinned Lead-Frame Style

Code	D max	L_1 max	L2 +/- 1.5	d max	F+/- 0.5	Tmax
F	3.8	9.5	17	5.0	2.5	3.5

Specification



Main Techno-Parameter

Part No.	Rated Resistance R_{25} (KΩ)	B Value (25/50°C) (K)	Rated Power(mw)	Dissi. Coef. (mW/ °C)	Thermal time Constant(S)	Operating Temp.(°C)
MF52□□□3100	0.1-20	3100	≤ 50	≥ 2.0 In Still Air	≤ 7 In Still Air	-55° - +125°C
MF52□□□3270	0.2-20	3270				
MF52□□□3380	0.5-50	3380				
MF52□□□3470	0.5-50	3470				
MF52□□□3600	1-100	3600				
MF52□□□3950	5-100	3950				
MF52□□□4000	5-100	4000				
MF52□□□4050	5-200	4050				
MF52□□□4150	10-250	4150				
MF52□□□4300	20-1000	4300				
MF52□□□4500	20-1000	4500				

Remark:
* B Value (25/50C) error is ±1% for components with rated resistance tolerance of ±1% and ±2% for all others.

Notice:
* The two ends of the lead wire cannot endure too big pull because of the small size and soldered spot in series of MF52.
* Solder at least 5mm from the bottom of wire.

CANTHERM

Supplying high-quality bimetal and thermal sensor products.

MF58 Glass Shell Precision NTC Thermistors

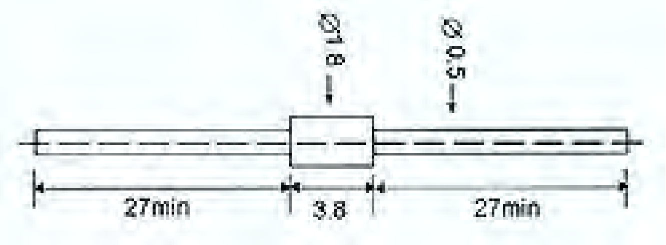
The MF58 is a NTC thermistor which is manufactured using a combination of ceramic and semiconductor techniques. It is equipped with tinned axial leads and then wrapped with purified glass.

Applications

Temperature compensation and detection for:

- Household appliances (air conditioners, microwave ovens, electric fans, electric heaters etc.)
- Office equipment (copiers, printers etc.)
- Industrial, medical, environmental, weather and food processing equipment
- Liquid level detection and flow rate measurement
- Mobile phone battery
- Apparatus coils, integrated circuits, quartz crystal oscillators and thermocouples.

Dimensions(mm)



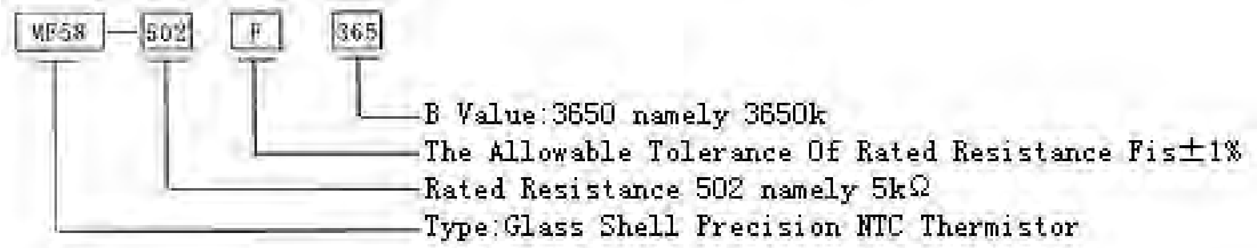
Features

- Good stability and repeatability
- High reliability
- Wide range of resistance: 0.1~1000KΩ
- Tight tolerance on resistance and Beta values
- Usable in high-temperature and high-moisture environments
- Small, light, strong package,
- Suitable for automatic insertion on thru-hole PCBs
- Rapid response
- High sensitivity

Main Techno-Parameter

- Zero power resistance range (R25): 0.1~1000KΩ
- Available tolerances of R25:
  F=±1% G=±2% H=±3% J=±5% K=±10%
- B value (B25/50°C) range: 3100~4500K
- Available tolerances of B value: ±0.5%, ±1%, ±2%
- Dissipation factor: ≥2mW/°C (In Still Air)
- Thermal time constant: ≤20S (In Still Air)
- Operating temperature range: -55°C ~ +200°C
- Rated Power: ≤50mW

Specifications



2008/Feb

COZIR™

Ultra Low Power Carbon Dioxide Sensor

COZIR is an ultra low power (3.5mW[4]), high performance CO_2 sensor, ideally suited for battery operation, portable instruments and HVAC. Based on GSS IR LED and Detector technology, and innovative optical designs, the *COZIR* offers the lowest power NDIR sensor available. Optional temperature, humidity and light sensing are available. *COZIR* is a third generation product from GSS – leaders in IR LED CO2 sensing.

- Ultra-low Power 3.5mW
- Measurement ranges from 2000ppm to 2%
- Low noise measurement (<10ppm)
- 3.3V supply.
- Peak current only 33mA.
- Optional Temperature and Humidity Output

Specifications

General Performance

Warm-up Time

- < 10s

Operating Conditions

- 0°C to 50°C (standard)
- -25°C to 55°C (extended range)
- 0 to 95% RH, non-condensing

Recommended Storage

- -30°C to +70°C

CO2 Measurement

Sensing Method

- Non-dispersive infrared (NDIR) absorption
- Patented Gold-plated optics
- Patented Solid-state source and detector

Sample Method

- Diffusion

Measurement Range

- 0-2,000ppm, 0-5,000ppm, 0-10,000ppm (1%) CO2
- Extended range (up to 100%) available

Accuracy

- ±50 ppm +/- 3% of reading[1]

Non Linearity

- < 1% of FS

Pressure Dependence

- 0.13% of reading per mm Hg

Operating Pressure Range

- 950 to 1050 bar[2]

Response Time

- 30 secs to 2 mins (user Configurable)[3]
- Reading refreshed twice per second.[3]

Electrical/Mechanical

Power Input

- 3.25V to 5.5V DC
- Peak Current 33mA[4].
- Average Current <1.5mA[4].

Power Consumption

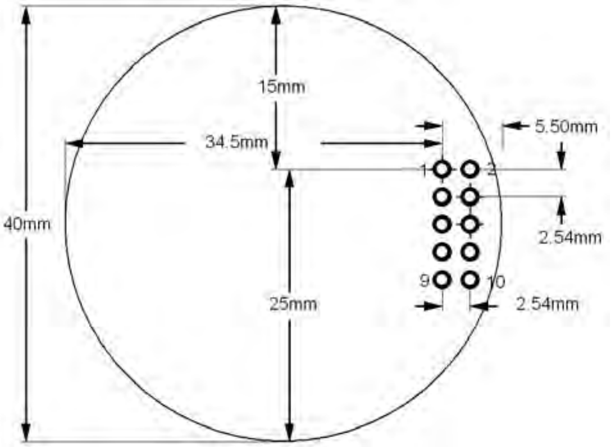
- 3.5 mW[4]

Wiring Connections

- 2x5 0.1” header.

view from underside (connector side)

1	GND	2	N/C
3	3.3V (nominal)	4	N/C
5	Rx	6	N/C
7	Tx	8	Nitrogen Zero
9	Analog (0.1 to 3.3V)	10	Fresh Air Zero



Note that the drawing shows details of the PCB inside the sensor casing. The outside dimension of the sensor casing is 43mm.

Pin 2 should not be connected. Pins 4 and 6 do not require connection and are internally connected to GND.

The zeroing options are for hardware zeroing (both active low). These functions can also be implemented by sending a serial command (recommended).

Typical connections for digital interface are GND, 3.3V, Rx and Tx.

The analog (voltage) output is available only when specified. Otherwise, N/C.

The serial connection is 9600baud, 8 bit, no parity, one stop bit. There is no hardware flow control. Note that Vh for the serial Rx and Tx lines will be 3V regardless on the supply voltage.

Temperature & Humidity Measurement[5]

Optional Temperature and Humidity sensor (only available as digital output)

Sensing Method

Humidity:	Capacitive
Temperature:	Bandgap

Measurement Range

- -25 to +55 °C
- 0 to 95% RH

Resolution

- 0.08 °C , 0.08% RH

Absolute Accuracy[5]

• +/- 1 °C	0°C to 55°C.
• +/- 3% RH	20°C to 55°C.
• +/- 2 °C	over the full temperature range.
• +/- 5% RH	over the full temperature range.

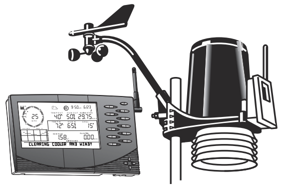
Repeatability

- +/- 0.1 °C
- +/- 0.1 % RH

Note 1: All measurements are at STP unless otherwise stated.
Note 2: External Pressure calibration required to eliminate pressure dependence.
Note 3: User Configurable Filter Response.
Note 4: Power measurements for standard CO2 sensor with 2 readings/second. Temp. and humidity measurements increase power consumption.
Note 5: Temperature and Humidity derived from Sensirion SHT21 chip. See Sensirion data sheet for full details.

Wireless Vantage Pro2™ & Vantage Pro2™ Plus Stations

(Including Fan-Aspirated Models)



6152 6162
6153 6163

Vantage Pro2™ (6152, 6153) and Vantage Pro2™ Plus (6162, 6163) Wireless Weather Stations include two components: the Integrated Sensor Suite (ISS) which houses and manages the external sensor array, and the console which provides the user interface, data display, and calculations. The ISS and Vantage Pro2 console communicate via an FCC-certified, license-free, spread-spectrum frequency-hopping (FHSS) transmitter and receiver. User-selectable transmitter ID codes allow up to eight stations to coexist in the same geographic area. The frequency hopping spread spectrum technology provides greater communication strength over longer distances and areas of weaker reception. The Wireless Vantage Pro2™ Plus weather station includes two additional sensors that are optional on the Vantage Pro2: the UV sensor and the solar radiation sensor. The console may be powered by batteries or by the included AC-power adapter. The wireless ISS is solar powered with a battery backup. Use WeatherLink™ for Vantage Pro and Vantage Pro2 to let your weather station interface with a computer, to log weather data, and to upload weather information to the internet.

The 6152 and 6162 rely on passive shielding to reduce solar-radiation induced temperature errors in the outside temperature sensor readings. The Fan-aspirated 6153 and 6163 combine passive shielding with a solar-powered fan that draws outside air in over the temperature and humidity sensors, providing a much more accurate temperature reading than that available using passive shielding alone.

Integrated Sensor Suite (ISS)

Operating Temperature	-40° to +150°F (-40° to +65°C)
Non-operating Temperature	-40° to +158°F (-40° to +70°C)
Current Draw (ISS SIM only)	0.14 mA (average), 30 mA (peak) at 4 to 6 VDC
Solar Power Panel	0.5 Watts (ISS SIM), plus 0.75 Watts (Fan-Aspirated)
Battery (ISS SIM /Fan-Aspirated)	CR-123 3-Volt Lithium cell / 2 - 1.2 Volt NiCad C-cells
Battery Life (3-Volt Lithium cell)	8 months without sunlight - greater than 2 years depending on solar charging
Battery Life (NiCad C-cells)	1 year
Fan Aspiration Rate (Fan-Aspirated Only)	190 feet/min. (0.9 m/s) (full sun), 80 feet/min. (0.4 m/s) (battery only) (intake flow rate) 500 feet/min. (2.5 m/s) (full sun), 280 feet/min. (1.4 m/s) (battery only) (sensor chamber flow rate)
Connectors, Sensor	Modular RJ-11
Cable Type	4-conductor, 26 AWG
Cable Length, Anemometer	40' (12 m) (included) 540' (165 m) (maximum recommended)
Wind Speed Sensor	Wind cups with magnetic switch
Wind Direction Sensor	Wind vane with potentiometer
Rain Collector Type	Tipping bucket, 0.01" per tip (0.2 mm with metric rain adapter), 33.2 in^2 (214 cm^2) collection area
Temperature Sensor Type	PN Junction Silicon Diode
Relative Humidity Sensor Type	Film capacitor element
Housing Material	UV-resistant ABS, ASA plastic

ISS Dimensions:

Product #	(Length x Width x Height)	Package Weight
6152	11.00" x 9.38" x 14.00" (279 mm x 238 mm x 355 mm)	5.7 lbs. (2.6 kg)
6162		6.1 lbs. (2.6 kg)
6153	11.00" x 9.38" x 21.00" (279 mm x 238 mm x 533 mm)	8.6 lbs. (3.9 kg)
6163		9 lbs. (4.1 kg)

Console

Console Operating Temperature	+32° to +140°F (0° to +60°C)
Non-Operating (Storage) Temperature	+14° to +158°F (-10° to +70°C)
Current Draw	0.9 mA average, 30 mA peak, (add 120 mA for display lamps, add 0.125 mA for each optional wireless transmitter received by the console) at 4 - 6 VDC
AC Power Adapter	5 VDC, 300 mA, regulated
Batteries	3 C-cells
Battery Life	up to 9 months
Connectors	Modular RJ-11
Housing Material	UV-resistant ABS plastic
Console Display Type	LCD Transflective
Display Backlight	LEDs
Dimensions (console: length x width x height, display length x height)	
Console with antenna down	10.625" x 6.125" x 1.625" (270 mm x 156 mm x 41 mm)
Console with antenna extended up	10.625" x 9.625" x 1.625" (270 mm x 245 mm x 41 mm)
Display	5.94" x 3.375" (151 mm x 86 mm)
Weight (with batteries)	1.88 lbs. (.85 kg)

Data Displayed on Console

Data display categories are listed with General first, then in alphabetical order.

General

Historical Data	Includes the past 24 values listed unless otherwise noted; all can be cleared and all totals reset
Daily Data	Includes the earliest time of occurrence of highs and lows; period begins/ends at 12:00 am
Monthly Data	Period begins/ends at 12:00 am on the first of the month
Yearly Data	Period begins/ends at 12:00 am on the first of January unless otherwise noted
Current Display Data	Current display data describes the current reading for each weather variable. In most cases, the variable lists the most recently updated reading or calculation. Some current variable displays can be adjusted so there is an offset for the reading
Current Graph Data	Current graph data appears in the right-most column in the console graph and represents the latest value within the last period on the graph; totals can be set or reset. Display intervals vary. Examples include: Instant, 15-min., and Hourly Reading; Daily, Monthly, High and Low
Graph Time Interval	1 min., 10 min., 15 min., 1 hour, 1 day, 1 month, 1 year (user-selectable, availability depends upon variable selected)
Graph Time Span	24 Intervals + Current Interval (see Graph Intervals to determine time span)
Graph Variable Span (Vertical Scale)	Automatic (varies depending upon data range); Maximum and Minimum value in range appear in ticker
Alarm Indication	Alarms sound for only 2 minutes (time alarm is always 1 minute) if operating on battery power. Alarm message is displayed in ticker as long as threshold is met or exceeded. Alarms can be silenced (but not cleared) by pressing the DONE key.
Transmission Interval	Varies with transmitter ID code from 2.25 seconds (#1=shortest), to 3 seconds (#8=longest)
Update Interval	Varies with sensor - see individual sensor specs

Barometric Pressure

Resolution and Units	0.01" Hg, 0.1 mm Hg, 0.1 hPa/mb (user-selectable)
Range	16.00" to 32.50" Hg, 410 to 820 mm Hg, 540 to 1100 hPa/mb
Elevation Range	-999’ to +15,000’ (-600 m to 4570 m) (Note that console screen limits entry of lower elevation to -999’ when using feet as elevation unit.)
Uncorrected Reading Accuracy	±0.03" Hg (±0.8 mm Hg, ±1.0 hPa/mb) (at room temperature)
Sea-Level Reduction Equation Used	United States Method employed prior to use of current "R Factor" method

Equation Source	Smithsonian Meteorological Tables
Equation Accuracy	±0.01" Hg (±0.3 mm Hg, ±0.3 hPa/mb)
Elevation Accuracy Required	±10’ (3m) to meet equation accuracy specification
Overall Accuracy	±0.03" Hg (±0.8 mm Hg, ±1.0 hPa/mb)
Trend (change in 3 hours)	Change 0.06" (2 hPa/mb, 1.5 mm Hg) = Rapidly Change 0.02" (.7hPa/mb, .5 mm Hg)= Slowly
Trend Indication	5 position arrow: Rising (rapidly or slowly), Steady, or Falling (rapidly or slowly)
Update Interval	1 minute or when console BAR key is pressed twice
Current Display	Instant
Current Graph Data	Instant, 15-min., and Hourly Reading; Daily, Monthly, High and Low
Historical Graph Data	15-min. and Hourly Reading; Daily, Monthly Highs and Lows
Alarms	High Threshold from Current Trend for Storm Clearing (Rising Trend Low Threshold from Current Trend for Storm Warning (Falling Trend)
Range for Rising and Falling Trend Alarms	0.01 to 0.25" Hg (0.1 to 6.4 mm Hg, 0.1 to 8.5 hPa/mb)

Clock

Resolution	1 minute
Units	Time: 12 or 24 hour format (user-selectable)
Date	US or International format (user-selectable)
Accuracy	±8 seconds/month
Adjustments	Time: Automatic Daylight Savings Time (for users in North America and Europe that observe it in AUTO mode, MANUAL setting available for all other areas) Date: Automatic Leap Year
Alarms	Once per day at set time when active

Dewpoint (calculated)

Resolution and Units	1°F or 1°C (user-selectable) °C is converted from °F rounded to the nearest 1°C
Range	-105° to +130°F (-76° to +54°C)
Accuracy	±3°F (±1.5°C) (typical)
Update Interval	10 to 12 seconds
Source	World Meteorological Organization (WMO)
Equation Used	WMO Equation with respect to saturation of moist air over water
Variables Used	Instant Outside Temperature and Instant Outside Relative Humidity
Current Display Data	Instant Calculation
Current Graph Data	Instant Calculation; Daily, Monthly High and Low
Historical Graph Data	Hourly Calculations; Daily, Monthly Highs and Lows
Alarms	High and Low Threshold from Instant Calculation

Evapotranspiration (calculated, requires solar radiation sensor)

Resolution and Units	0.01" or 0.1 mm (user-selectable)
Range	Daily to 32.67" (832.1 mm); Monthly & Yearly to 199.99" (1999.9 mm)
Accuracy	Greater of 0.01" (0.25 mm) or ±5%, Reference: side-by-side comparison against a CIMIS ET weather station
Update Interval	1 hour
Calculation and Source	Modified Penman Equation as implemented by CIMIS (California Irrigation Management Information System) including Net Radiation calculation
Current Display Data	Latest Hourly Total Calculation
Current Graph Data	Latest Hourly Total Calculation, Daily, Monthly, Yearly Total
Historical Graph Data	Hourly, Daily, Monthly, Yearly Totals
Alarm	High Threshold from Latest Daily Total Calculation

Forecast

Variables Used	Barometric Reading & Trend, Wind Speed & Direction, Rainfall, Temperature, Humidity, Latitude & Longitude, Time of Year
Update Interval	1 hour
Display Format	Icons on top center of display; detailed message in ticker at bottom
Variables Predicted	Sky Condition, Precipitation, Temperature Changes, Wind Direction and Speed

Heat Index (calculated)

Resolution and Units	1°F or 1°C (user-selectable) °C is converted from °F rounded to the nearest 1°C
Range	-40° to +165°F (-40° to +74°C)
Accuracy	±3°F (±1.5°C) (typical)
Update Interval	10 to 12 seconds
Source	United States National Weather Service (NWS)/NOAA
Formulation Used	Steadman (1979) modified by US NWS/NOAA and Davis Instruments to increase range of use
Variables Used	Instant Outside Temperature and Instant Outside Relative Humidity
Current Display Data	Instant Calculation
Current Graph Data	Instant Calculation; Daily, Monthly High
Historical Graph Data	Hourly Calculations; Daily, Monthly Highs
Alarm	High Threshold from Instant Calculation

Humidity

Inside Relative Humidity (sensor located in console)

Resolution and Units	1%
Range	1 to 100% RH
Accuracy	±3% (0 to 90% RH), ±4% (90 to 100% RH)
Update Interval	1 minute
Current Display Data	Instant (user-adjustable offset available)
Current Graph Data	Instant; Hourly Reading; Daily, Monthly High and Low
Historical Graph Data	Hourly Readings; Daily, Monthly Highs and Lows
Alarms	High and Low Threshold from Instant Reading

Outside Relative Humidity (sensor located in ISS)

Resolution and Units	1%
Range	1 to 100% RH
Accuracy	±3% (0 to 90% RH), ±4% (90 to 100% RH)
Temperature Coefficient	0.03% per °F (0.05% per °C), reference 68°F (20°C)
Drift	±0.5% per year
Update Interval	50 seconds to 1 minute
Current Display Data	Instant (user-adjustable offset available)
Current Graph Data	Instant; Hourly Reading; Daily, Monthly High and Low
Historical Graph Data	Hourly Readings; Daily, Monthly Highs and Lows
Alarms	High and Low Threshold from Instant Reading

Extra Outside Relative Humidity (sensor located inside Temperature/Humidity Station)

Resolution and Units	1%
Range	1 to 100% RH
Accuracy	±3% (0 to 90% RH), ±4% (90 to 100% RH)
Temperature Coefficient	0.03% per °F (0.05% per °C), reference 68°F (20°C)
Drift	±0.5% per year
Update Interval	50 seconds to 1 minute
Current Display Data	Instant Reading (user adjustable)
Alarms	High and Low Threshold from Instant Reading

Leaf Wetness (requires leaf wetness sensor)

Resolution	1
Range	0 to 15
Dry/Wet Threshold	User-selectable
Accuracy	±0.5
Update Interval	15 to 18 seconds
Current Graph Data	Instant Reading; Daily High and Low; Monthly High
Historical Graph Data	Hourly Readings; Daily Highs and Lows; Monthly Highs
Alarms	High and Low Thresholds from Instant Reading

Moon Phase

Console Resolution	1/8 (12.5%) of a lunar cycle, 1/4 (25%) of lighted face on console
WeatherLink Resolution	0.09% of a lunar cycle, 0.18% of lighted face maximum (depends on screen resolution)
Range	New Moon, Waxing Crescent, First Quarter, Waxing Gibbous, Full Moon, Waning Gibbous, Last Quarter, Waning Crescent
Accuracy	±38 minutes

Rainfall

Resolution and Units	0.01" or 0.2 mm (user-selectable) (1 mm at totals ≥ 2000 mm)
Daily/Storm Rainfall Range	0 to 99.99" (0 to 999.8 mm)
Monthly/Yearly/Total Rainfall Range	0 to 199.99" (0 to 6553 mm)
Rain Rate	0 to 96" (0 to 2438 mm)
Accuracy	For rain rates up to 2"/hr (50 mm/hr): ±4% of total or +0.01" (0.2mm) (0.01" = one tip of the bucket), whichever is greater. For rain rates from 2"/hr (50 mm/hr) to 4"/hr (100 mm/hr): ±4% of total or +0.01" (0.25 mm) (0.01" = one tip of the bucket), whichever is greater
Update Interval	20 to 24 seconds
Storm Determination Method	0.02" (0.5 mm) begins a storm event, 24 hours without further accumulation ends a storm event
Current Display Data	Totals for Past 15-min
Current Graph Data	Totals for Past 15-min, Past 24-hour, Daily, Monthly, Yearly (start date user-selectable) and Storm (with begin date); Umbrella is displayed when 15-minute total exceeds zero
Historical Graph Data	Totals for 15-min, Daily, Monthly, Yearly (start date user-selectable) and Storm (with begin and end dates)
Alarms	High Threshold from Latest Flash Flood (15-min. total, default is 0.50", 12.7 mm), 24-Hour Total, Storm Total,
Range for Rain Alarms	0 to 99.99" (0 to 999.7 mm)

Rain Rate

Resolution and Units	0.01" or 0.1 mm (user-selectable) at typical rates (see Fig. 3 and 4)
Range	0, 0.04"/hr (1 mm/hr) to 96"/hr (0 to 2438 mm/hr)
Accuracy	±5% for rates less than 5" per hour (127 mm/hr)
Update Interval	20 to 24 seconds
Calculation Method	Measures time between successive tips of tipping bucket. Elapsed time greater than 15 minutes or only one tip of the rain collector constitutes a rain rate of zero.
Current Display Data	Instant
Current Graph Data	Instant and 1-min. Reading; Hourly, Daily, Monthly and Yearly High
Historical Graph Data	1-min Reading; Hourly, Daily, Monthly and Yearly Highs
Alarm	High Threshold from Instant Reading

Soil Moisture (requires soil moisture Sensor)

Resolution	1 cb
Range	0 to 200 cb
Update Interval	75 to 90 seconds
Current Graph Data	Instant Reading; Daily and Monthly High and Low
Historical Graph Data	Hourly Readings; Daily and Monthly Highs and Lows
Alarms	High and Low Thresholds from Instant Reading

Solar Radiation (requires solar radiation sensor)

Resolution and Units	1 W/m^2
Range	0 to 1800 W/m^2
Accuracy	±5% of full scale (Reference: Eppley PSP at 1000 W/m^2)
Drift	up to ±2% per year
Cosine Response	±3% for angle of incidence from 0° to 75°
Temperature Coefficient	-0.067% per °F (-0.12% per °C); reference temperature = 77°F (25 °C)
Update Interval	50 seconds to 1 minute (5 minutes when dark)
Current Graph Data	Instant Reading and Hourly Average; Daily, Monthly High
Historical Graph Data	Hourly Average, Daily, Monthly Highs
Alarm	High Threshold from Instant Reading

Sunrise and Sunset

Resolution	1 minute
Accuracy	±1 minute
Reference	United States Naval Observatory

Temperature

Inside Temperature (sensor located in console)

Resolution and Units	Current Data: 0.1°F or 1°F or 0.1°C or 1°C (user-selectable) °C is converted from °F rounded to the nearest 1°C Historical Data and Alarms: 1°F or 1°C (user-selectable)
Range	+32° to +140°F (0° to +60°C)
Sensor Accuracy	±1°F (±0.5°C)
Update Interval	1 minute
Current Display Data	Instant (user-adjustable offset available)
Current Graph Data	Instant Reading; Daily and Monthly High and Low
Historical Graph Data	Hourly Readings; Daily and Monthly Highs and Lows
Alarms	High and Low Thresholds from Instant Reading

Outside Temperature (sensor located in ISS)

Resolution and Units	Current Data: 0.1°F or 1°F or 0.1°C or 1°C (user-selectable) nominal (see Fig. 1) °C is converted from °F rounded to the nearest 1°C Historical Data and Alarms: 1°F or 1°C (user-selectable)
Range	-40° to +150°F (-40° to +65°C)
Sensor Accuracy	±1°F (±0.5°C) above 20°F (-7°C), ±2°F (±1°C) under 20°F (-7°C) (see Fig. 2)
Radiation Induced Error (Passive Shield)	+4°F (2°C) at solar noon (insolation = 1040 W/m^2, avg. wind speed ≤ 2 mph (1 m/s)) (reference: RM Young Model 43408 Fan-Aspirated Radiation Shield)
Radiation Induced Error (Fan-Aspirated Shield)	+0.6°F (0.3°C) at solar noon (insolation = 1040 W/m^2, avg. wind speed ≤ 2 mph (1 m/s)) (reference: RM Young Model 43408 Fan-Aspirated Radiation Shield)
Update Interval	10 to 12 seconds
Current Display Data	Instant (user-adjustable offset available)
Current Graph Data	Instant Reading; Daily, Monthly, Yearly High and Low
Historical Graph Data	Hourly Readings; Daily, Monthly, Yearly Highs and Lows
Alarms	High and Low Thresholds from Instant Reading

Extra Temperature Sensors or Probes

Resolution and Units	Current Data: 1°F or 1°C (user-selectable) °C is converted from °F rounded to the nearest 1°C Historical Data and Alarms: 1°F or 1°C (user-selectable)

Range	-40° to +150°F (-40° to +65°C)
Sensor Accuracy	±1°F (±0.5°C) above 20°F (-7°C), ±2°F (±1°C) under 20°F (-7°C) (see Fig. 2)
Update Interval	10 to 12 seconds (40 to 48 seconds for Leaf Wetness/Temperature and Soil Moisture/Temperature Stations)
Current Display Data	Instant Reading (user-adjustable offset available)
Alarms	High and Low Thresholds from Instant Reading

Temperature Humidity Sun Wind Index (requires solar radiation sensor)

Resolution and Units	1°F or 1°C (user-selectable) °C is converted from °F rounded to the nearest 1°C
Range	-90° to +165°F (-68° to +74°C)
Accuracy	±4°F (±2°C) (typical)
Update Interval	10 to 12 seconds
Sources and Formulation Used	United States National Weather Service (NWS)/NOAA Steadman (1979) modified by US NWS/NOAA and Davis Instruments to increase range of use and allow for cold weather use
Variables Used	Instant Outside Temperature, Instant Outside Relative Humidity, 10-minute Average Wind Speed, 10-minute Average Solar Radiation
Formulation Description	Uses Heat Index as base temperature, affects of wind and solar radiation are either added or subtracted from this base to give an overall effective temperature
Current Graph Data	Instant and Hourly Calculation; Daily, Monthly High
Historical Graph Data	Hourly Calculation; Daily, Monthly Highs
Alarm	High Threshold from Instant Reading

Ultra Violet (UV) Radiation Dose (requires UV sensor)

Resolution and Units	0.1 MEDs to 19.9 MEDs; 1 MED above 19.9 MEDS
Range	0 to 199 MEDs
Accuracy	±5% of daily total
Drift	up to ±2% per year
Update Interval	50 seconds to 1 minute (5 minutes when dark)
Current Graph Data	Latest Daily Total (user resetable at any time from Current Screen)
Historical Graph Data	Hourly, Daily Totals (user reset from Current Screen does not affect these values)
Alarm	High Threshold from Daily Total
Alarm Range	0 to 19.9 MEDs

Ultra Violet (UV) Radiation Index (requires UV sensor)

Resolution and Units	0.1 Index
Range	0 to 16 Index
Accuracy	±5% of full scale (Reference: Yankee UVB-1 at UV index 10 (Extremely High))
Cosine Response	±4% (0° to 65° incident angle); 9% (65° to 85° incident angle)
Update Interval	50 seconds to 1 minute (5 minutes when dark)
Current Graph Data	Instant Reading and Hourly Average; Daily, Monthly High
Historical Graph Data	Hourly Average, Daily, Monthly Highs
Alarm	High Threshold from Instant Calculation

Wind

Wind Chill (Calculated)

Resolution and Units	1°F or 1°C (user-selectable) °C is converted from °F and rounded to the nearest 1°C
Range	-110° to +135°F (-79° to +57°C)
Accuracy	±2°F (±1°C) (typical)
Update Interval	10 to 12 seconds
Source	United States National Weather Service (NWS)/NOAA
Equation Used	Osczevski (1995) (adopted by US NWS in 2001)
Variables Used	Instant Outside Temperature and 10-min. Avg. Wind Speed
Current Display Data	Instant Calculation

Current Graph Data	Instant Calculation; Hourly, Daily and Monthly Low
Historical Graph Data	Hourly, Daily and Monthly Lows
Alarm	Low Threshold from Instant Calculation
Wind Direction	
Range	0 - 360°
Display Resolution	16 points (22.5°) on compass rose, 1° in numeric display
Accuracy	±3°
Update Interval	2.5 to 3 seconds
Current Display Data	Instant (user-adjustable offset available)
Current Graph Data	Instant; 10-min. Dominant; Hourly, Daily, Monthly Dominant
Historical Graph Data	Past 6 10-min. Dominants on compass rose only; Hourly, Daily, Monthly Dominants
Wind Speed	
Resolution and Units	1 mph, 1 km/h, 0.4 m/s, or 1 knot (user-selectable). Measured in mph, other units are converted from mph and rounded to nearest 1 km/hr, 0.1 m/s, or 1 knot.
Range	2 to 180 mph, 2 to 156 knots, 1 to 80 m/s, 3 to 290 km/h
Update Interval	Instant Reading: 2.5 to 3 seconds, 10-minute Average: 1 minute
Accuracy	±2 mph (2 kts, 3 km/h, 1 m/s) or ±5%, whichever is greater
Maximum Cable Length	540’ (165 m)
Current Display Data	Instant
Current Graph Data	Instant; 10-minute and Hourly Average; Hourly High; Daily, Monthly and Yearly High with Direction of High
Historical Graph Data	10-min. and Hourly Averages; Hourly Highs; Daily, Monthly and Yearly Highs with Direction of Highs
Alarms	High Thresholds from Instant Reading and 10-minute Average

Wireless Communications

Transmit/Receive Frequency	US Models: 902-928 MHz FHSS, Overseas Models: 868.0 - 868.6 MHz FHSS
ID Codes Available	8
Output Power	902-928 MHz FHSS: FCC-certified low power, less than 8 mW, no license required 868.0 - 868.6 MHz FHSS. CE-certified, less than 8 mW, no license required
Range	
Line of Sight	up to 1000 feet (300 m)
Through Walls	200 to 400 feet (60 to 120 m)
Sensor Inputs	
RF Filtering	RC low-pass filter on each signal line

Sensor Charts

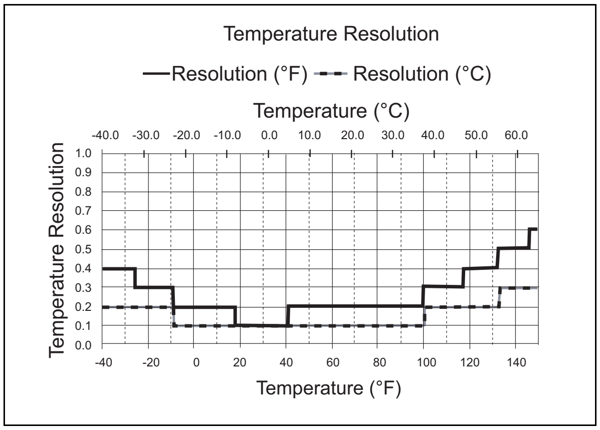


Figure 1. Temperature Resolution

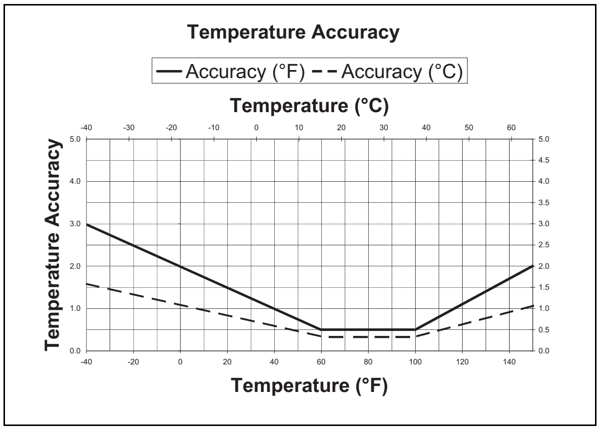


Figure 2. Temperature Accuracy

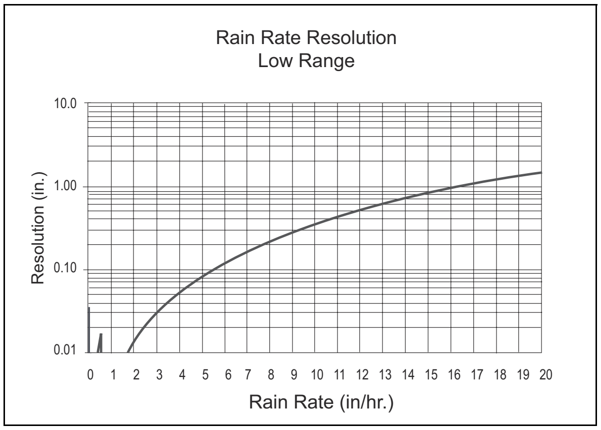


Figure 3. Low Range Rain Rate Resolution

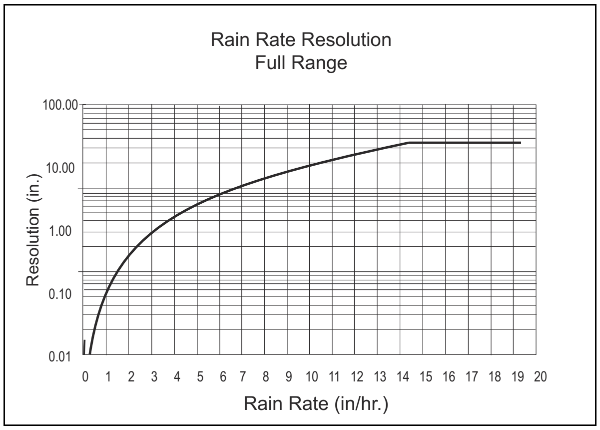


Figure 4. Full Range Rain Rate Resolution

Package Dimensions

Product #	Package Dimensions (Length x Width x Height)	Package Weight	UPC Codes
6152 6152EU 6152UK	17.0" x 11.0" x 13.0" (410 mm x 264 mm x 330 mm)	12.8 lbs. (5.8 kg)	011698 00229 0 011698 00347 1 011698 00348 8
6162 6162EU 6162UK		13.3 lbs. (6.0 kg)	011698 00306 8 011698 00307 5 001698 00308 2
6153 6153EU 6153UK	15.0" x 13.0" x 24.0" (378 mm x 327 mm x 594 mm)	12.8 lbs. (5.8 kg)	011698 00335 8 011698 00336 5 001698 00337 2
6163 6163EU 6163UK		13.3 lbs. (6.0 kg)	011698 00341 9 011698 00342 6 001698 00342 3

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Representative photograph, actual product appearance may vary.

Due to regional agency approval requirements, some products may not be available in your area. Please contact your regional Honeywell office regarding your product of choice.

HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

Features

- Molded thermoset plastic housing with cover
- Linear voltage output vs %RH
- Laser trimmed interchangeability
- Low power design
- High accuracy
- Fast response time
- Stable, low drift performance
- Chemically resistant

Typical Applications

- Refrigeration
- Drying
- Meteorology
- Battery-powered systems
- OEM assemblies

Description

The HIH-4000 Series Humidity Sensors are designed specifically for high volume OEM (Original Equipment Manufacturer) users. Direct input to a controller or other device is made possible by this sensor's linear voltage output. With a typical current draw of only 200 µA, the HIH-4000 Series is ideally suited for low drain, battery operated systems. Tight sensor interchangeability reduces or eliminates OEM production calibration costs. Individual sensor calibration data is available.

The HIH-4000 Series delivers instrumentation-quality RH (Relative Humidity) sensing performance in a low cost, solderable SIP (Single In-line Package). Available in two lead spacing configurations, the RH sensor is a laser trimmed, thermoset polymer capacitive sensing element with on-chip integrated signal conditioning. The sensing element's multilayer construction provides excellent resistance to most application hazards such as wetting, dust, dirt, oils and common environmental chemicals.

Honeywell

HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

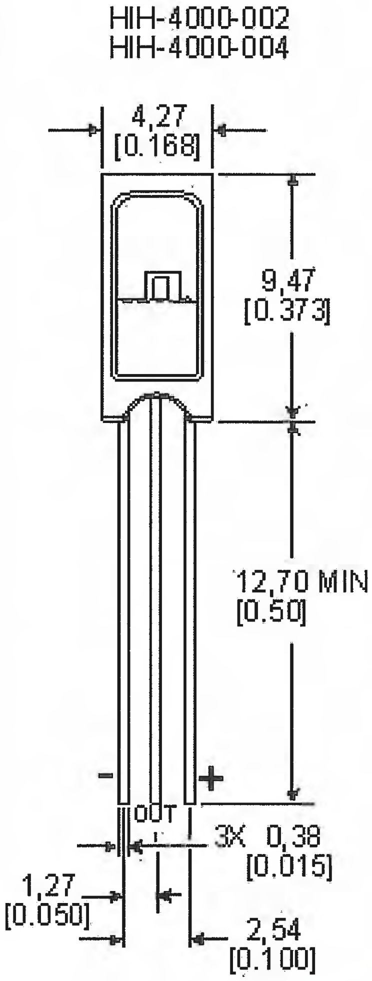
Product Specifications	
Package Style	Solderable SIP
Termination Details	2,54 mm [0.100 in] Lead Pitch
Series Name	HIH-4000 Series
RH Accuracy	± 3.5% RH, 0-100 % RH non-condensing, 25 °C, 5 Vdc supply
RH Interchangeability	± 5% RH, 0-60% RH; ± 8% @ 60-100% RH Typical
RH Hysteresis	± 3% of RH Span Maximum
RH Repeatability	± 0.5% RH
RH response time, 1/e	15 s in slowly moving air @ 25 °C
RH Stability	± 0.2% RH Typical at 50% RH in 1 Year
Supply Voltage	4.0 Vdc to 5.8 Vdc
Supply Current	500 µA Max.
Operating Humidity Range	0 to 100% RH, non-condensing
Operating Temperature Range	-40 °C to 85 °C (-40 °F to 185 °F)
Temperature Compensation	True RH = Sensor RH/(1.0305+0.000044T-0.0000011T^2) T in °C (True RH = Sensor RH/(0.9237-0.0041T+0.000040T^2) T in °C)
Availability	Global
Comment	Light sensitive, shield from bright light.
UNSPSC Code	411121
UNSPSC Commodity	411121 Transducers

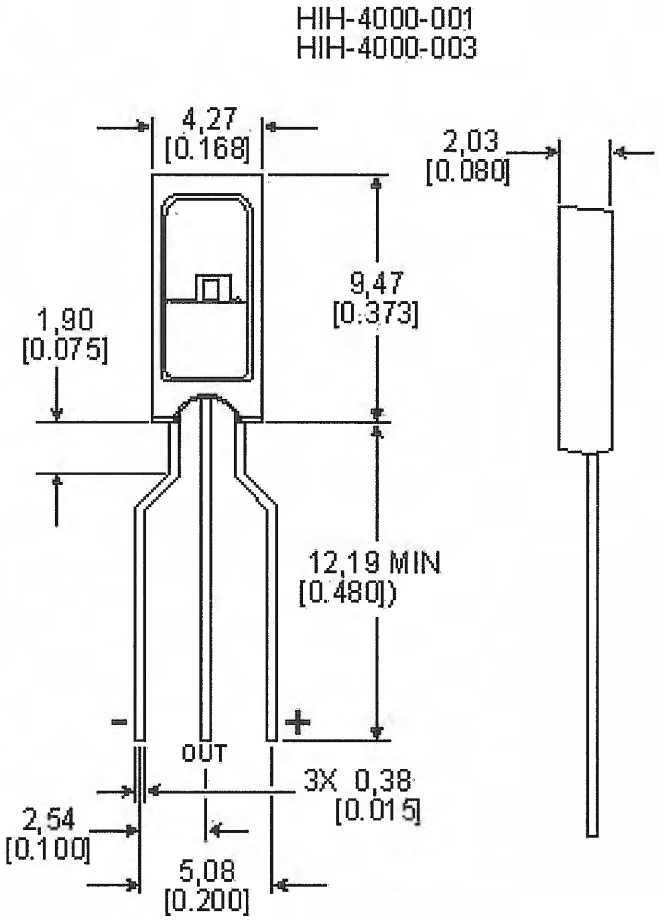
Honeywell

HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

Mounting Dimensions
For Reference Only [mm/in]



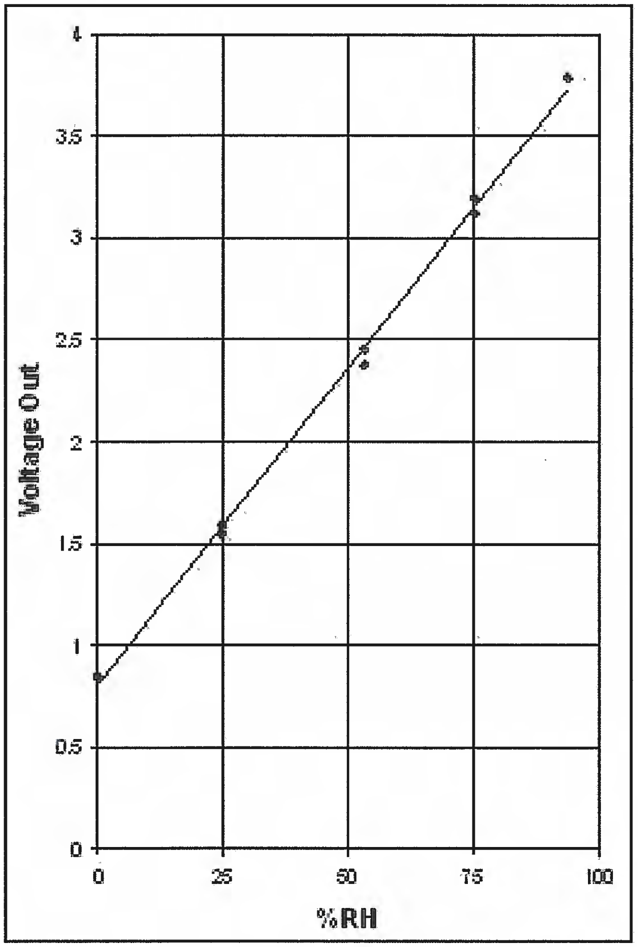


Honeywell

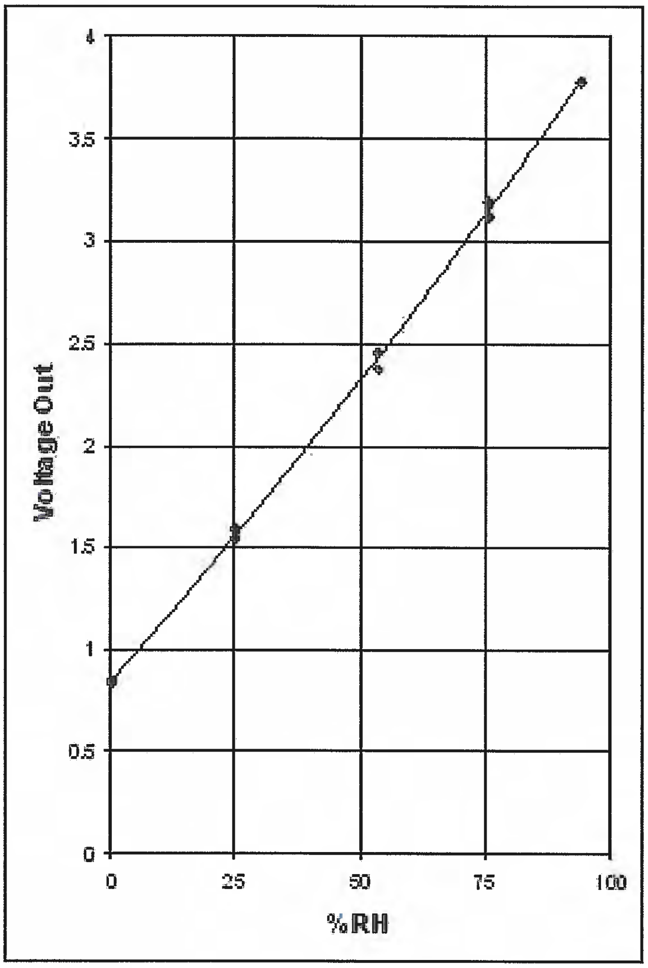
HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

TYPICAL BEST FIT STRAIGHT LINE



TYPICAL 2nd ORDER CURVE FIT

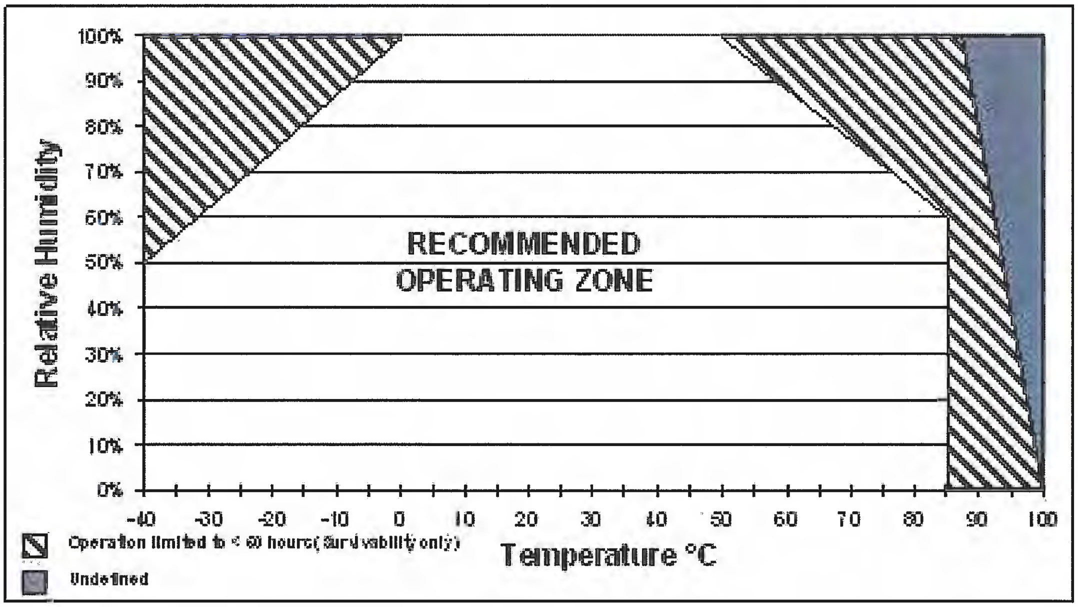


Honeywell

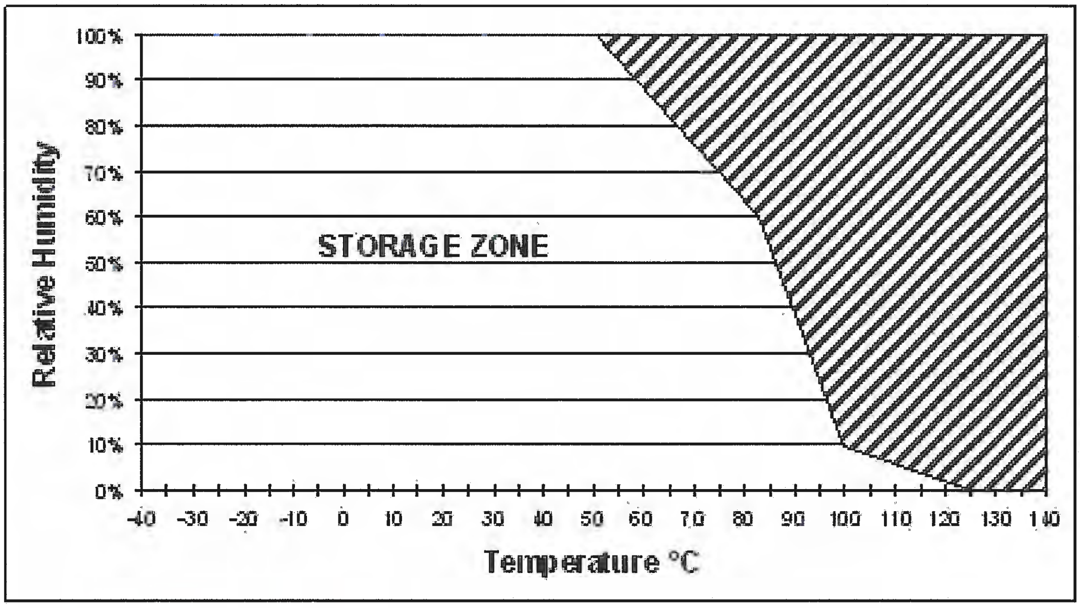
HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

Recommended Operating Conditions



Storage Environment



Honeywell

HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

⚠ WARNING

PERSONAL INJURY

DO NOT USE these products as safety or emergency stop devices, or in any other application where failure of the product could result in personal injury.

Failure to comply with these instructions could result in death or serious injury.

⚠ WARNING

MISUSE OF DOCUMENTATION

- The information presented in this product sheet (or catalog) is for reference only. DO NOT USE this document as product installation information.
- Complete installation, operation and maintenance information is provided in the instructions supplied with each product.

Failure to comply with these instructions could result in death or serious injury.

HTM25X0LF – Temperature and Relative Humidity Module

- **Hermetic Housing**
- **Humidity calibrated within +/-2% @55%RH**
- **Temperature measurement through NTC 10kOhms +/-1% direct output**
- **Small size product**
- **Typical 1 to 4 Volt DC output for 0 to 100%RH at 5Vdc**

DESCRIPTION

Based on the rugged HTS2230 humidity / temperature sensor, HTM25X0LF is a dedicated humidity and temperature transducer designed for OEM applications where a reliable and accurate measurement is needed. Direct interface with a micro-controller is made possible with the module's humidity linear voltage output.

FEATURES

- Full interchangeability
- High reliability and long term stability
- Not affected by water immersion
- Ratiometric to voltage supply
- Suitable for 3 to 10 Vdc supply voltage

Humidity Sensor Specific Features

- Instantaneous de-saturation after long periods in saturation phase
- Fast response time
- High resistance to chemicals
- Patented solid polymer structure

Temperature Sensor Specific Features

- Stable
- High sensitivity

APPLICATIONS

- Industrial
- Process control
- Hygrostat
- Data logger

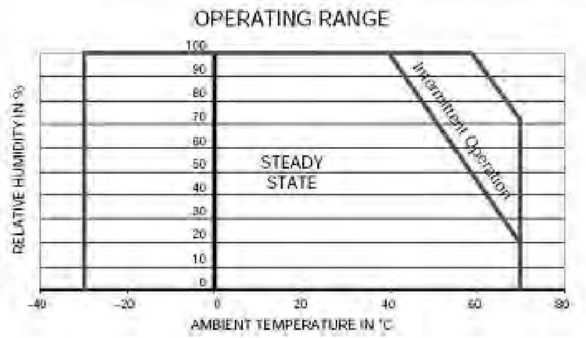
…

PERFORMANCE SPECS

MAXIMUM RATINGS

Ratings	Symbol	Value	Unit
Storage Temperature	Tstg	-40 to 125	°C
Storage Humidity	RHstg	0 to 100	% RH
Supply Voltage (Peak)	Vs	12	Vdc
Humidity Operating Range	RH	0 to 100	% RH
Temperature Operating Range	Ta	-40 to 125	°C

Peak conditions: less than 10% of the operating time



NOMENCLATURE

HTM25X0LF

Output Temperature Sensor:
X = 0 – Direct NTC Output
X = 3 – Voltage Output

ELECTRICAL CHARACTERISTICS

(Ta=23°C, Vs=5Vdc +/-5%, R_L>1MΩ unless otherwise stated)

Humidity Characteristics	Symbol	Min	Typ	Max	Unit
Humidity Measuring Range	RH	1		99	%RH
Relative Humidity Accuracy (10 to 95% RH)	RH		+/-3	+/-5	%RH
Supply Voltage	Vs	4.75	5.00	5.25	Vdc
Nominal Output @55%RH (at 5Vdc)	Vout	2.42	2.48	2.54	V
Current consumption (HTM2500LF)	Ic		1.0	1.2	mA
Current consumption (HTM2530LF)	Ic		3.4	3.6	mA
Temperature Coefficient (10 to 50°C)	Tcc		+0.1		%RH/°C
Average Sensitivity from 33% to 75%RH	ΔVout/ΔRH		+26		mV/%RH
Sink Current Capability (R_L=15kΩ)	Is			300	µA
Recovery time after 150 hours of condensation	tr		10		s
Humidity Hysteresis			+/-1.5		%RH
Long term stability	T		+/-0.5		%RH/yr
Time Constant (at 63% of signal, static) 33% to 76%RH (1)	τ		5		s
Output Impedance	Z		70		Ω

(1) At 1m/s air flow

(Ta=25°C)

Temperature Characteristics	Symbol	Min	Typ	Max	Unit
Nominal Resistance @25°C	R		10		kΩ
Beta value: B25/50	β	3347	3380	3413	K
Temperature Measuring Range*	Ta	-40		125	°C
Nominal Resistance Tolerance @25°C	R_N			1	%
Beta Value Tolerance	β		1		%
Response Time	τ		10		s

** For temperature upper than 85°C, specific cable is required: HTM25X0LF-L products*

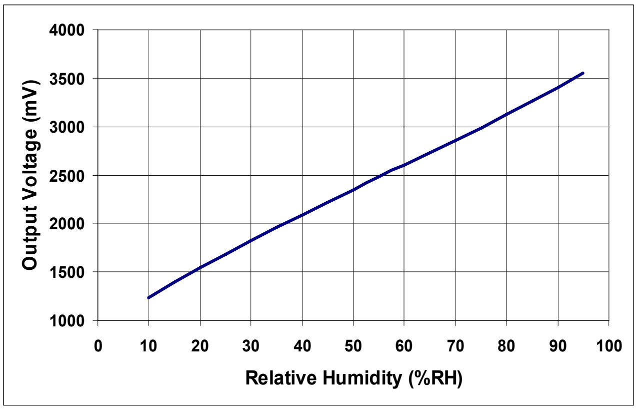
TYPICAL PERFORMANCE CURVES

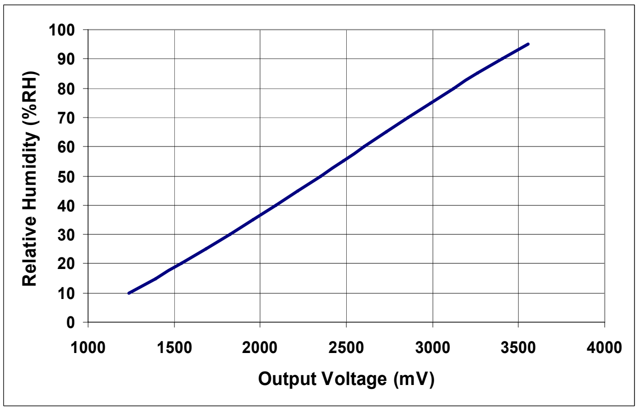
HUMIDITY SENSOR

- **Typical response look-up table**

RH (%)	Vout (mV)	RH (%)	Vout (mV)
10	1235	**55**	2480
15	1390	**60**	2605
20	1540	**65**	2730
25	1685	**70**	2860
30	1825	**75**	2990
35	1960	**80**	3125
40	2090	**85**	3260
45	2220	**90**	3405
50	2350	**95**	3555

- **Modeled linear voltage output (Vs = 5V)**





- **Linear Equations**

$$\mathbf{Vout = 26.65\,RH + 1006}$$
$$\mathbf{RH = 0.0375\,Vout - 37.7}$$

with Vout in mV and RH in %

- **Polynomial Equations**

$$\mathbf{Vout = 1.05E^{-3}RH^{3} - 1.76E^{-1}RH^{2} + 35.2RH + 898.6}$$
$$\mathbf{RH = -1.92E^{-9}Vout^{3} + 1.44E^{-5}Vout^{2} + 3.4Vout - 1.2}$$

with Vout in mV and RH in %

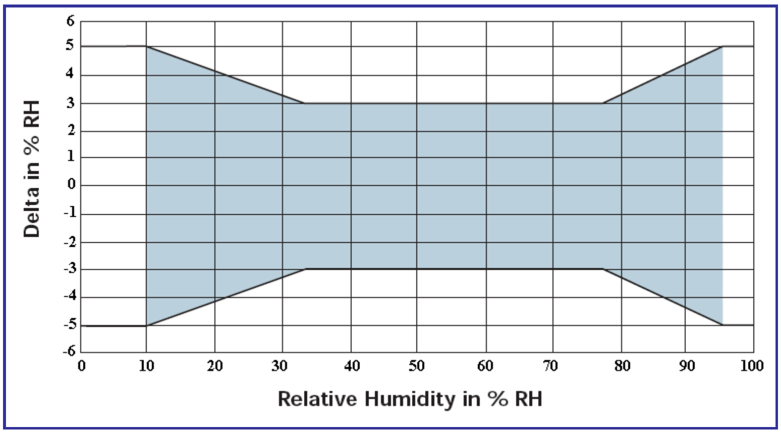
- **Measurement Conditions**

HTM25X0LF is specified for accurate measurements within 10 to 95% RH.

Excursion out of this range (<10% or >95% RH, including condensation) does not affect the reliability of HTM25X0LF characteristics.

- **Error Budget at 23°C**

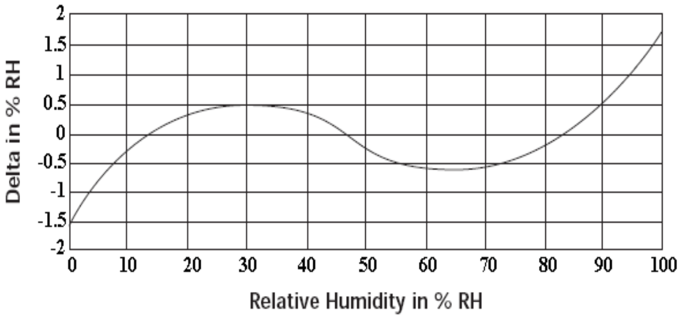
HTM25X0LF Error Limits:



Temperature coefficient compensation:

$$RH_{Cor}\% = RH_{read}\% \times \left(1-\left(T_a-23\right)\times 2.4E^{-3}\right)$$

HTM25X0LF Linearity Error:



Non-linearity and temperature compensation:

$$RH\% = \frac{-1.9206E^{-9}V_{out}^{3} + 1.437E^{-5}V_{out}^{2} + 3.421E^{-3}V_{out} - 12.4}{1+\left(T_a-23\right)\times 2.4E^{-3}}$$

All equations Vout in mV, RH in % and Ta in °C

HTM2500LF TEMPERATURE SENSOR: DIRECT NTC OUTPUT

Typical temperature output

Depending on the needed temperature measurement range and associated accuracy, we suggest two methods to access to the NTC resistance values.

$$R_T = R_N \times e^{\beta\left(\frac{1}{T}-\frac{1}{T_N}\right)}$$

R_T	NTC resistance in Ω at temperature T in K
R_N	NTC resistance in Ω at rated temperature T in K
T, T_N	Temperature in K
β	Beta value, material specific constant of NTC
e	Base of natural logarithm (e=2.71828)

① The exponential relation only roughly describes the actual characteristic of an NTC thermistor can, however, as the material parameter β in reality also depend on temperature. So this approach is suitable for describing a restricted range around the rated temperature or resistance with sufficient accuracy.
② For practical applications, a more precise description of the real R/T curve may be required. Either more complicated approaches (e.g. the Steinhart-Hart equation) are used or the resistance/temperature relation as given in tabulation form. The below table has been experimentally determined with utmost accuracy for temperature increments of 1 degree.

Actual values may also be influenced by inherent self-heating properties of NTCs. Please refer to MEAS-France Application Note HPC106 “Low power NTC measurement”.

Temperature look-up table

Temp (°C)	R (Ω)	Temp (°C)	R (Ω)
-40	195652	**25**	10000
-35	148171	**30**	8315
-30	113347	**35**	6948
-25	87559	**40**	5834
-20	68237	**45**	4917
-15	53650	**50**	4161
-10	42506	**55**	3535
-5	33892	**60**	3014
0	27219	**65**	2586
5	22021	**70**	2228
10	17926	**75**	1925
15	14674	**80**	1669
20	12081	**85**	1452

- ### Steinhart-Hart coefficients

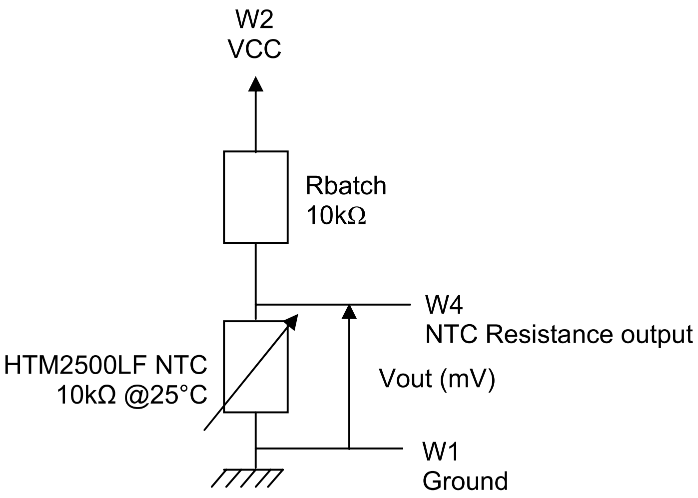
According to the equation below, the Steinhart-Hart coefficients for the operating temperature range for HTM2500LF thermistor are:

$$\frac{1}{T} = a + b * \ln(R) + C * \ln(R) * \ln(R) * \ln(R)$$

R	NTC resistance in Ω at temperature T in K
T	Temperature in K
a	Constant value (a = 8.54942E-04)
b	Constant value (b = 2.57305E-04)
c	Constant value (c = 1.65368E-07)

- ### Temperature Interface Circuit

Concerning the temperature sensor of the HTM2500LF, the following measuring method described below is based on a voltage bridge divider circuit. It uses only one resistor component (Rbatch) at 1% to design HTM2500LF temperature sensor interfacing circuit.
Rbatch is chosen to be equal to NTC @25°C to get: Vout = Vcc/2 @25°C.
The proposal method connects Rbatch to Vcc (5Vdc) and NTC to Ground. It leads to a negative slope characteristic (Pull-Up Configuration).



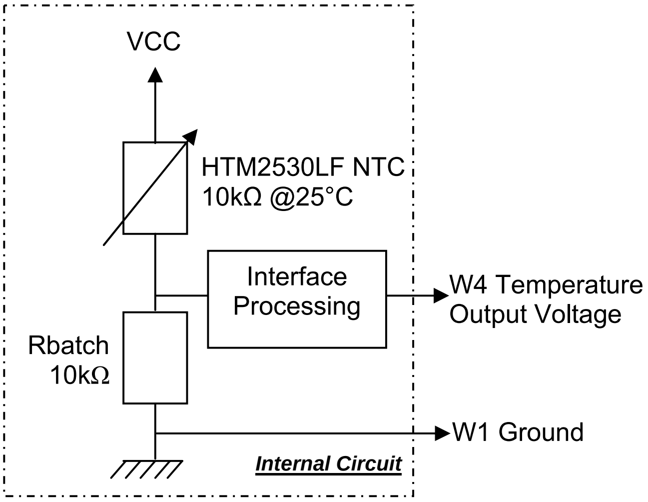
$$V_{OUT}(mV) = \frac{Vcc(mV) * NTC_{HTM2500LF}(\Omega)}{R_{batch}(\Omega) + NTC_{HTM2500LF}(\Omega)}$$

Temp (°C)	R (Ω)	Pull-up Configuration Vout (mV)
-40	195652	4757
-30	113347	4595
-20	68237	4361
-10	42506	4048
0	27219	3657
10	17926	3210
20	12081	2736
25	10000	2500
30	8315	2270
40	5834	1842
50	4161	1469
60	3014	1158
70	2228	911
80	1669	715

HTM25X0LF – Temperature and Relative Humidity Module

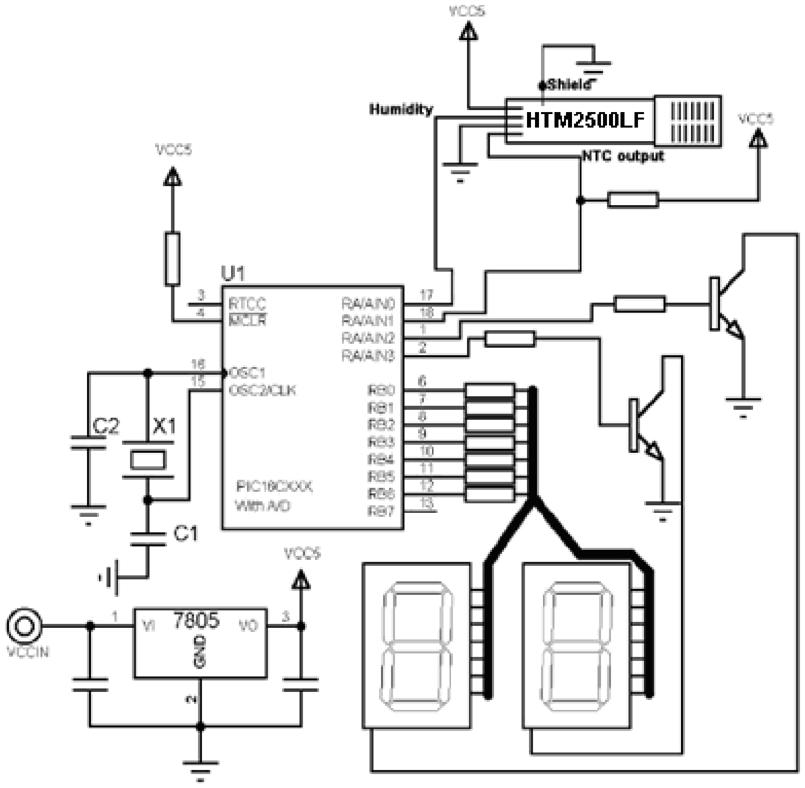
HTM2530LF TEMPERATURE SENSOR: VOLTAGE OUTPUT

Concerning the temperature sensor of the HTM2530LF, it is built as the HTM2500LF temperature sensor interface circuit. The voltage bridge divider circuit is internal. It uses only one resistor component (Rbatch) at 1% to design HTM2530LF temperature sensor interfacing circuit.
Rbatch is chosen to be equal to NTC @25°C to get: Vout = Vcc/2 @25°C.
The difference is based on internal connections: Rbatch connected to Ground and NTC to Vcc (5Vdc). It leads to a positive slope characteristic (Pull-Down Configuration).

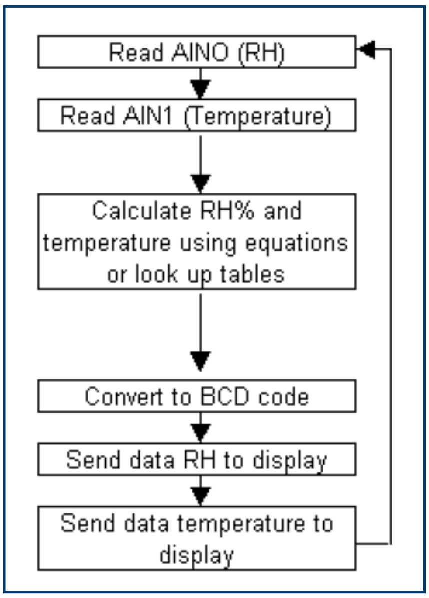


Temp (°C)	R (Ω)	Pull-Down Configuration Vout (mV)
-20	68237	1280
-10	42506	1515
0	27219	1775
10	17926	2050
20	12081	2330
25	10000	2470
30	8315	2600
40	5834	2850
50	4161	3070
60	3014	3240
70	2228	3360

SUGGESTED APPLICATION



Steps of 1% RH are achievable by using 8-bit A/D.
If more resolution is required, a 10-bit A/D needs to be used and a third display will be added, giving steps of 0.2% RH.



HTM25X0LF – Temperature and Relative Humidity Module

QUALIFICATION PROCESS

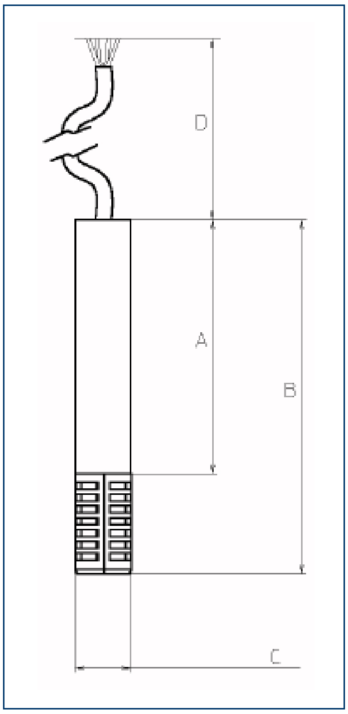
RESISTANCE TO PHYSICAL AND CHEMICAL STRESSES

- HTM25X0LF has passed through qualification processes of MEAS-France including vibration, shock, storage, high temperature and humidity, ESD.
- Additional tests under harsh chemical conditions demonstrate good operation in presence of salt atmosphere, SO2 (0.5%, H2S (0.5%), 03, NOx, NO, CO, CO2, Softener, Soap, Toluene, acids (H2SO4, HNO3, HCl), HMDS, Insecticide, Cigarette smoke, this is not an exhaustive list.
- HTM25X0LF is not light sensitive.

SPECIFIC PRECAUTIONS

- HTM25X0LF is not protected against reversed polarity - Check carefully when connecting the device.
- If you wish to use HTM25X0LF in a chemical atmosphere not listed above, consult us.

PACKAGE OUTLINE



Dim	Min (mm)	Max (mm)
A	53	55
B	74.3	76.3
C	11.2	11.6
D*	200	250

** Specific lenght available on request*
For operating temperature upper than 85°C, specific cable is required (1500mm long)

Wire	Color	Function
W1	Brown	Ground
W2	White	Supply Voltage
W3	Yellow	Humidity Voltage Output
W4	Green	Temperature Output (NTC Direct or Voltage)
W5	Black	Shield

Weight: 17.5g
Wire characteristics: AWG 24 for W1, W2, W3 and W4 / AWG 22 for W5

ORDERING INFORMATION

HPP809A031 : HTM2500LF

HUMIDITY VOLTAGE OUTPUT + NTC (TEMPERATURE DIRECT OUTPUT)

HPP809A032 : HTM2530LF

VOLTAGE OUTPUT FOR HUMIDITY AND TEMPERATURE

HPP809A033 : HTM2500LFL

HUMIDITY VOLTAGE OUTPUT + NTC (TEMPERATURE DIRECT OUTPUT) WITH LONG CABLE

HPP809A034 : HTM2530LFL

VOLTAGE OUTPUT FOR HUMIDITY AND TEMPERATURE WITH LONG CABLE

(MULTIPLE PACKAGE QUANTITY OF 10 PIECES)

Customer Service contact details

Measurement Specialties, Inc.
105 av. du Général Eisenhower
BP 23705 31037 TOULOUSE CEDEX 1
FRANCE
Tél: +33 (0) 561 194 848
Fax:+33 (0) 561 194 553
Sales: humidity.sales@meas-spec.com

Revision	Comments	Who	Date
0	Document creation	D. LE GALL	July 09
A	Temperature operating range updated, HTM25X0LFL references added	D. LE GALL	December 09

SMT-A2 – Wireless Data Acquisition Unit

General Description

The SMT-A2 Wireless Data Acquisition unit is a high precision measurement device designed for distributed remote sensor data acquisition. The built-in 24-bit A/D converter and low noise high precision measurement circuitry facilitates data acquisition from a wide variety of sensors.

Integrated Moisture Content, RH and temperature sensors make the SMT-A2 suitable for building monitoring applications.

External sensor inputs, LCD display, large memory capacity and extended wireless range gives the SMT-A2 flexibility in a wide range of applications.

The SMT-A2 unit communicates wireless sensor readings to the SMT Building Intelligence gateway. Optional powered repeaters can be used to extend the wireless range.

Applications

- Remote sensor analysis and data collection
- High precision data acquisition
- Building science research
- Targeted repair monitoring
- Restoration monitoring

Features

- Integrated moisture content sensing elements.
- Integrated relative humidity and temperature sensors.
- Two external resistance channels capable of reading wide moisture content ranges and precision thermistors.
- Sensor inputs use compact audio jacks for quick and simple connectivity.
- Internal memory capable of logging 340,000 data points.
- Auxiliary input for voltage measurement capable of reading 0-5V sensors.
- Wireless transceiver with 1000m line of sight communication.
- Communicates to SMT Building Intelligence Gateway (BiG) via USB to Wireless device; SMT-I2.
- Extreme low power device suitable for long term battery operation.
- USB connectivity supports data downloads and firmware upgrades.
- Backlit LCD user interface for easy network and sensor verification
- Rechargeable batteries via USB port.

Data Acquisition
(SMT-A2)

→

Repeater(SMT-I2)
(optional)

→

Gateway (BiG) with USB
Interface (SMT-I2)

→

Internet (Analytics)

Performance/Functional Specifications

Electrical Performance

Wireless

Specification	IEEE 802.15.4
Max Distance from coordinator	1000m line of site. Powered repeaters can be added to extend range.
Max Nodes per coordinator	32 (dependent on application density and acquisition speed)

Battery

Life	1000 hours (dependent on sample frequency)
Type	Ni-MH Rechargeable Eneloop HR-4UTGA
Voltage	1.2V
Capacity	Typical: 800 mAh Minimum 750 mAh
Self Discharge	75% after 3 years
Charging Cycles	Up to 1500
Charger	USB 5V

Memory and USB

Memory	16 Mbit EEPROM for data storage Stores 340,000 samples.
USB	USB 1.0 Interface

Environmental

Operating Temperature	0° to 40°C / 32° to 104°F
Storage Temperature	-25° to 70°C / -13° to 158°F
Humidity	5% to 100% RH non-condensing
Electrostatic Discharge (ESD)	8kVdc air, 4 kVDC contact (exposed inputs)

Safety/Regulatory

Safety Requirements	SELV Separated Extra Low Voltage
Regulatory	Contains FCC ID: OA3MRF24J40MA

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Measurement Specifications

Internal Temperature

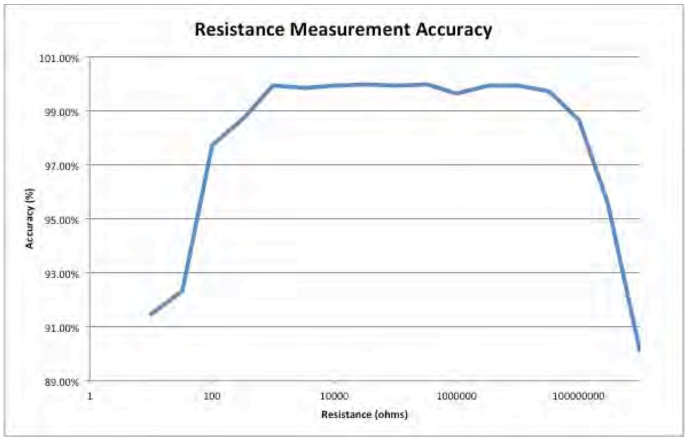
Sensor	Cantherm MF58104F3950 Beta 4390K
Range	-40°C to +70°C
Resolution	0.1°C
Accuracy	±1°C

Internal Relative Humidity

Sensor	Honeywell HCH-1000-001
Accuracy Range	10-95% RH
Resolution	±0.5%
Accuracy	±5%

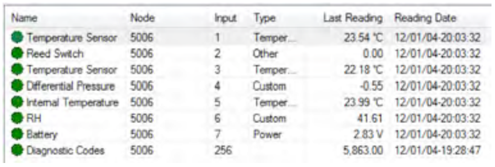
Resistance

Range	10Ω to 100Ω
Resolution	1Ω
Accuracy	±5%
Range	100Ω to 100KΩ
Resolution	10Ω
Accuracy	±1%
Range	100KΩ to 1GΩ
Resolution	1KΩ
Accuracy	±5%



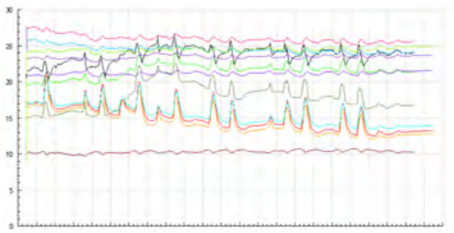
Specifications are subject to change without notice

Building Intelligence Gateway



Name	Node	Input	Type	Last Reading	Reading Date
🟢 Temperature Sensor	5006	1	Temper...	23.54 °C	12/01/04-20:03:32
🟢 Reed Switch	5006	2	Other	0.00	12/01/04-20:03:32
🟢 Temperature Sensor	5006	3	Temper...	22.18 °C	12/01/04-20:03:32
🟢 Differential Pressure	5006	4	Custom	-0.55	12/01/04-20:03:32
🟢 Internal Temperature	5006	5	Temper...	23.99 °C	12/01/04-20:03:32
🟢 RH	5006	6	Custom	41.61	12/01/04-20:03:32
🟢 Battery	5006	7	Power	2.83 V	12/01/04-20:03:32
🟢 Diagnostic Codes	5006	256		5,863.00	12/01/04-19:28:47

Building Analytics



Mechanical

Standard Enclosure

Dimensions	100mm (L) x 50 mm (W) x 24mm(H)
Weight	150g

Connections

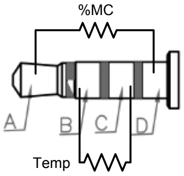
Port A Resistance	Two channels Resistance 100Ω to 1GΩ
Port B Voltage	5V, GND, Vin Or Differential voltage

Interface

LCD	Network join/rejoin Display measurements
LEDs	Green – USB Power Red - Charging
Buttons	Menu/Select buttons

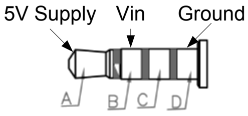
External Port Connectivity

Resistance based and voltage based sensors can be connected to the external audio jack ports:



Resistance Based Sensors

Plug resistance based sensors into the blue audio jack port (input 1/2)



Scale: 2:1

0-5V Sensors

Plug 0-5V Sensors into the white audio jack port. (input 3/4)

Thermistor or short must be connected between C and D to signal port is active.

BiG and Analytics Input Configuration

Inputs appear in the Building Intelligence Gateway (BiG) as *Autonomous* nodes with default values in resistance (Ω) or voltage (mV) depending on the sensor. Select the appropriate sensor type and temperature sensor for compensation (if applicable) to have the desired unit of measurement displayed. Refer to the BiG User Manual for further instructions on programming the sensor inputs.

Restoration Model Configuration:

Input	Function	Sensor Type
1	Internal Temperature	1-04JT (°C)
2 Probes	Moisture Content	Moisture (%)
3 White	RH Temperature	Temperature HTM2500 (°C)
4 White	RH (%RH)	HTM2500
5	Internal Temperature	1-04JT (°C)
6	Integrated RH (%RH)	Custom x=.01
7	Battery	Battery (V)

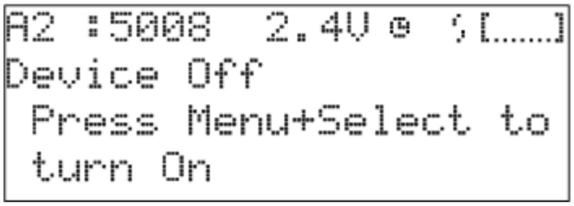
Research Model Configuration:

Input	Function	Sensor Type
1 Blue	Resistance (ohms)	
2 Blue	Resistance (ohms)	
3 White	Resistance (ohms)	
4 White	Voltage (mV)	
5	Integrated Temperature	1-04JT (°C)
6	Integrated RH (%RH)	Custom x=.01
7	Battery	Battery (V)

User Interface

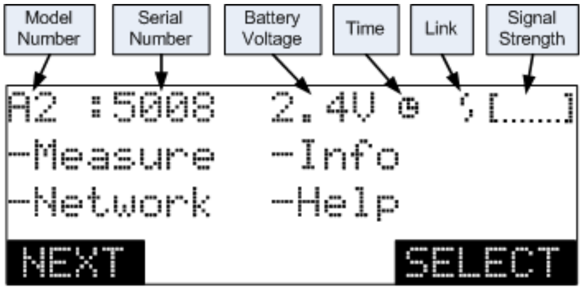
If the A2 is OFF, press Menu followed by Select to turn the unit ON. You will be prompted to turn the unit ON.

To turn the unit OFF at anytime, press Menu followed by Select.



```
A2 :5008  2.4V ◷  ⁏ [.......]
Device Off
 Press Menu+Select to
 turn On
```

The main menu contains links to the submenus as shown below. The header reports the immediate status of the unit.



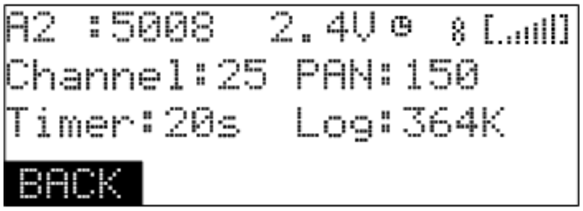
```
A2 :5008  2.4V ◷  ⁏ [.......]
-Measure  -Info
-Network  -Help
NEXT            SELECT
```

Status Menu	Description
Serial Number	Unique identifier of this unit used in BiG and Analytics
Battery Voltage	Unit should be recharged or batteries changed at 2V (this is dependent on sample frequency) . The unit will stop functioning if the battery is less than 1.8V.
Time	◷ Indicates A2 has time ⌀ Indicates A2 does not have time. Join network with BiG to establish time.
Link	⁏ No link established 8 Link established. Message transmit successful
Signal Strength	[.......] No signal. Ensure connectivity to network. [..ıll] Full signal strength

To join the network ensure BiG is running with an SMT-I2 USB to Wireless interface and select Network.

Joining network will be displayed, if joining was successful Joining Network on 25 will be displayed where 25 is the wireless channel, otherwise No Network will be displayed.

To rejoin the network select Join. To see the status of the network select Info from the main menu.



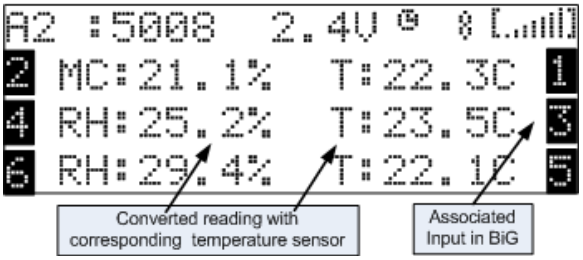
```
A2 :5008  2.4V ◷  8 [..ıll]
Channel:25 PAN:150
Timer:20s  Log:364K
BACK
```

Function	Description
Channel	Channel is autoset by the SMT-A2
PAN	Personalized Area Network (PAN) is specific to all A2 and I2 devices on the network.
Timer	Sample/Log frequency. This is inherited from the SMT-I2 setting in BiG. All units on the network will have the same timer.
Log	Number of samples in memory.
Nwk ID	Unique network ID identifier

Measurements can be taken at anytime regardless of the network status. If a network is available, a reading will be displayed and transmitted. If not, the readings will be logged and transmitted later when the network becomes available.

Measure Display - Restoration:

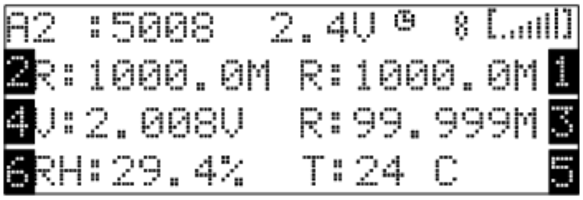
Values are converted to moisture content, temperature and relative humidity. The associated temperature sensor used for temperature compensation is displayed next to each reading.



```
A2 :5008  2.4V ◷  8 [..ıll]
2 MC:21.1%   T:22.3C 1
4 RH:25.2%   T:23.5C 3
6 RH:29.4%   T:22.1C 5
```

Measure Display - Research:

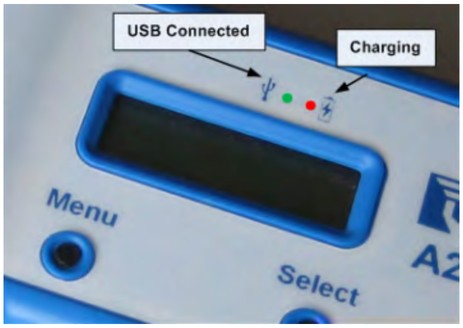
Resistance is in ohms and voltage in volts. Range will be adjusted automatically. Full values will be transmitted and stored in BiG.



```
A2 :5008  2.4V ◷  8 [..ıll]
2R:1000.0M R:1000.0M1
4V:2.008V  R:99.999M3
6RH:29.4%  T:24 C   5
```

The display will time out after 10 seconds. Press *SELECT* to keep it from timing out.

Battery Charging



The SMT-A2 is equipped with a rechargeable battery. To recharge the battery, power the unit using a USB 2.0 A Male to Mini-B Male cable from a standard computer USB port or wall adaptor.

The *USB Connected* (Green LED) indicates that USB power is available and that charging circuitry is enabled.

The *Charging* (Red LED) indicates that the batteries are being charged. The Red LED will turn off when charging is complete. A flashing LED indicates that USB power is insufficient.

The SMT-A2 will continue to take readings when powered over USB. If it is plugged into a USB port on a computer with BiG running data will be communicated via USB to BiG.

Depending on the application, different batteries may be used and charging may not be available.

Installation

The SMT-A2 can be housed in a mobile unit used for indoor applications, sealed in an IP67 enclosure or mounted on a double gang face plate.

Consult Application Notes and specific installation instructions for further details.

Data collection and analysis

Data is collected by the *Building Intelligence Gateway* (BiG) and forwarded to the *Building Analytics* server database for further analysis and user access. See the BiG and Analytics user manuals for sensor configuration and data analysis capabilities.

Troubleshooting

Unit appears to be frozen or has difficulty turning on:

- Battery power may be too low. Charge the batteries until the Charge LED is off.
- If the screen appears to be frozen wait 10 seconds and then reattempt. The A2 periodically handles critical tasks and could take up to 10 seconds to timeout or complete the task.
- Reset the unit: Hold down Menu and Select for 5+ seconds. Do not do this while USB is plugged in.

RH readings are not accurate:

- RH sensor may have been wet and requires recalibration. The unit will need to be sent back to SMT for recalibration.
- Make sure audio jacks are firmly plugged in.

SMT-A2 does not appear in BiG

- Ensure the I2 and A2 are on the same PAN. The PAN on the I2 can be queried by double clicking on the BiN serial number in BiG. Select *Get* under PAN to view the PAN. To query the PAN on the A2 select Info from the main screen on the unit.

Ordering Information	
Restoration SMT-A2 w/ moisture probes, RH/T	SMT-A2-M12-R21-L
Research SMT-A2 External sensors inputs, RH/T	SMT-A2-M12-H21-L
External RH Sensor	HTM2500-01-006
Point Moisture Measurement w/ thermistor	PMM-02-006
Thermistor	104JT-01-006

SMT-A3 – 8 Channel Wireless Data Acquisition Unit

General Description

The SMT-A3 Wireless Data Acquisition unit is a multi-channel high precision measurement device designed to interface with a variety of different building sensors.

The sleek design of the SMT-A3 allows it to be installed in occupied spaces in building units and homes. The SMT-A3 seamlessly attaches to a double junction box and supports up to eight external sensors with optional integrated sensors.

The 24-bit A/D and long range wireless proven on the SMT-A2 platform is duplicated on the SMT-A3 making it ideal for building monitoring in both new construction and retrofit work.

Options for integrated CO2, RH, temperature and differential pressure are available upon request.

The SMT-A3 communicates wireless sensor readings to the SMT Building Intelligence gateway. Optional powered repeaters can be used to extend the wireless range.

Applications

- Permanent monitoring solutions
- Remote sensor analysis and data collection
- High precision data acquisition
- Building science research
- Targeted repair monitoring

Features

- Supports up to 8 external resistance channels capable of reading wide moisture content ranges and precision thermistors.
- Supports up to 8 0-5V sensors such as RH, pressure differential, LVDT, displacement, light sensors and more.
- Supports up to 4 differential voltage inputs capable of reading sensors such as thermocouples, heat flux and more. Gain amplification boost circuitry is available to measure very small voltage differentials.
- Optional integrated relative humidity and temperature sensors.
- Sensors are installed using a two part terminal block permitting sensor lengths to be cut to their appropriate lengths and terminated prior to installing electronics.
- Large internal memory allows an 8 channel unit to log hourly data for up to 3 years without extracting data.
- Wireless transceiver with 1000m line of sight communication. Optional repeaters can be used to extend the wireless range.
- Communicates to SMT Building Intelligence Gateway (BiG) via USB to Wireless device; SMT-I2.
- Extreme low power device and 3 AA battery pack makes the SMT-A3 suitable for long term battery operation.
- USB connectivity supports data downloads, configuration and firmware upgrades.
- Backlit LCD user interface for easy network and sensor verification

Data Acquisition (SMT-A3)

→

Gateway (BiG) with USB Interface (SMT-I2)

→

Internet (Analytics)

Electrical Performance

Wireless

Specification	IEEE 802.15.4
Working Frequency	2.4 GHz – 2.4835 GHz
Power	20dBm (100mW)
Output Range (free air)	1000m. Powered repeaters can be added to extend range.
Max Nodes per coordinator	32 (dependent on application density and acquisition speed)

Battery

Life	3 - 5 years (depending on sample rate)
Type	3 AA Alkaline Battery Pack

Memory and USB

Memory	16 Mbit EEPROM for data storage Stores 340,000 data points.
USB	USB 1.0 Interface

Environmental

Operating Temperature	0° to 40°C / 32° to 104°F
Storage Temperature	-25° to 70°C / -13° to 158°F
Humidity	5% to 100% RH non-condensing
Electrostatic Discharge (ESD)	8kVdc air, 4 kVDC contact (exposed inputs)
Enclosure	The enclosure is designed for indoor use only. Consult SMT for outdoor rated units.

Regulatory

Regulatory	Contains FCC ID: OA3MRF24J40MB
FC	This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.
	Contains IC: 7693A-24J40MB

Specifications are subject to change without notice

Measurement Specifications

Internal Temperature

Sensor	Cantherm MF58104F3950 Beta 4390K
Range	-40°C to +70°C
Resolution	0.1°C
Accuracy	±1°C

Internal Relative Humidity (optional)

Sensor	Honeywell HIH-4000-001
Interchangeability	0-59% RH ±5% 60-100% RH ±8%
Resolution	0.5% RH
Accuracy	±5% RH
Hysteresis	3% RH
Repeatability	±0.5% RH

Resistance

Range	10Ω to 100Ω
Resolution	1Ω
Accuracy	±5%
Range	100Ω to 100KΩ
Resolution	10Ω
Accuracy	±1%
Range	100KΩ to 1GΩ
Resolution	1KΩ
Accuracy	±5%

Voltage

Range	0V to 5V
Resolution	100mV
Accuracy	±5%

Mechanical

Standard Enclosure

Dimensions	
Weight	

Connections

Resistance Ports	4 to 8 channels Resistance 100Ω to 1GΩ
Voltage Ports	4 to 8 channels 5V, GND, Vin Or Differential voltage

Interface

LCD	Network join/rejoin Display measurements
Buttons	Menu/Select buttons

Input Port Connectivity

A3's can be configured to have 8 resistance inputs, 8 voltage inputs or 4 resistance and 4 voltage inputs.

In addition to the sensor inputs, the A3 has a variety of optional integrated sensors.

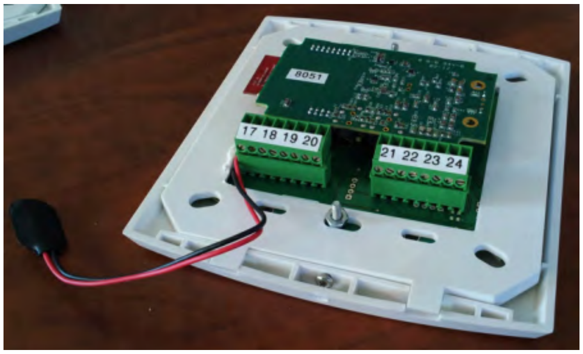
Integrated Sensors

A variety of sensors are available to measure parameters at the installed location of the A3. Faceplates are vented accordingly to allow the sensor to access the parameter being sensed.

Optional sensors that can be included are as follows:

1. Relative Humidity sensor
2. Temperature sensor
3. CO2 sensor (5000 ppm range)
4. Differential pressure sensor

Resistance Based Sensors



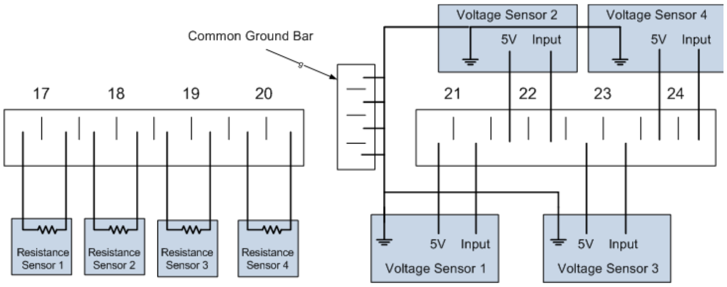
Resistance based sensors such as PMM's, EMS sensors thermistors and linear displacement potentiometers can be used.

Connect sensors to ports 17 to 24. Polarity is not important unless specified by the sensor. Unused ports can be left open or factory negated. Sensors that require temperature compensation should have the temperature inserted into the lower number (so it is recorded first). For example, a PMM should connect temperature to port 17 and moisture content to port 18.

0-5V Sensors

0-5V sensors such as RH sensors, differential pressure sensors and solar radiation sensors can be connected to the A3. The A3 can be configured to have 8 voltage ports (8R) or 4 resistance ports and 4 voltage ports (4R4V) as shown in the diagram below. Power is switched on individually to all connected sensors, each sensor is permitted to draw a maximum current of 50mA. Sensors have a warm up time of 3 seconds.

4R4V unit with CO2. Install resistance sensors in 17-20 and voltage sensors in 21 to 24 using the centre connector as a ground bar. Connect the CO2 sensor to input 24.



Typical sensor connectivity for 4R4V model. Grounds are interconnected on ground bar located in the center between the two 8 pin terminal blocks.

Installation

Install a non-metallic double gang mounting box at the desired location. Ensure the junction box has clearance for the center mounting screw on the A3.

Double gang low voltage bracket used in existing construction:

Manufacturer: Arlington LV2
Distribution: MCM Model: 28-6356

Double gang plastic junction box used in new construction:

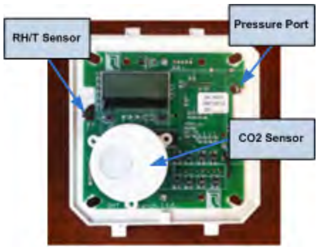
Manufacturer: T&B NuTek 2FWSW-CRT

Distributor: Home Depot
Model: 2WSW-UPC

Affix battery back to rear or side of junction box.

Route sensor wires into junction box and terminate on provided terminal block headers.

Secure the A3 to a double gang junction box.



A3 with integrated RH/T, Differential Pressure and CO2 sensors.

Configuration

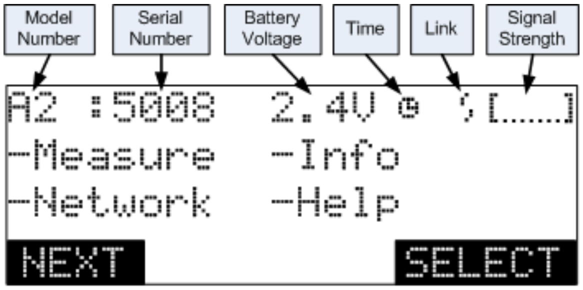
Use the LCD display and menu buttons to verify the operation of the A3. It is recommended to place the Building Intelligence Gateway (BiG) in its desired location so wireless signal strength and communication could be verified. Refer to the BiG Quick Reference Guide and Manual for further setup and configuration options.

User Interface

If the A3 is OFF, press Menu followed by Select to turn the unit ON. You will be prompted to turn the unit ON.

To turn the unit OFF at anytime, press Menu followed by Select.

The main menu contains links to the submenus as shown below. The header reports the immediate status of the unit.

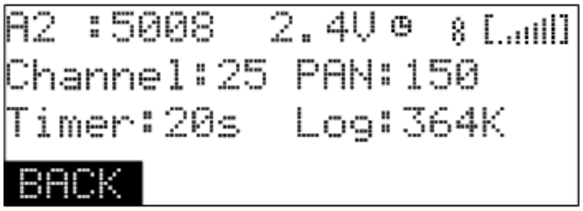


Status Menu	Description
Serial Number	Unique identifier of this unit used in BiG and Analytics
Battery Voltage	Replace batteries if the voltage is less than 2.4V. The unit will stop functioning if the battery voltage is less than 1.8V.
Time	◷ Indicates A3 has time ◷ Indicates A3 does not have time. Join network with BiG to establish time. You may need to wait up to 5 minutes for the unit to establish time.
Link	⁝ No link established ⁝ Link established. Message transmit successful
Signal Strength	[.......] No signal. Ensure connectivity to network. Ensure PAN is correct and there are no range/obstacle issues. [..ıılll] Full signal strength

To join the network, ensure BiG is running with an SMT-I2 USB to Wireless interface and select Network.

Joining Network will be displayed, if joining was successful *Joining Network on 25* will be displayed where 25 is the wireless channel, otherwise *No Network* will be displayed.

To rejoin the network select Join. To see the status of the network select Info from the main menu.



```
A2 :5008   2.4V      [..ıll]
Channel:25  PAN:150
Timer:20s   Log:364K
BACK
```

Function	Description
Channel	Channel is autoset by the SMT-A3
PAN	Personalized Area Network (PAN) is specific to all A3 and I2 devices on the network.
Timer	Sample/Log frequency. This is inherited from the SMT-I2 setting in BiG. All units on the network will have the same timer.
Log	Number of samples in memory. To clear the log hold Menu and press Select 5 times. Select Erase Log.
Nwk ID	Unique network ID identifier

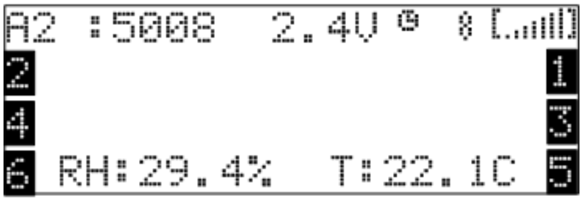
Measurements can be taken at anytime regardless of the network status. If a network is available, a reading will be displayed and transmitted. If not, the readings will be logged and transmitted later when the network becomes available.

The A3 MUST have time in order to log a reading.

Measure

Select Measure to force a reading.

Values for internal sensors will be displayed.



```
A2 :5008   2.4V      [..ıll]
2                          1
4                          3
6 RH:29.4%    T:22.1C      5
```

The display and backlight will time out after 10 seconds. Press *SELECT* to keep it from timing out.

The display is normally OFF for power savings.

Building Intelligence Gateway Configuration

Inputs appear in the Building Intelligence Gateway (BiG) as *New SMT-A2* with default values in resistance (Ω) or voltage (mV) depending on the sensor. Select the appropriate sensor type and identify the temperature sensor for compensation (if applicable) to have the desired unit of measurement displayed. Refer to the BiG User Manual for further instructions on programming the sensor inputs, creating jobs and synchronizing with Analytics.

Name	ID	State	Firmware
GM MAC	1	Normal	
New SMT-A2	8125	Normal	

Name	Node	Input	Type	Last Reading	Reading Date
Internal Temperature	8125	5	Temper...	23.33 °C	12/09/11-12:00:00
Internal RH	8125	6	Humidity	45.53 %RH	12/09/11-12:00:00
Battery	8125	7	Power	4.03 V	12/09/11-12:00:00
PMM Temp 1	8125	17	Temper...	-89.73 °C	12/09/11-12:00:00
PMM MC 1	8125	18	Moisture	8.80 %	12/09/11-12:00:00
PMM Temp 2	8125	19	Temper...	-89.73 °C	12/09/11-12:00:00
PMM MC 2	8125	20	Moisture	8.80 %	12/09/11-12:00:00
PMM Temp 3	8125	21	Temper...	-89.73 °C	12/09/11-12:00:00
PMM MC 3	8125	22	Moisture	8.80 %	12/09/11-12:00:00
PMM Temp 4	8125	23	Temper...	-89.73 °C	12/09/11-12:00:00

Last successful sync at 24/07/2012 12:45:07 AM | Project: [90] My Project | Gateway: [261] GM_Mac | Job: [0] Default Job

A list of the various inputs and sensor types is listed in the table below:

Input	Function	Sensor Type
5	Internal Temperature	1-04JT (ºC)
6	Integrated RH	HIH-4000 (%RH)
7	Battery	Battery (V)
17	Resistance	
18	Resistance	
19	Resistance	
20	Resistance	
21	Resistance/Voltage	
22	Resistance/Voltage	
23	Resistance/Voltage Pressure if included	All Sensors .25”
24	Resistance/Voltage CO2 if included	COZIR 5000 PPM

Inputs 21 to 24 can be either configured as resistance based or voltage based sensors depending on the configuration selected. If Pressure is included it will be allocated to input 23 and if CO2 is included it will be allocated to input 24. Specific delays and warm up times are included to support these sensors.

USB Interface

The USB port can be used for data collection, unit configuration and firmware upgrades.

If an SMT-I2 isn't available to facilitate a wireless data download to BiG, data can be collected using the onboard USB port.

Connect the SMT-A3 mini USB port to a computer running the Building Intelligence Gateway software. The A3 serial number should show up under the Devices tab. If there are readings the data will automatically be transferred into the BiG database.

Configuration settings can be changed by selecting Device ID under the devices tab. Do not change settings here if you are unsure what you are doing.

The A3 will continue to take readings and transmit to BiG when powered over USB.

Data collection and analysis

Data is collected by the *Building Intelligence Gateway* (BiG) and forwarded to the *Building Analytics* server database for further analysis and user access. See the BiG and Analytics user manuals for sensor configuration and data analysis capabilities.

Faceplate Installation

After the inputs on the A3 are confirmed and data is being transmitted, slide the faceplate on by hooking it to the top and then pushing firmly on the bottom.

Hook faceplate on top and push down.

Push CO2 unit up while pushing down on faceplate

A3 with RH/T, CO2 and pressure port.

A3 installed in living space

Troubleshooting

Unit appears to be frozen or will not turn on:

- Battery power may be too low. Check the battery voltage and change the batteries if they are less than 2.4v
- If the screen appears to be frozen wait 10 seconds and then reattempt. The A3 periodically handles critical tasks and could take up to 10 seconds to timeout or complete a task.
- Reset the unit: Make sure A2 is not plugged into USB. Hold down Menu and Select for 5+ seconds.

Internal RH/T readings are not accurate:

- RH sensor may have been wet and requires recalibration. The unit will need to be sent back to SMT for recalibration.
- Ensure the RH sensor has good venting out the front face plate.
- Unplug the A3 from USB as the unit heats up while charging.

A3 does not appear in BiG

- Ensure the I2 and A3 are on the same PAN. The PAN on the I2 can be queried by double clicking on the serial number under Devices in BiG. Select *Get* next to PAN. To query the PAN on the A3 select Info from the main screen on the unit.

Ordering Information	
A3 8 Resistance Channels with RH/T	A3-J22-H00-8R
A3 4 Resistance 4 Voltage Channels with RH/T	A3-J22-H00-4R4V
A3 4 Resistance 4 Voltage Channels with RH/T and CO2	A3-J22-H00-4R3V-CO2
A3 4 Resistance Channel with RH/T, Differential Pressure	A3-J22-H00-4R-P
A3 4 Resistance Channel with RH/T Pressure and CO2	A3-J22-H00-4R-P-CO2
Industrial NEMA IP66 Hammond Weatherproof Case with 2 cinch connectors and desiccant	A3-1554N2
Double gang low voltage bracket	A3-LV2
Double gang plastic junction box	A3-2FWSW

Structure Monitoring Technology

Building Intelligence Gateway

Building Intelligence Gateway©

General Description

The Building Intelligence Gateway© (BiG) is a compact yet powerful computer system used to provide continuous monitoring and data collection of distributed sensors used for automated structure monitoring.

The BiG system collects data from a variety of different sensors located within the monitored structure and provides local analysis of data as well as synchronization with SMT's on-line monitoring and reporting system, Analytics©.

The BiG system uses the Windows platform to provide a familiar and user friendly interface for configuration and local data viewing. The software can communicate with wireless and wired sensors and is capable of scaling for large sensor networks, where real-time data of hundreds of sensors is required.

BiG can monitor sensors using configurable thresholds and can be setup to react to threshold violations with a variety of built-in actions including e-mail, pager, and triggering an electrical relay.

Applications

Building Science Research

- Window and wall module evaluation
- External façade sensing
- Moisture, RH and temperature sensing
- Pressure, solar radiation and displacement

Field Applications/Research

- Long term structure monitoring
- Targeted repair monitoring
- Restoration Monitoring

Flood Monitoring

- Flood detection and alarm forwarding

Roof Monitoring

- Automated leak detection

Features

- Compact design. Fits in standard wall mount cabinets.
- Rugged and portable. Rugged case available for portable and outdoor applications.
- Local Windows user interface displayed on 7 inch backlit LCD display.
- Simple configuration. Keyboard and touchpad used for local configuration.
- Solid state storage permits rugged installations and is expandable using the local MMC/SD interface.
- Standard 10/100 Mbit Ethernet and 802.11 b/g wireless.
- USB ports permit expansion and compatibility to 3rd party systems.
- Optional GSM interface to cellular network for installations where internet is not available.
- Interface to 802.15.4 wireless and Controller Area Network wired sensor units.
- Multithreaded communication permits communication to large sensor networks.
- Event handling and alarm processing allows system to be used as a stand-alone monitoring center.
- Displays sensor data in real-time.
- Unique graph manipulation tools available for viewing and scanning large data sets. Advanced graphing functions permit detailed analysis of sensor data.
- Synchronizes sensor configurations and recorded data with SMT Analytics©
- Facilitates data set groupings per job and synchronizes with Analytics server.
- Unique sensor groupings and mass configuration schemes available.
- Real time clock and built in battery backup.

SMT

Structure Monitoring Technology

Building Intelligence Gateway

Hardware Specifications

Operating System	Microsoft® Windows XP/Vista/7
Display	7" with LED backlight
Memory	512MB
Storage	Solid State 4GB. Expansion SD cards available.
Local Input	Keyboard/Touchpad
User Connectivity	10/100 Mbit Ethernet 802.11 b/g wireless LAN GSM cell network
Expansion	3 USB 2.0 ports MMC/SD card reader
Sensor Connectivity	Wireless 802.15.4 Wired CAN 2.0
Max Distance from coordinator node	Wireless 30m (IEEE 802.15.4) Wired 300m (CAN)
Power	5200 mAh battery backup 120VAC
Dimension	225mm (L) x 165mm (D) x 35mm(H)
Weight	1 kg (2.2 lb)

Sensor Monitoring Performance

See specific sensor datasheets

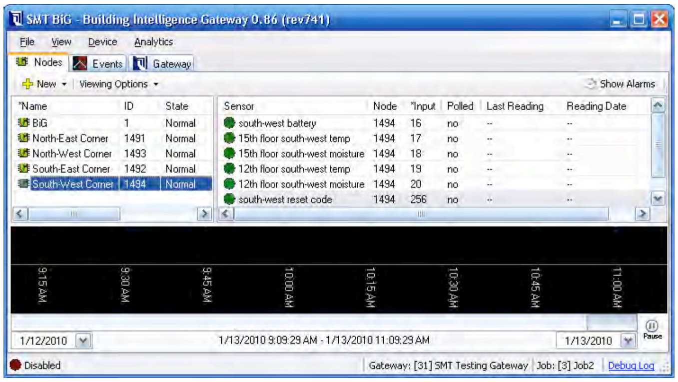
Regulatory

EMC Radiated and Conducted Emissions	FCC Part 15 Class B Industry Canada ICES 003
Safety Requirements	cULus and CE

MMC/SD card reader and USB ports

Ethernet and USB port

BIG General Configuration



SMT BiG - Building Intelligence Gateway 0.86 (rev741)

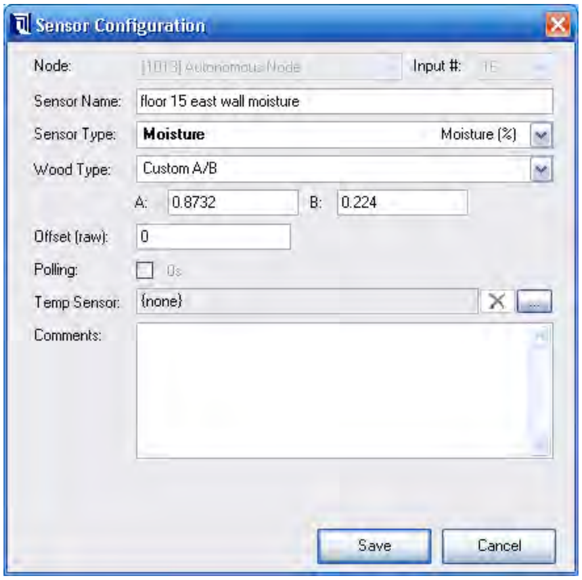
*Name	ID	State
BiG	1	Normal
North-East Corner	1491	Normal
North-West Corner	1493	Normal
South-East Corner	1492	Normal
South-West Corner	1494	Normal

Sensor	Node	*Input	Polled	Last Reading	Reading Date
south-west battery	1494	16	no	--	--
15th floor south-west temp	1494	17	no	--	--
15th floor south-west moisture	1494	18	no	--	--
12th floor south-west temp	1494	19	no	--	--
12th floor south-west moisture	1494	20	no	--	--
south-west reset code	1494	256	no	--	--

1/12/2010 1/13/2010 9:09:29 AM - 1/13/2010 11:09:29 AM 1/13/2010

Disabled Gateway: [31] SMT Testing Gateway Job: [3] Job2 Debug Log

- Compatible sensors on network are automatically discovered.
- Sensors are grouped by hardware by default. Custom groupings can be defined.
- Ascending or descending sort can be applied to any column.



Sensor Configuration

Node: [1013] Autonomous Node Input #: 16

Sensor Name: floor 15 east wall moisture

Sensor Type: **Moisture** Moisture (%)

Wood Type: Custom A/B

A: 0.8732 B: 0.224

Offset (raw): 0

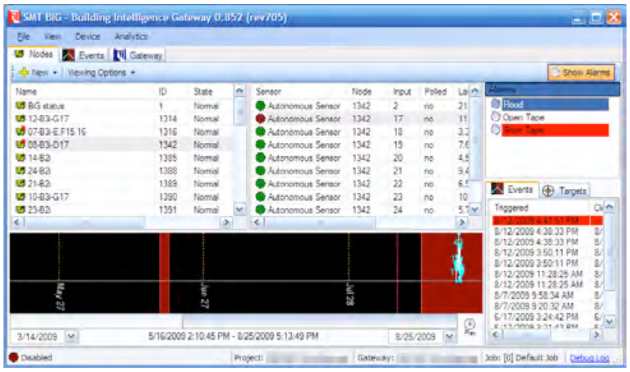
Polling: ☐ 0s

Temp Sensor: {none}

Comments:

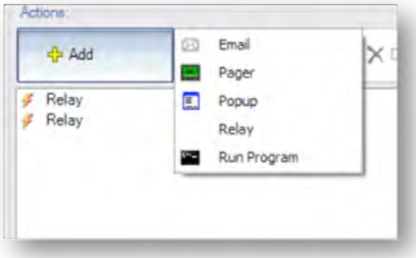
Parameters of each sensor can be easily modified. Batch modifications are possible for applying changes to more than one sensor. BiG comes with a large library of built-in sensor conversions. Sensor conversion formulas can also be manually entered with a custom quadratic equation.

Alarm Handling



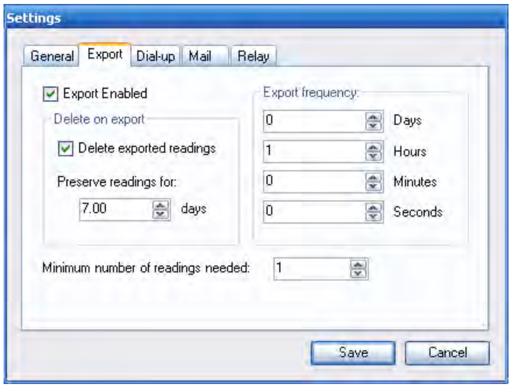
- Thresholds can be defined with configurable durations. Any number of alarms can be linked to a sensor.
- Nodes and sensors in alarm are logged along with details on the alarm.

Targets



Alarms can be forwarded via Email, Pager, Relay contact or custom actions can be defined.

Export Functionality



☑ Export Enabled

Delete on export

☑ Delete exported readings

Preserve readings for: 7.00 days

Export frequency:

0 Days

1 Hours

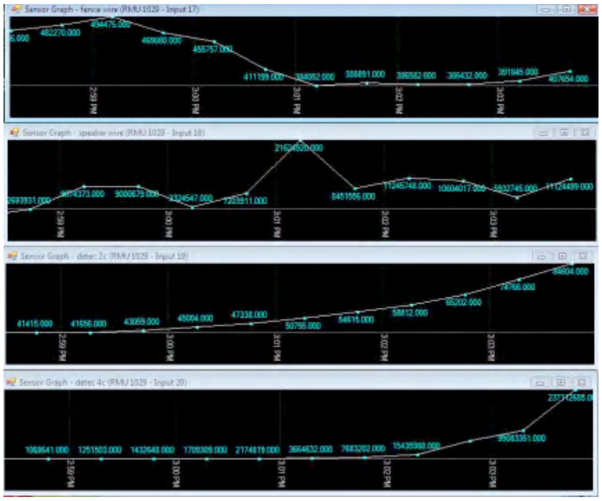
0 Minutes

0 Seconds

Minimum number of readings needed: 1

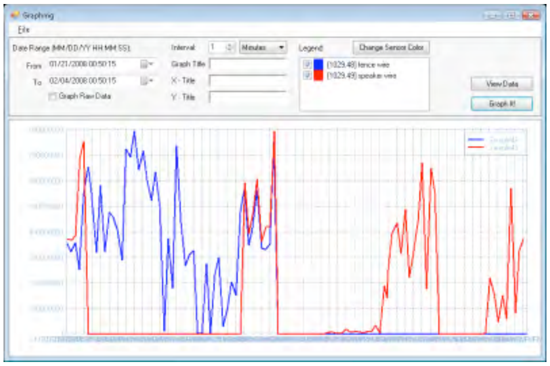
- Specific interval can be defined for forwarding data to Analytics$^{©}$.
- All data can be easily exported for analysis in custom tools if desired.

Real Time Data Analysis



Sensor data is recorded and graphed in real-time. Using simple mouse controls the view can be panned forward/backward and zoomed in/out on the time axis.

Advanced Graphing



Sensor inputs can be analyzed using an advanced graphing feature. Graphs can customized, compared and printed.

Ordering Information

Standard Gateway (6 months monitoring)	BIG-001

CAN and Wireless
interfaces sold separately.

Specifications are subject to change without notice

Appendix E

Section 5 - Airtightness Testing Procedure & Schematic

Airtightness Testing Procedure and Schematics

Airtightness testing of the suites including of compartmentalizing elements was performed using the following 6 steps:

- Step 1: All 6 Sides – No adjacent zone pressure neutralized
- Step 2: Floor Above – Floor above pressure neutralized
- Step 3: Floor Below – Floor below and floor above pressure neutralized
- Step 4: Corridor – Corridor, floor below, and floor above pressure neutralized
- Step 5: Suite to Right – Suite to right, corridor, floor below, and floor above pressure neutralized
- Step 6: Suite to Left – Suite to left, suite to right, corridor, floor below, and floor above pressure neutralized

These steps were performed first for pressurization and then for depressurization. A schematic of the test set-up for these steps for pressurization testing of an -02 suite is shown in Fig. 1.2. The direction of the fans is simply reversed for the depressurization testing. A legend of the symbols used in these schematics is shown in Fig. 1.1.

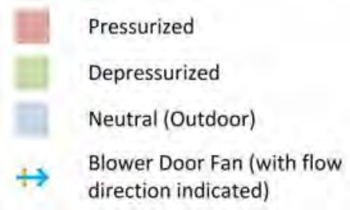


Fig. 1.1 Legend for airtightness testing schematics

Step 1

Floor Below

Test Floor

Floor Above

Step 2

Floor Below

Test Floor

Floor Above

Step 3

Floor Below

Test Floor

Floor Above

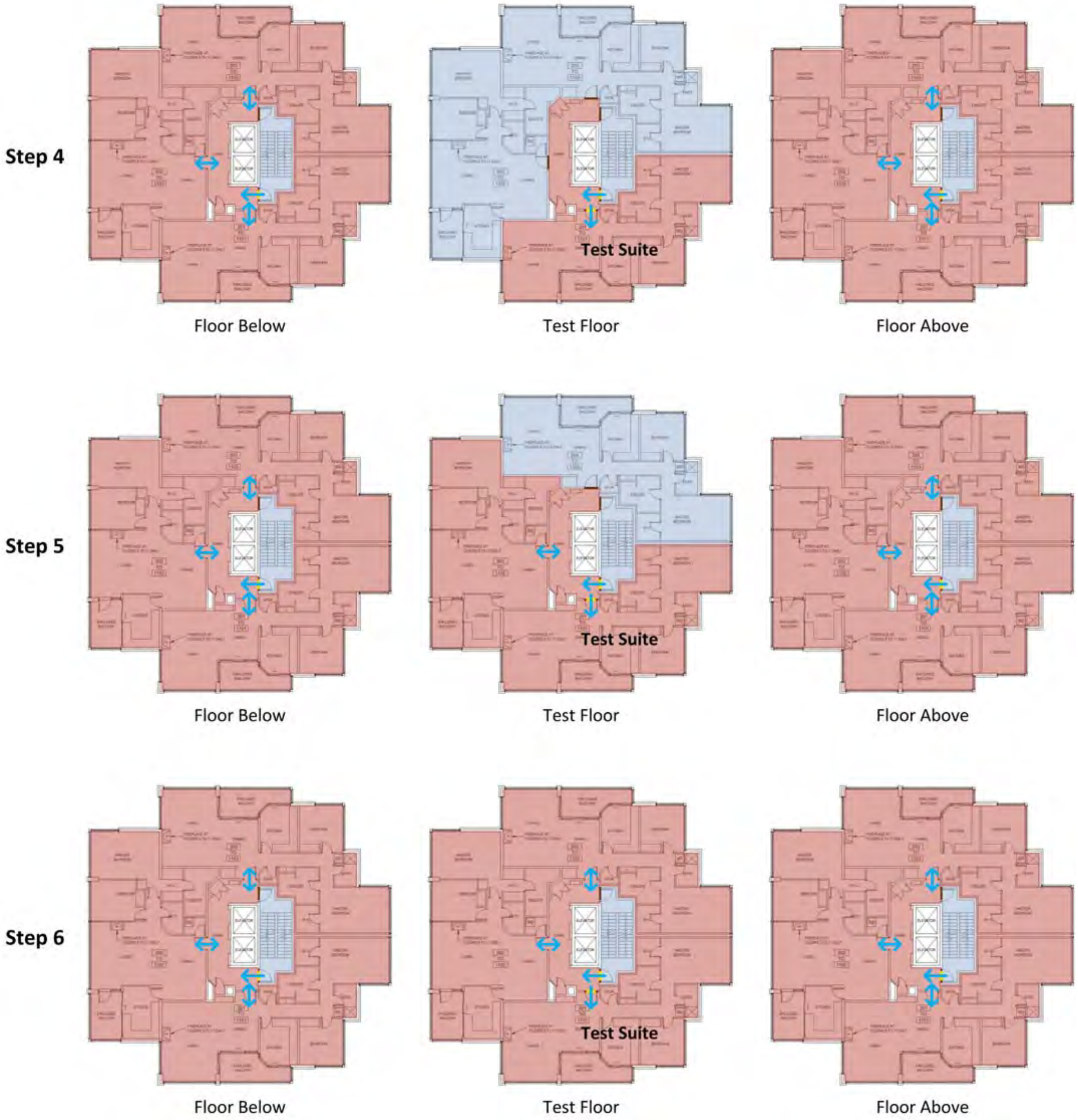


Fig. 1.2 Schematics of 6 testing steps for pressurization testing of an -02 suite.

Airtightness testing of the corridors was performed using the following 20 steps:

- Step 1: Pressurize - All 6 Sides – No adjacent zones pressure neutralized or sealed
- Step 2: Depressurize – All 6 Sides – No adjacent zones pressure neutralized or sealed
- Step 3: Pressurize – Door -01 – Door -01 sealed
- Step 4: Depressurize – Door -01 – Door -01 sealed
- Step 5: Pressurize – Door -02 – Door -02 sealed
- Step 6: Depressurize – Door -02 – Door -02 sealed
- Step 7: Pressurize – Door -03 – Door -03 sealed
- Step 8: Depressurize – Door -03 – Door -03 sealed
- Step 9: Pressurize – Elevator Doors – Elevator doors sealed
- Step 10: Depressurize – Elevator Doors – Elevator doors sealed
- Step 11: Pressurize – Stairwell Door – Stairwell door is sealed
- Step 12: Depressurize – Stairwell Door – Stairwell door is sealed
- Step 13: Pressurize – Electrical Closet Door – Electrical closet door is sealed
- Step 14: Depressurize – Electrical Closet Door – Electrical closet door is sealed
- Step 15: Pressurize – Garbage Chute Door – Garbage chute room door is sealed
- Step 16: Depressurize – Garbage Chute Door – Garbage chute room door is sealed
- Step 17: Pressurize – Floor Above – Floor above is pressure neutralized
- Step 18: Depressurize – Floor Above – Floor above is pressure neutralized
- Step 19: Pressurize – Floor Below – Floor below is pressure neutralized
- Step 20: Depressurize – Floor Below – Floor below is pressure neutralized

A schematic of the test set-up for these steps is shown in Fig. 1.3. Note that the results for the Step 11 and Step 12, stairwell door are for one stairwell door since the testing fan is installed in the other door. It is assumed that the stairwell doors are similar and thus the quantity of airflow through this door is multiplied by two to account for both doors.

Step 1


Floor Below


Test Floor


Floor Above

Step 2


Floor Below


Test Floor


Floor Above

Step 3


Floor Below

Test Floor


Floor Above

Step 4

Floor Below

Test Floor

Floor Above

Step 5

Floor Below

Test Floor

Floor Above

Step 6

Floor Below

Test Floor

Floor Above

Step 7

Floor Below

Test Floor

Floor Above

Step 8

Floor Below

Test Floor

Floor Above

Step 9

Floor Below

Test Floor

Floor Above

Step 10

Floor Below

Test Floor

Floor Above

Step 11

Floor Below

Test Floor

Floor Above

Step 12

Floor Below

Test Floor

Floor Above

Step 13

Floor Below

Test Floor

Floor Above

Step 14

Floor Below

Test Floor

Floor Above

Step 15

Floor Below

Test Floor

Floor Above

Step 16

Floor Below

Test Floor

Floor Above

Step 17

Floor Below

Test Floor

Floor Above

Step 18

Floor Below

Test Floor

Floor Above

Fig. 1.3 Schematics of 20 testing steps for airtightness testing of a corridor.

Appendix F

Section 5 - Airtightness Testing Results

Suite Airtightness Testing Results

Zone Type	Zone	Adjacent Zone	Flow Coefficient, C [cfm/Pa^n]	Flow Exponent, n	Area [ft^2]	Volume [ft^3]	Q$_{50}$ [cfm]	Q$_{75}$ [cfm]	Normalized Flow Coefficient, C$_N$ [cfm/Pa^n·ft^2]	NAR$_{50}$ [cfm/ft^2]	NAR$_{75}$ [cfm/ft^2]	EqLA (Cd = 0.61 ΔP_{ref} = 10 Pa) [in^2]	EfLA (Cd = 1.0 ΔP_{ref} = 4 Pa) [in^2]	SLA$_{eq}$ (Cd = 0.61 ΔP_{ref} = 10 Pa) [in^2/100 ft^2]	SLA$_{ef}$ (Cd = 1.0 ΔP_{ref} = 4 Pa) [in^2/100 ft^2]	ACH$_{50}$ [1/h]	ACH$_{75}$ [1/h]
Typical Suites	Suite 301	**Suite Above**	3.29	0.75	1354	10833	63	85	0.002	0.05	0.06	5.5	2.7	0.41	0.20	0.35	0.47
		Suite Below	6.78	0.60	1354	10833	72	92	0.005	0.05	0.07	8.0	4.4	0.59	0.33	0.40	0.51
		Corridor	4.44	0.69	150	10833	65	86	0.030	0.44	0.58	6.4	3.3	4.25	2.18	0.36	0.48
		Suite to Right	1.12	0.62	192	10833	13	16	0.006	0.07	0.08	1.4	0.7	0.72	0.39	0.07	0.09
		Suite to Left	1.69	0.62	209	10833	19	24	0.008	0.09	0.12	2.1	1.1	0.99	0.54	0.11	0.14
		Exterior Enclosure - Pre-Retrofit	51.39	0.55	907	10833	442	552	0.057	0.49	0.61	53.6	31.2	5.90	3.44	2.45	3.06
		Exterior Enclosure - Post-Retrofit	14.72	0.67	907	10833	205	270	0.016	0.23	0.30	20.4	10.6	2.25	1.17	1.14	1.49
	Suite 302	**Suite Above**	3.25	0.64	1314	10514	40	52	0.002	0.03	0.04	4.2	2.2	0.32	0.17	0.23	0.29
		Suite Below	10.80	0.59	1314	10514	109	138	0.008	0.08	0.11	12.4	6.9	0.94	0.53	0.62	0.79
		Corridor	11.03	0.67	280	10514	153	201	0.039	0.55	0.72	15.2	7.9	5.44	2.84	0.87	1.15
		Suite to Right	1.89	0.63	192	10514	22	28	0.010	0.11	0.15	2.3	1.3	1.22	0.67	0.12	0.16
		Suite to Left	1.90	0.63	192	10514	22	28	0.010	0.11	0.15	2.4	1.3	1.23	0.67	0.13	0.16
		Exterior Enclosure - Pre-Retrofit	29.13	0.65	759	10514	371	483	0.038	0.49	0.64	38.2	20.3	5.04	2.68	2.12	2.75
		Exterior Enclosure - Post-Retrofit	14.32	0.71	759	10514	228	304	0.019	0.30	0.40	21.5	10.8	2.83	1.43	1.30	1.74
	Suite 303	**Suite Above**	3.09	0.59	1354	10833	30	39	0.002	0.02	0.03	3.5	2.0	0.26	0.15	0.17	0.21
		Suite Below	7.38	0.59	1354	10833	73	92	0.005	0.05	0.07	8.3	4.7	0.62	0.35	0.40	0.51
		Corridor	4.44	0.76	150	10833	88	120	0.030	0.59	0.80	7.6	3.6	5.05	2.42	0.49	0.66
		Suite to Right	0.00	0.59	209	10833	0	0	0.000	0.00	0.00	0.0	0.0	0.00	0.00	0.00	0.00
		Suite to Left	2.71	0.59	192	10833	27	34	0.014	0.14	0.18	3.1	1.7	1.60	0.90	0.15	0.19
		Exterior Enclosure - Pre-Retrofit	54.92	0.58	907	10833	525	663	0.061	0.58	0.73	60.9	34.6	6.71	3.82	2.91	3.67
		Exterior Enclosure - Post-Retrofit	16.06	0.61	907	10833	176	225	0.018	0.19	0.25	19.3	10.6	2.13	1.17	0.97	1.25
	Suite 1101	**Suite Above**	9.72	0.58	1354	10833	94	119	0.007	0.07	0.09	10.9	6.2	0.80	0.45	0.52	0.66
		Suite Below	4.17	0.73	1354	10833	73	98	0.003	0.05	0.07	6.6	3.3	0.49	0.24	0.40	0.54
		Corridor	3.62	0.76	150	10833	71	97	0.024	0.48	0.65	6.1	2.9	4.10	1.97	0.39	0.54
		Suite to Right	3.97	0.62	192	10833	44	57	0.021	0.23	0.30	4.8	2.6	2.52	1.38	0.25	0.32
		Suite to Left	2.36	0.61	209	10833	26	33	0.011	0.12	0.16	2.8	1.6	1.36	0.75	0.14	0.18
		Exterior Enclosure - Pre-Retrofit	49.17	0.57	907	10833	465	588	0.054	0.51	0.65	54.2	30.9	5.98	3.40	2.58	3.25
		Exterior Enclosure - Post-Retrofit	20.42	0.66	907	10833	268	350	0.022	0.30	0.39	27.3	14.4	3.01	1.59	1.48	1.94
	Suite 1102	**Suite Above**	10.84	0.69	1314	10514	160	212	0.008	0.12	0.16	15.5	8.0	1.18	0.61	0.91	1.21
		Suite Below	5.27	0.79	1314	10514	118	163	0.004	0.09	0.12	9.6	4.5	0.73	0.34	0.67	0.93
		Corridor	26.53	0.61	280	10514	289	370	0.095	1.03	1.32	31.8	17.5	11.36	6.26	1.65	2.11
		Suite to Right	1.06	0.61	192	10514	12	15	0.006	0.06	0.08	1.3	0.7	0.66	0.36	0.07	0.08
		Suite to Left	3.18	0.59	192	10514	32	41	0.017	0.17	0.22	3.7	2.1	1.91	1.07	0.18	0.24
		Exterior Enclosure - Pre-Retrofit	68.79	0.61	759	10514	749	960	0.091	0.99	1.26	82.4	45.4	10.86	5.99	4.28	5.48
		Exterior Enclosure - Post-Retrofit	37.74	0.50	759	10514	262	320	0.050	0.35	0.42	34.7	21.2	4.57	2.80	1.49	1.83
	Suite 1103	**Suite Above**	10.20	0.59	1354	10833	102	129	0.008	0.08	0.10	11.6	6.5	0.86	0.48	0.56	0.72
		Suite Below	3.55	0.65	1354	10833	44	58	0.003	0.03	0.04	4.6	2.5	0.34	0.18	0.25	0.32
		Corridor	5.41	0.80	150	10833	126	174	0.036	0.84	1.16	10.1	4.7	6.76	3.12	0.70	0.96
		Suite to Right	1.29	0.65	209	10833	16	21	0.006	0.08	0.10	1.7	0.9	0.80	0.43	0.09	0.12
		Suite to Left	3.22	0.65	192	10833	40	52	0.017	0.21	0.27	4.2	2.2	2.18	1.16	0.22	0.29
		Exterior Enclosure - Pre-Retrofit	71.57	0.54	907	10833	585	727	0.079	0.64	0.80	72.4	42.7	7.98	4.70	3.24	4.03
		Exterior Enclosure - Post-Retrofit	23.72	0.62	907	10833	267	343	0.026	0.29	0.38	29.0	15.8	3.19	1.75	1.48	1.90
1st Floor Suites	Suite 101	**Exterior Enclosure - Pre-Retrofit**	56.31	0.62	2335	10833	634	815	0.024	0.27	0.35	68.8	37.6	2.95	1.61	3.51	4.51
		Exterior Enclosure - Post-Retrofit	33.57	0.67	2335	10833	464	610	0.014	0.20	0.26	46.3	24.1	1.98	1.03	2.57	3.38
	Suite 102	**Exterior Enclosure - Pre-Retrofit**	52.92	0.60	2094	10514	548	698	0.025	0.26	0.33	61.5	34.3	2.94	1.64	3.13	3.98
		Exterior Enclosure - Post-Retrofit	16.86	0.68	2094	10514	237	312	0.008	0.11	0.15	23.5	12.2	1.12	0.58	1.35	1.78
13th Floor Suites	Suite 1301	**Exterior Enclosure - Pre-Retrofit**	134.44	0.65	2794	13098	1699	2210	0.048	0.61	0.79	175.8	93.6	6.29	3.35	7.78	10.12
		Exterior Enclosure - Post-Retrofit	60.90	0.67	2794	13098	844	1109	0.022	0.30	0.40	84.1	43.8	3.01	1.57	3.87	5.08
	Suite 1302	**Exterior Enclosure - Pre-Retrofit**	216.02	0.58	2794	13098	2052	2591	0.077	0.73	0.93	238.7	135.9	8.54	4.86	9.40	11.87
		Exterior Enclosure - Post-Retrofit	59.69	0.60	2794	13098	616	785	0.021	0.22	0.28	69.3	38.7	2.48	1.38	2.82	3.60

Full Floor Airtightness Testing Results

Full Floors	Floor 01	**Exterior Enclosure - Pre-Retrofit**	300.30	0.63	6030	28778	3523	4547	0.050	0.58	0.75	375.8	203.6	6.23	3.38	7.34	9.48
		Exterior Enclosure - Post-Retrofit	209.66	0.60	6030	28778	2207	2817	0.035	0.37	0.47	246.2	136.8	4.08	2.27	4.60	5.87
	Floor 13	**Exterior Enclosure - Pre-Retrofit**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		Exterior Enclosure - Post-Retrofit	291.32	0.71	6084	30155	4684	6247	0.048	0.77	1.03	438.9	220.9	7.21	3.63	9.32	12.43

Corridor Airtightness Testing

Suite	Adjacent Zone	Flow Coefficient, C [cfm/Pa^n]	Flow Exponent, n
Corridor 03	**Door 301**	16.7	0.56
	Door 302	7.3	0.58
	Door 303	8.9	0.64
	Elevator Doors	126.4	0.54
	Stairwell Doors	90.1	0.53
	Electrical Closet Door	4.2	0.56
	Garbage Chute Door	9.9	0.56
	Floor Above	3.6	0.56
	Floor Below	0.0	0.56
	Remaining	17.2	0.56
Corridor 11	**Door 1101**	5.2	0.58
	Door 1102	20.1	0.72
	Door 1103	16.9	0.58
	Elevator Doors	114.4	0.58
	Stairwell Doors	69.6	0.58
	Electrical Closet Door	8.5	0.73
	Garbage Chute Door	2.8	0.68
	Floor Above	2.9	0.68
	Floor Below	6.5	0.58
	Remaining	-9.0	0.58
Corridor 09	**Door 901**	35.7	0.55
	Door 902	13.6	0.61
	Door 903	18.3	0.55
	Elevator Doors	109.8	0.55
	Stairwell Doors	100.2	0.55
	Electrical Closet Door	0.0	n/a
	Garbage Chute Door	23.1	0.55
	Floor Above	13.8	0.50
	Floor Below	4.6	0.55
	Remaining	-21.9	0.55
Average	**Suite Door**	15.8	0.60
	Elevator Doors	116.9	0.56
	Stairwell Doors	86.6	0.55
	Electrical Closet Door	6.4	0.64
	Garbage Chute Door	11.9	0.60
	Floor Above	6.8	0.58
	Floor Below	3.7	0.56
	Remaining	-4.6	0.57

Appendix G

Section 6 – Additional Analysis

Metered and Weather Normalized Energy Consumption

TABLE G.1 POST-RETROFIT METERED ENERGY CONSUMPTION DATA				
Month	Actual HDDs	Gas, GJ	Common Electricity, kWh	Suite Electricity, kWh
January	470.8	243	18,210	27,378
February	352.4	207	15,037	23,450
March	334.3	169	15,637	22,328
April	254.8	127	15,220	15,388
May	145.4	101	15,779	13,250
June	50.8	79	15,270	10,761
July	11	57	15,328	9,523
August	5.7	55	15,371	10,232
September	72.7	88	15,013	11,678
October	254	153	15,851	18,703
November	355.6	200	16,439	23,711
December	474.4	239	17,640	28,784
TOTAL	**2,782**	**1,717**	**190,794**	**215,186**

TABLE G.2 WEATHER NORMALIZED POST-RETROFIT ENERGY CONSUMPTION DATA				
Month	CWEC (Average) HDDs	Gas, GJ	Common Electricity, kWh	Suite Electricity, kWh
January	459	240	17,486	27,853
February	361	194	16,216	22,801
March	369	198	16,303	23,190
April	279	158	15,510	19,043
May	191	123	15,112	15,486
June	88	85	15,121	11,949
July	35	68	15,324	10,392
August	30	66	15,350	10,254
September	127	99	15,057	13,209
October	253	147	15,353	17,941
November	382	204	16,449	23,832
December	445	234	17,276	27,094
TOTAL	**3,019**	**1,816**	**190,558**	**223,044**

Metered Energy Consumption Trends by Year, Without Weather Normalizing

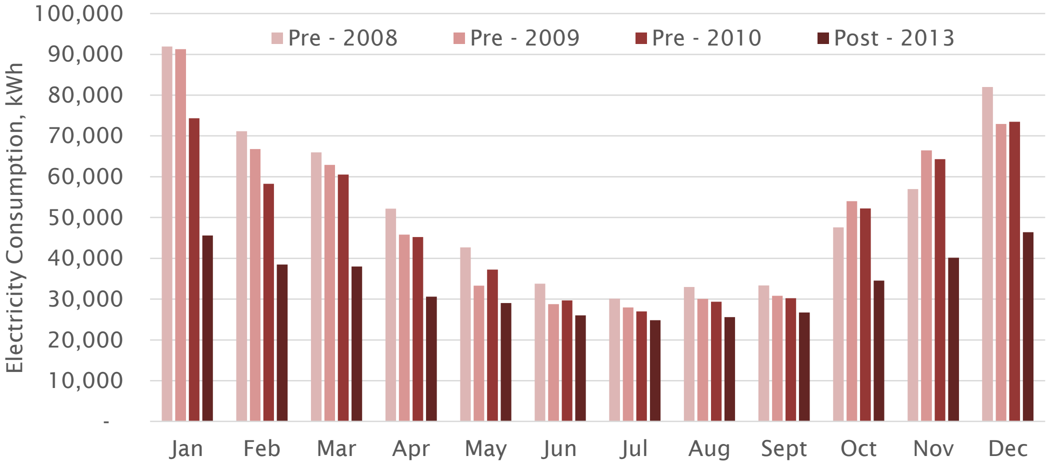


Figure G.1 Metered electricity consumption by year (not weather normalized), kWh.

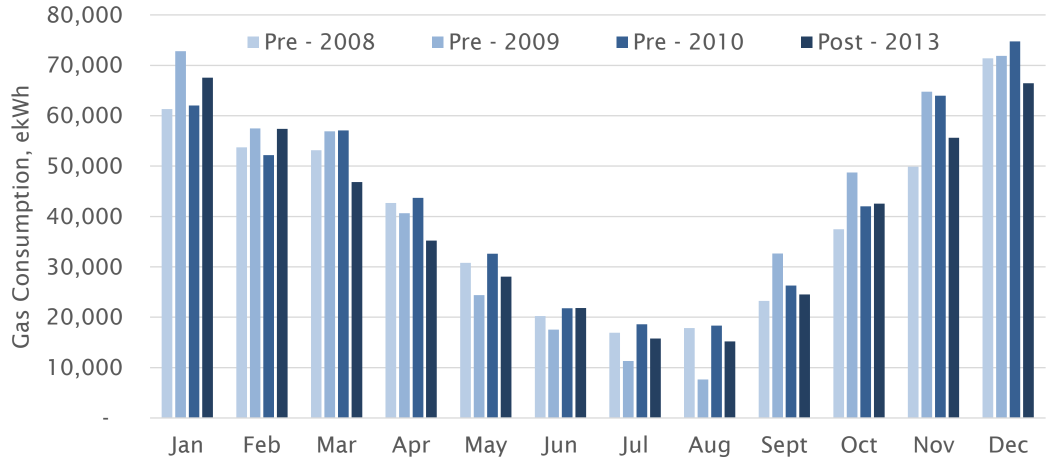


Figure G.2 Metered gas consumption by year (not weather normalized), ekWh.

Energy Trends by Orientation and Floor

Energy consumption by suite was analyzed to determine whether there are any trends with respect to suite orientation or floor.

Figure G.3 and Figure G.4 show the average monthly energy consumption by suite orientation, based on pre- and post-retrofit data, respectively. Figure G.5 shows the orientation of the three suite plans. The data shows that consumption does not vary significantly based on suite orientation.

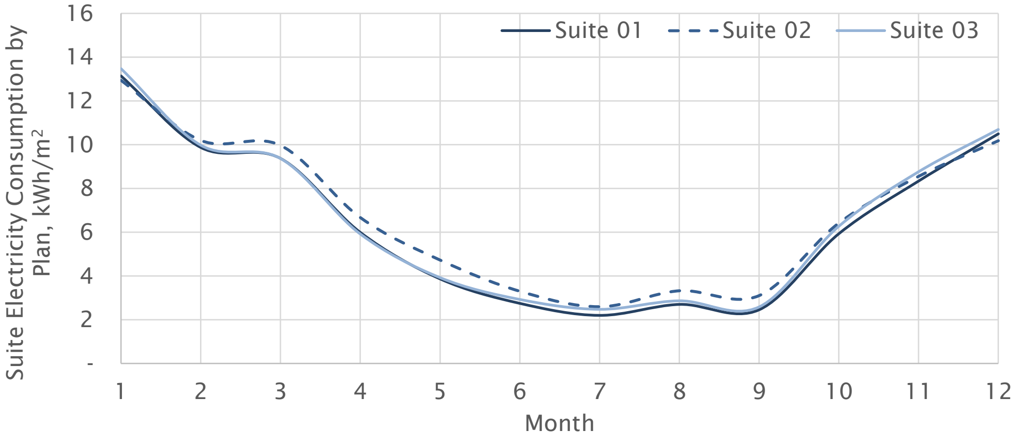


Figure G.3 Total pre-retrofit suite electricity consumption by suite orientation, averaged from 2006 through 2011, kWh/m².

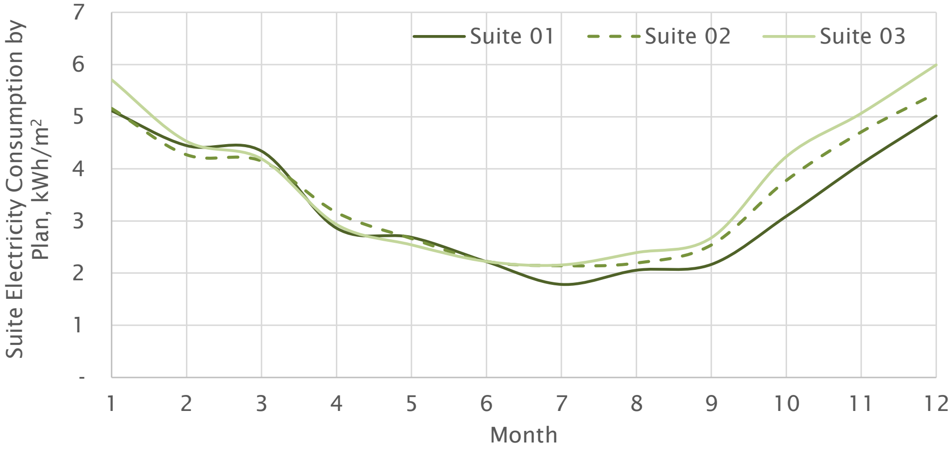


Figure G.4 Total post-retrofit suite electricity consumption by suite orientation, kWh/m².

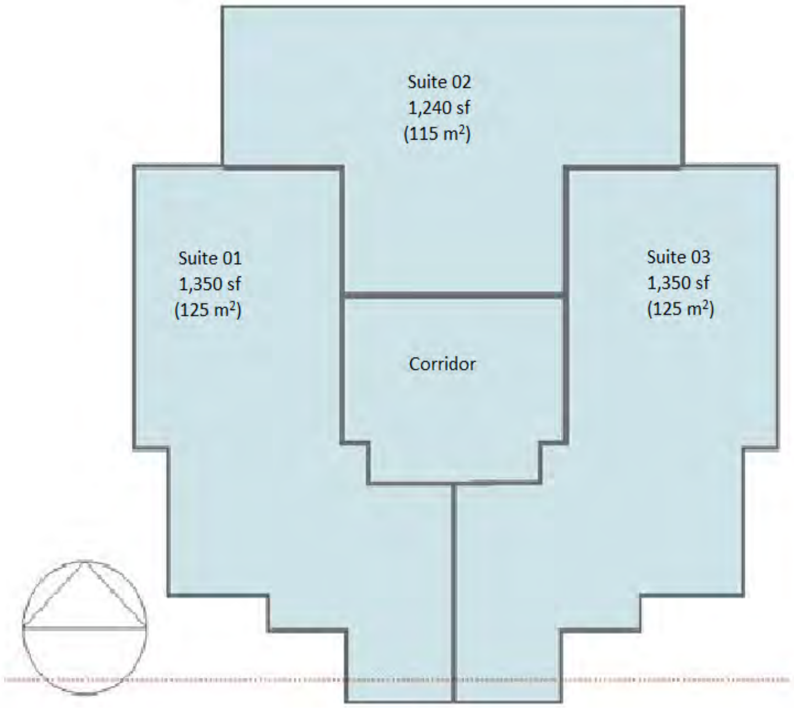


Figure G.5 Suite orientations.

Figure G.6 shows the average monthly electricity consumption by floor for the post-retrofit data; pre-retrofit data by floor was not available. Figure G.7 shows the total electricity consumption by floor, ordered from highest to lowest consuming floors.

The data shows that the first-floor suites have the highest energy use intensity and the top floor penthouse suites (floor 13) the second highest. This could be affected by heat loss through the slab (to the parkade) at the first floor and through the roof at the top floor. The first-floor heating energy may also be affected by increased infiltration due to stack effect.

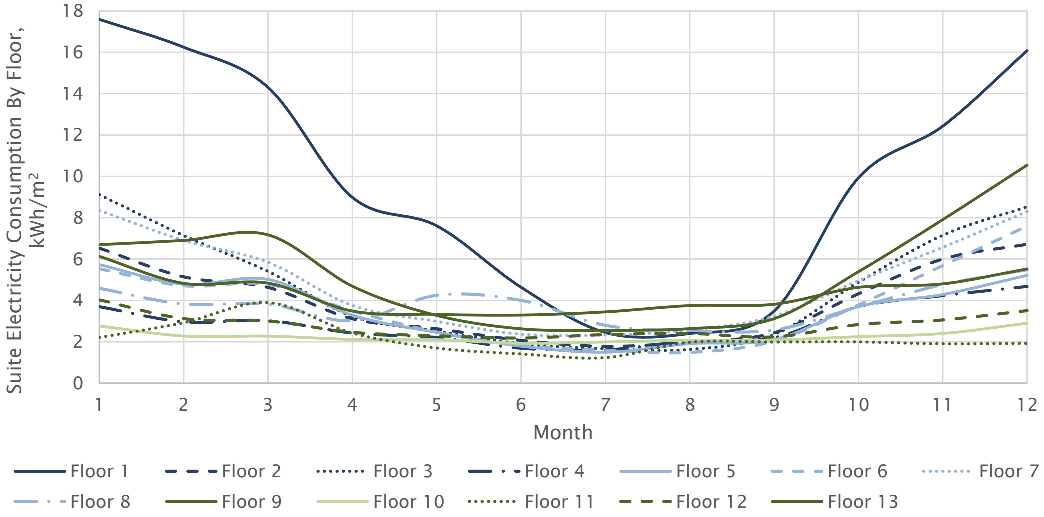


Figure G.6 Total post-retrofit suite electricity consumption by floor, kWh/m^2.

On an annual basis, floors 10, 11, and 12 have the lowest energy consumption; this could correspond with less heating energy due to stack effect within the building. Floor 13 (the top floor) is likely higher than floors 10, 11, and 12 due to the additional heat loss through the roof.

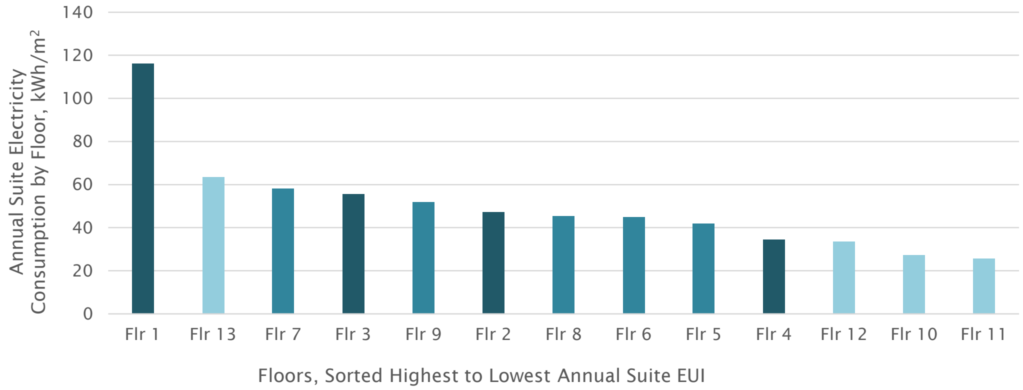


Figure G.7 Total post-retrofit suite electricity consumption by floor, kWh/m². Lower four floors are dark coloured bars, upper four floors are light coloured bars.

Gas Consumption Sub-Metering

Gas sub-metering was installed at the make-up air unit and domestic hot water, as well as fireplace on/off sensors in order to measure gas consumption by end-use. Figure G.8 shows the breakdown of sub-metered gas consumption. Fireplace consumption was estimated based on the measured 'on' periods and the known gas consumption rate of the fireplaces. Several periods of missing data were seen in the sub-metering measurements; these periods were estimated by extrapolating from adjacent periods.

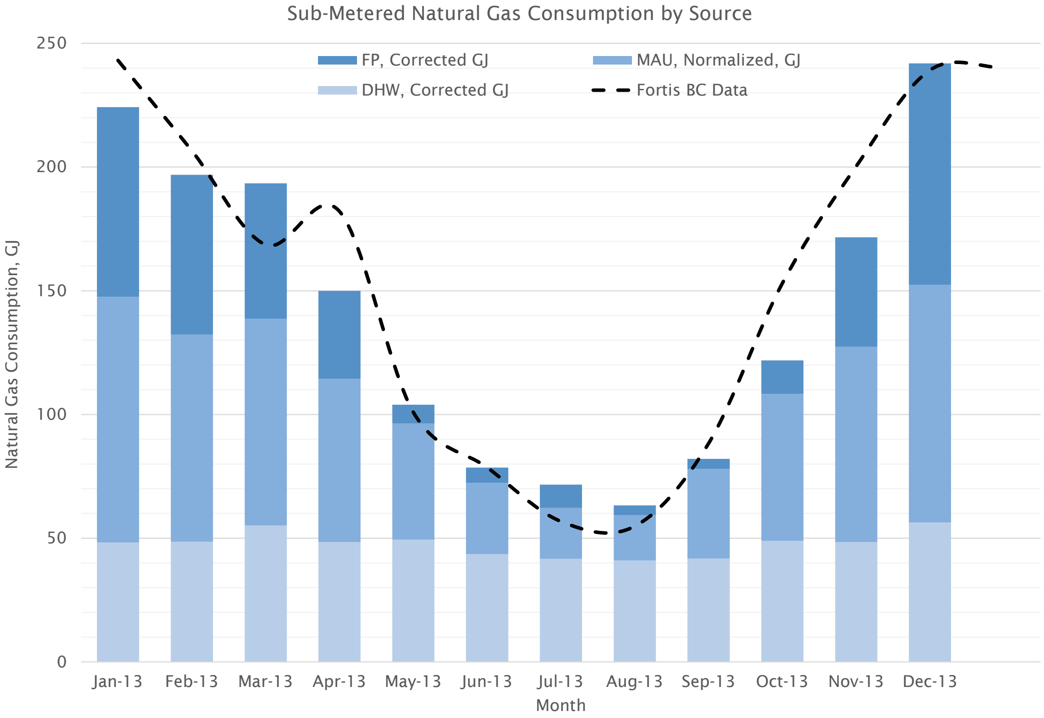


Figure G.8 Sub-metered gas consumption data, corrected for missing data periods. Sum of sub-metered consumption is close to consumption metered by FortisBC; some discrepancy is expected due to issues with sub-metering equipment.

Figure G.9 shows the breakdown of gas consumption by end-use that was metered through sub-metering (left), and estimated in the calibrated energy modeling (right). The results show that the modeled gas consumption distribution was very close to actual use. DHW was slightly lower than metered (29% modeled versus 34% metered) and make-up air was slightly higher than metered (47% modeled versus 42% metered).

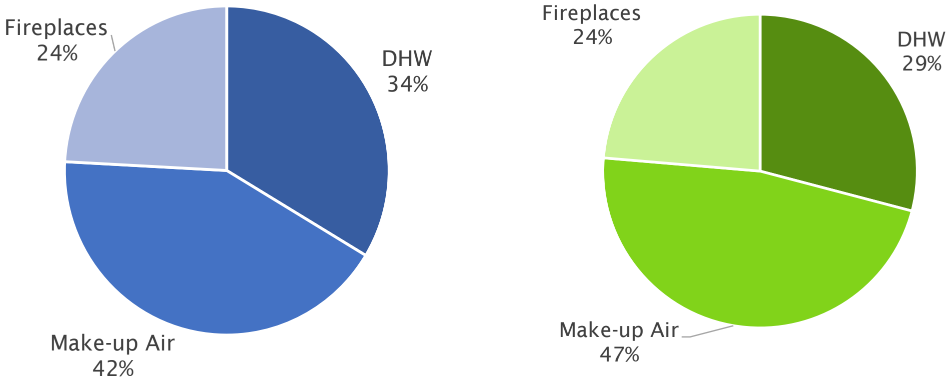


Figure G.9 Comparison of gas consumption by end use based on sub-metering (left) and calibrated energy modeling (right).