Indoor Environmental Quality of Social Housing Buildings in British Columbia

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Executive Summary

RDH Building Science Inc. conducted a monitoring study for BC Housing with the goal of understanding the indoor environmental quality (IEQ) of existing multi-unit social housing buildings in the Metro Vancouver area. The project objectives included identifying trends in the monitored temperature, humidity, and carbon dioxide (CO_2) concentrations as well as analysing the IEQ impact of building retrofits and upgrades.

Twenty-five suites across five buildings were selected for this study. Indoor conditions were quantified with sensors that collected ambient air temperature, relative humidity (RH), and CO_2 concentrations at 15-minute intervals. Suite airtightness and airflow rates through the bathroom exhaust fans were also measured both before and after the retrofit periods.

The monitoring study revealed overheating to be a significant IEQ issue. On average, the suites experienced more than 700 hours with the indoor air temperature exceeding 26°C, with peaks in excess of 31°C. Four of five buildings were equipped with central heating systems with no suite-level control, and all buildings relied on passive measures for cooling (e.g., opening windows). While the building with more window openings and suite-level control of thermostats experienced less overheating, it was a general finding that passive cooling was insufficient to ensure BC Housing's overheating guidelines were met.

CO_2 concentrations generally remained below 1,100 ppm, with elevated concentrations typically experienced overnight. Elevated CO_2 concentrations overnight suggests reduced ventilation (i.e., closing windows, turning off exhaust fans) and/or increased occupancy (i.e., returning from work).

All of the measured suites are ventilated with an exhaust only strategy, with the intent that make-up air is provided from the corridor and open windows. Prior to the building retrofits, the measured exhaust airflow rates were generally lower than those specified by the relevant codes and standards. While some of the building retrofit packages included replacement of the exhaust fans, improved exhaust fan performance had no significant impact on the monitored IEQ parameters. This is likely the result of a lack of use, which may be due to fan noise or other factors.

Pre- and post-retrofit airtightness measurements varied significantly across the suites. No significant trends were observed. This is likely a result of retrofits not being specifically focused on improving airtightness. However, buildings that underwent window replacements generally showed an improvement in airtightness of between 5% and 20%.

The building retrofit measures from this study were focused on building enclosure and mechanical upgrades. While retrofit measures such as window and exhaust fan replacements have an impact on IEQ, the reliance on open windows for ventilation and cooling likely reduced the potential impact of these upgrades and no change in the IEQ trends were observed post-retrofit. For future building retrofits seeking IEQ improvements, specific IEQ strategies including suite-level controls, active cooling, and suite compartmentalization should be considered.

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1 Introduction

This study evaluated the indoor environmental quality (IEQ) of social housing suites throughout the Metro-Vancouver area. IEQ encompasses the conditions within a space that impact occupant health and comfort. Although IEQ includes many factors such as lighting, air quality, acoustics, and more, this study focused primarily on indoor air properties including air temperature, relative humidity, dew point temperature and CO_2 concentrations. The specific project objectives included:

- → Analyzing the IEQ of units both before and after the buildings have undergone various retrofit upgrades,
- → Characterizing the impact of building enclosure and ventilation system retrofit measures with respect to IEQ metrics, and
- → Examining the impact of wildfire smoke ingress and COVID-19 on suite IEQ.

Other indoor air contaminants, such as particulate matter and volatile organic compounds were not measured as part of this study. The following subsections describe the measured variables from this study in further detail.

1.1 Air Temperature & Relative Humidity

Air temperature and relative humidity are basic properties used to characterize ambient conditions within a space and to predict thermal comfort. Ambient air temperature is affected by many factors including solar heat gain, mechanical heating and cooling, internal gains (e.g., computers), air leakage, and more. Air temperatures between 20˚C and 26˚C are typically considered to be within an acceptable thermal comfort zone, although individual sensations of comfort vary significantly on clothing, activity, radiant temperature, air speed, and relative humidity.[1]

Relative Humidity (RH) is a measure of the moisture in the air compared to the maximum amount of moisture air at that temperature can hold. HVAC systems serving residential occupancies in BC are typically designed to remove excess moisture through fresh air ventilation.

A thorough discussion of RH is provided by Lstiburek.[2] While ASHRAE and CSA provide limited guidance on appropriate levels of RH, there is no consensus on the appropriate RH within a building. Typically, the industry accepts RH values from 20% to 60%, with Health Canada recommending a narrower range between 30% and 55%. Note that lower condensation values are often required to avoid condensation in cold climates.

The human comfort range for RH again depends on the individual and other environmental factors but is generally considered to be between 30-55%.[3] RH levels below this range can cause irritation and levels above may cause feelings of discomfort or deterioration of interior finishes. The World Health Organization identifies high levels of

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[1] ASHRAE 2017, "ANSI/ASHRAE Standard 55-2017 – Thermal Environmental Conditions for Human Occupancy". American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

[2] RH – Research Report 0203. Building Science Corporation. https://buildingscience.com/documents/reports/rr-0203-relative-humidity/view.

[3] ASHRAE, 2013. 2013 ASHRAE Handbook: Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, 2013.

moisture as a hazard to human health. This is at least partially due to biological growth on interior surfaces (mould, bacteria, fungi, etc.)[4] which has been correlated with increases in respiratory symptoms such as coughing and wheezing[5] and infections.[6]

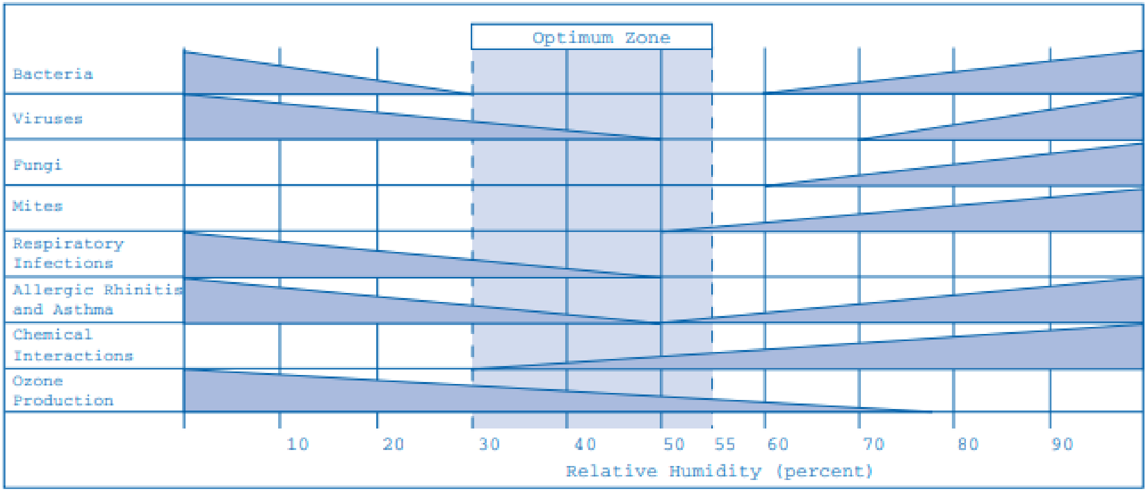

Figure 1.1 – Health range of indoor RH according to Health Canada.

1.2 Carbon Dioxide & Ventilation

Ventilation is provided to the indoor environment to control pollutant build-up and to contribute to satisfactory IEQ conditions. Ventilation can be provided to residential buildings through a variety of system types including corridor make-up air units, balanced in-suite ventilation, intermittent exhaust fans (washroom or kitchen), or natural ventilation designs. The ASHRAE standards for ventilation distinguish between low-rise residential (ASHRAE 62.2-2019) and other residential (mid- and high-rise) or commercial buildings (ASHRAE 62.1-2019).[7,8] These standards have been adopted in numerous forms within North American building codes including the British Columbia (BC) Building Code, the International Mechanical Code, the Uniform Mechanical Code, and California Title 24, Part 6, among other codes.

ASHRAE Standards 62.1 and 62.2 provide a prescriptive *Ventilation Rate Procedure* used to size the ventilation equipment. The procedure aims to maintain indoor carbon dioxide (CO_2) levels less than ~700 ppm above the outdoor air concentration (i.e. ~1,100 ppm) by specifying a per person ventilation rate for various occupancy types. This target is based on earlier research that linked CO_2 with perceived IEQ issues related to bioeffluents and

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[4] WHO, 2009, "WHO Guidelines for Indoor Air Quality: Dampness and Mould". The WHO European Centre for Environmental Health, Bonn, Germany.

[5] Fisk et al., 2007. "Meta-analyses of the associations of respiratory health effects with dampness and mold in homes". Indoor Air 17: 284-296

[6] Fisk et al., 2010. "Association of residential dampness and mold with respiratory tract infections and bronchitis: a meta-analysis". Environmental Health 9: 72.

[7] ASHRAE 2019a, "ANSI/ASHRAE Standard 62.1-2019 – Ventilation for Acceptable Indoor Air Quality". American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

[8] ASHRAE 2019b, "ANSI/ASHRAE Standard 62.2-2019 – Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings". American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

odours. An additional floor area-based ventilation rate is included to control build-up of other indoor contaminants such as volatile organic compounds (VOCs) that impact IEQ.[9]

While there are numerous indoor pollutants that could be monitored to evaluate IEQ, the majority of the current indoor environmental design methodologies use CO_2 as a proxy for measuring IEQ and controlling ventilation. There are three advantages to using CO_2 as a proxy for IEQ:

1) CO_2 has a consistent indoor source (occupant respiration),
2) CO_2 can easily be measured, and
3) CO_2 has historically been considered benign at the low concentrations typically seen in buildings.

While several studies have linked CO_2 concentrations to negative health outcomes, other studies have contradicted these findings.[10] Recognizing the need for further study, research in the area of IEQ, ventilation, and work performance is identified as a goal in ASHRAE's current strategic research plan as well as their 2019–2024 Strategic Plan.

Numerous studies have linked exposure to poor IEQ to detrimental health impacts including: cognitive decline, fatigue, eye, nose, and throat irritation, headaches, dizziness, respiratory disease, heart disease, and cancer.[11] As a result of these studies and potential health impacts, exposure limits have been set for a number of pollutants.[12] A 2012 study showed moderate declines in cognitive performance with exposure to CO_2 concentrations of 1,000 parts per million (ppm) and significant declines at concentrations of 2,500 ppm compared to baseline testing at 600 ppm.[13] A follow-up study controlling both CO_2 and VOC concentration in a simulated office environment similarly showed that increased CO_2 concentration reduced cognitive function.[14] In addition, the study found that a 500 $\mu g/m^3$ increase in Total VOC 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 1,300 ppm to 900 ppm.[15] 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.[16] The research indicates that CO_2 levels in homes and workplaces can lead to productivity losses even at near to design concentration levels. Research also suggests that CO_2 is a potential indicator of health impacts from other pollutant sources.

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[9] Persily, A. 2015, "Challenges in Developing Ventilation and Indoor Air Quality Standards: The Story of ASHRAE Standard 62", Building and Environment 91: 61-69.

[10] Fisk, Wargocki, and Zhang. 2019, "Do Indoor CO2 Levels Directly Affect Perceived Air Quality, Health, or Work Performance?

[11] WHO 2010, "WHO Guidelines for Indoor Air Quality", The WHO European Centre for Environmental Health, Bonn, Germany.

[12] Government of Canada 2015, "Residential Indoor Air Quality Guidelines" Available at: http://healthycanadians.gc.ca/healthy-living-vie-saine/environment-environnement/air/guidelines-lignes-directrices-eng.php

[13] Satish et al. 2012, "Is CO2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO2 Concentrations on Human Decision-Making Performance", Environmental Health Perspectives 120(12): 1671-1677.

[14] Allen, J.A. et al. 2015, "Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments", Environmental Health Perspectives, DOI:10.1289/ehp.1510037

[15] Wargocki, P. and Wyon, D.P. 2007, "The Effects of Outdoor Air Supply Rate and Supply Air Filter Condition in Classrooms on the Performance of Schoolwork by Children (RP-1257)", HVAC&R Research 13(2): 165-191.

[16] Strom-Telsen, P et al. 2015, "The Effects of Bedroom Air Quality on Sleep and Next-Day Performance", Indoor Air, doi: 10.1111/ina.12254.

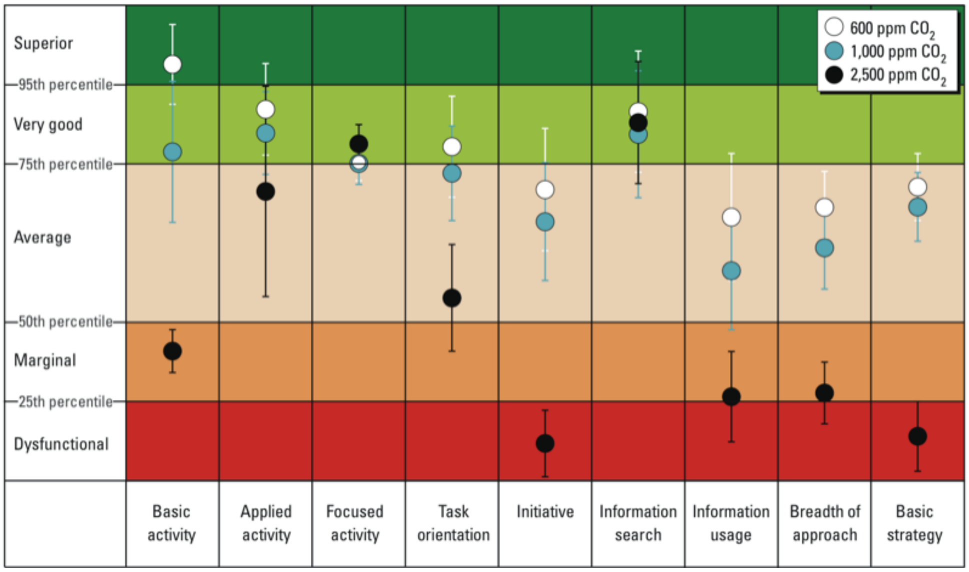

Figure 1.2 – Cognitive function test results for variations in CO_2 exposure (from Satish et al. 2012).

Despite the observed relationships between CO_2 exposure and cognitive performance, the design and operation of many of our buildings expose occupants to elevated CO_2 levels. Numerous indoor CO_2 studies have documented concentrations in excess of 1,000 ppm in schools, daycares, offices, and homes with potentially significant impacts on human performance.[17,18,19,20]

In addition to elevated CO_2 concentrations, a long-term monitoring study of a 13-storey multi-unit residential building (The Belmont) performed by RDH Building Science Inc. (RDH), and funded by an industry consortium including BC Hydro, BC Housing, FortisBC and others, showed that CO_2 concentrations in multi-unit residential buildings varied based on suite location within the building.[21] Figure 1.3 shows the fraction of time the average concentration in suites on six different floors is above a specified threshold. CO_2 concentrations in suites on the upper floors were generally below the design threshold of 1,100 ppm, whereas concentrations in suites on the lower floors were found to exceed this concentration more than 65% of the time. What this study and others have shown is that the in-service CO_2 concentration of a building, even one designed to ASHRAE standards, is generally unknown. IEQ and the importance of effective ventilation are garnering increased interest within the building industry and the public. This interest has identified a need for further monitoring studies aimed at establishing a baseline for the existing IEQ within our buildings and to subsequently measure the potential impacts of common retrofits strategies.

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[17] Bakó-Biró, Zs. Et al.2012, "Ventilation rates in schools and pupils' performance", Building and Environment 48: 215-223.

[18] St-Jean, M. et al. 2012, "Indoor Air Quality in Montreal Area Day-Care Centres, Canada", Environmental Research 118: 1-7.

[19] Montgomery et al. 2015, "Comparison of the indoor air quality in an office operating with natural or mechanical ventilation using short-term intensive pollutant monitoring", Indoor and Built Environment 24(6): 777-787.

[20] Eklund K. et al. 2015, "Pacific Northwest Residential Ventilation Effectiveness Study" Northwest Energy Efficiency Alliance Report #E15-015.

[21] Montgomery, J. 2015, "Air Quality in Multi-unit residential buildings", RDH Technical Bulletin No. 009.

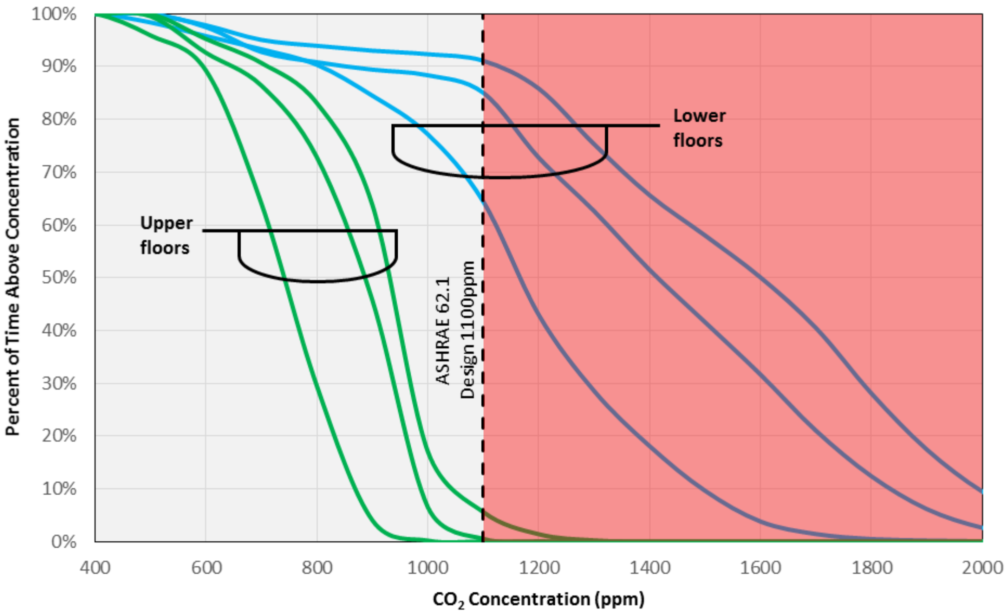

Figure 1.3 – Fraction of time the average suite CO_2 level is above a given concentration in The Belmont Building. Each line represents a separate floor in the building.

1.2.1 Ventilation Codes & Standards

The requirements for ventilation system are outlined in the BC Building Code (BCBC) in Part 9.32 for self-contained dwelling units and Part 6.2.2 for ventilation in Part 3 Buildings. The ventilation system design requirements consist of both continuous general ventilation for the building as well as local exhaust ventilation requirements in kitchens and washrooms. A description of the compliance paths and the referenced standards are provided below along with a summary of the required ventilation rates in Table 1.1.

The ventilation requirements in Part 9 – *Housing and Small Buildings* of the building code differ depending on the type of system installed and are outlined in Subsection 9.32.3. Ventilation (i.e., outdoor air) is required to be provided to all living areas and all bedrooms within a dwelling unit. The code allows for compliance through prescriptive details in the subsection or alternately through CAN/CSA-F326-M.

CAN/CSA-F326-M91 *Residential Mechanical Ventilation Systems* “defines the requirements for performance, installation and application, and performance verification of mechanical ventilation systems”. It is specifically listed as a compliance path in the BCBC 9.32. The standard provides design guidelines for the ventilation system and specifies the minimum ventilation airflow requirements.

The ventilation requirements for Part 3 buildings are outlined in subsection 6.2.2 and indicate that compliance can be shown through adherence to the details in that part or through Subsection 9.32.3 for self-contained mechanical ventilation systems serving only one dwelling unit. The ventilation airflow rates for systems designed to conform with Part 6 reference ASHRAE 62-2001 (except Addendum n).

ASHRAE 62-2001 *Ventilation for Acceptable Indoor Air Quality* (ASHRAE 2001) provides guidance on the minimum ventilation to be provided in commercial, institutional, and residential buildings. It is referenced in the existing BCBC 2018 Part 6 as the basis for the ventilation flow rates (6.3.1.1.2). The ventilation rate procedure described in Section 6.1

of ASHRAE 62-2001 indicates the amount of supply air required for residential facilities (Table 2.3 of ASHRAE 62-2001) as well as installed mechanical exhaust capacities.

In 2004, ASHRAE 62 was split into separate standards for low-rise residential buildings (62.2) and all other buildings (62.1). Standard 62.1 was responsible for multi-family residential buildings of four stories or more while 62.2 was responsible for other residential spaces. The revisions for the 2016 version of the standards removed residential occupancies from the scope of 62.1 and placed the responsibility of the dwelling units within 62.2 regardless of building height while maintaining the criteria for common areas (i.e., corridors) within 62.1. ASHRAE 62.1 and 62.2-2016 are not referenced in the building codes but are the latest iteration of this ventilation standard. A summary of the ventilation system design airflow rates is compared in Table 1.1.

TABLE 1.1 COMPARISON OF VENTILATION AIR REQUIREMENTS FOR DIFFERENT DESIGN STANDARDS (L/S). (MULTIPLY L/S BY 2.12 TO DETERMINE CFM.)

Code	**Note**	**Continuous**	**Kitchen** (Intermittent/continuous)	**Washroom** (Intermittent/continuous)
BCBC 9.32	Based on the number of bedrooms and floor area.	14 - 78	47 / n.a.	23 / 9
	Example: 1 bdrm, <140m^2	14		
	Example: >7 bdrms, >700m^2	78		
CSA-F326	Based on the number of rooms of each type	5 – 10 per room	50 / 30	25 / 10
	Example: 1 bdrm, 1 bath, living room, kitchen	25		
BCBC 6.2.2	ASHRAE 62-2001 except addendum n referenced for airflow rates.			
ASHRAE 62-2001	Ventilation rate of 0.35 ACH required. Typically satisfied by natural ventilation. Example: 140 m^2 apartment with 8 ft ceilings	33	50 / 12	25 / 10
ASHRAE 62.2-2016	Ventilation based on occupants (3.5 L/s/pp) and floor area (0.15 L/s/m^2) Example: 1 bdrm, 140m^2	28	50 / 5 ACH kitchen volume	25 / 10

2 Methodology

2.1 Building & Suite Selection

The buildings included in this study were selected by BC Housing from their building stock in the Metro Vancouver area. Buildings were limited to those scheduled for a retrofit some time after the initial monitoring period. Retrofits of interest included envelope upgrades, weatherization, make-up air unit replacements, roof replacements, and upgrades to in-suite exhaust fans.

Attempts were made to select suites within each building to provide a representation of the different types (single room occupancy, 1 bedroom, 2 bedroom, etc.) and suite locations. The general selection criteria, if applicable were to monitor at least two suites per floor on three floors in each building to cover a representative selection of suite locations and to capture differences in occupant behaviour. The actual suites included in the study were influenced by vacancies and willingness of occupants to participate.

Generally, monitoring was limited to six suites in each building. Sensors were installed in the main bedroom and in the common area (kitchen or living room) of each suite with one or more bedrooms. Studio or single room occupancy (SRO) units were equipped with a single sensor.

2.2 Data Collection & Processing

The methodology used in this work consisted of pre/post-retrofit monitoring of IEQ metrics within individual suites of each of the five buildings. The following subsections present the collected data and describe how the data was processed prior to analysis.

2.2.1 Suite Airtightness

Airtightness tests were performed pre- and post-retrofit to identify potential changes in the air leakage rates and to compare against other ventilation rates. The methodology chosen for the blower door test is outlined in the Residential Energy Services Network (RESNET) Section 802 Procedures for Building Enclosure Airtightness Testing with modifications to treat the individual suites as dwelling units.[22] The suites were tested in an operational state with the windows closed, the kitchen/bathroom exhaust ventilation off, and the mechanical penetrations un-taped. Calculations were performed in accordance with ASTM E779-10. This information will be used to characterize the relative change in air leakage caused by the retrofits.

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[22] RESNET Mortgage Industry National Home Energy Rating Systems Standard. http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf

2.2.2 Indoor Environmental Quality

Monitoring equipment was installed to monitor environmental conditions within each suite. The sensors used were Onset's HOBO MX1102 sensors.[23] These sensors collect measurements of the ambient air temperature, the RH and the CO_2 concentrations at a 15-minute interval. The sensor is shown in Figure 2.1. Outdoor weather data from a local weather station was used for analytical purposes. To avoid skewing the results, sensor locations were carefully chosen to minimize impact of localized variations in the suite, such as proximity to local heat sources or direct exposure to solar radiation.

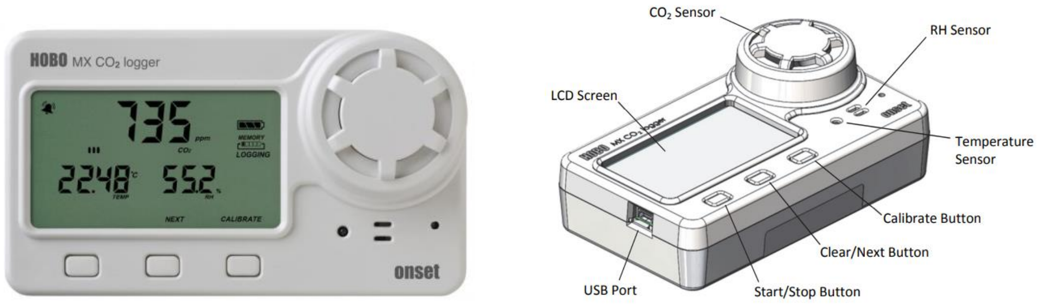

Figure 2.1 – HOBO MX1102 sensors for measuring ambient air temperature, RH and CO_2.

Data Processing

The raw data collected from the sensors was processed prior to analysis. The processing included removal of outliers and blank data, standardized the time zone, calibrating the CO_2 results, and calculation of additional outputs.
Figure *2.2* summarizes the data processing procedure.

2.2.3 Other Characteristics

In addition to the monitoring data, information regarding the building characteristics and typical operation was gathered including:

- Building enclosure design characteristics
- HVAC system design, controls and operation information for common areas and suite specifics
- Airflow and pressure measurements
- Exhaust fan flow rates pre/post-retrofit
- Description of suite operation (including frequency of window opening) and typical schedules from tenants
- Notes on any moisture damage, condensation, or fungal growth concerns

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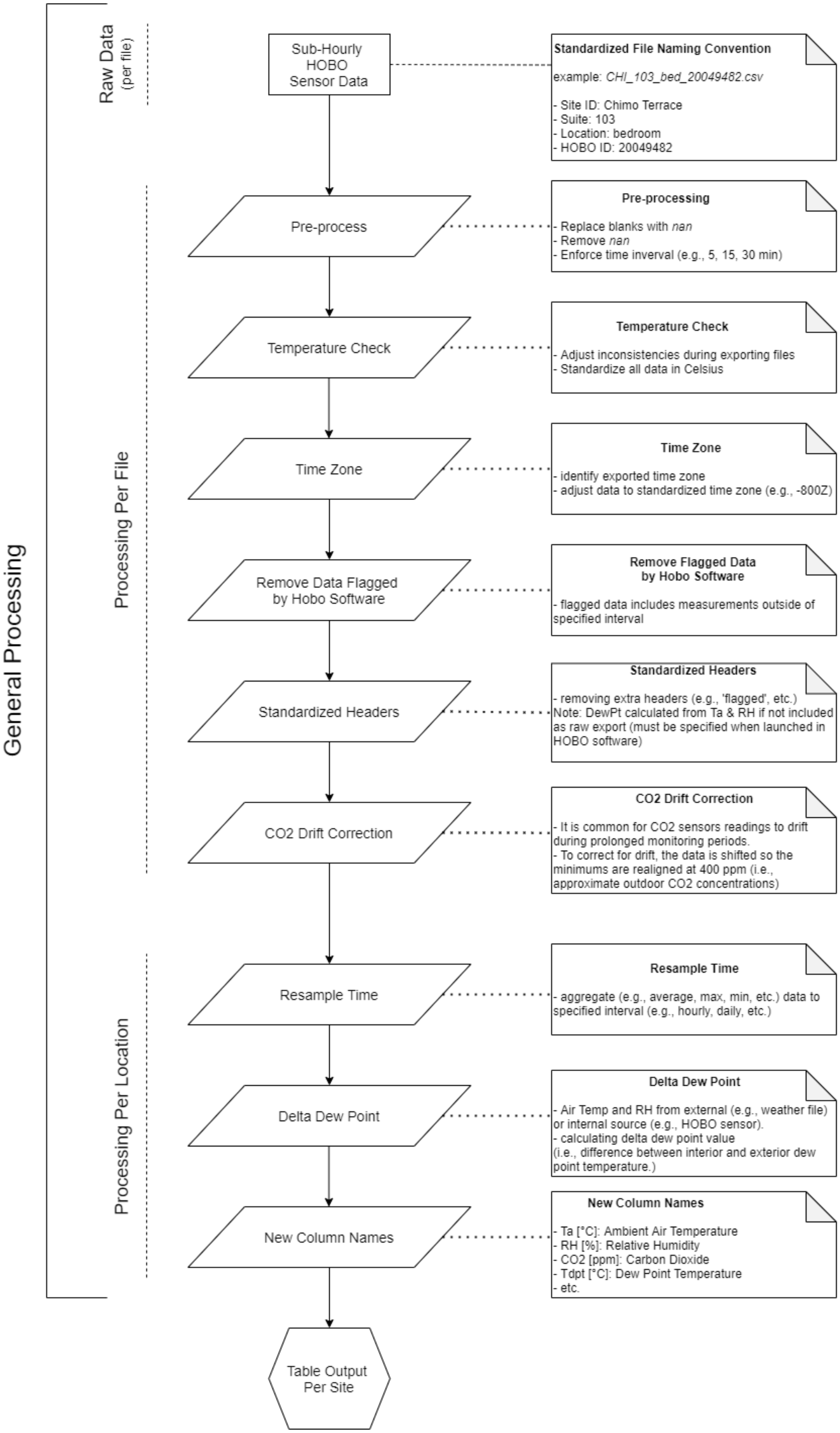
[23] Carbon dioxide measurement accuracy is ±50 ppm ±5% of reading at 25°C (77°F), less than 70% RH and 1,013 mbar. Temperature measurement accuracy is ±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F). RH reading accuracy is ±2.5% from 10% to 90% RH (typical), to a maximum of ±3.5%.



Standardized File Naming Convention

example: *CHI_103_bed_20049482.csv*

- Site ID: Chimo Terrace
- Suite: 103
- Location: bedroom
- HOBO ID: 20049482

Pre-processing

- Replace blanks with *nan*
- Remove *nan*
- Enforce time inverval (e.g., 5, 15, 30 min)

Temperature Check

- Adjust inconsistencies during exporting files
- Standardize all data in Celsius

Time Zone

- identify exported time zone
- adjust data to standardized time zone (e.g., -800Z)

Remove Flagged Data by Hobo Software

- flagged data includes measurements outside of specified interval

Standardized Headers

- removing extra headers (e.g., 'flagged', etc.)

Note: DewPt calculated from Ta & RH if not included as raw export (must be specified when launched in HOBO software)

CO2 Drift Correction

- It is common for CO2 sensors readings to drift during prolonged monitoring periods.
- To correct for drift, the data is shifted so the minimums are realigned at 400 ppm (i.e., approximate outdoor CO2 concentrations)

Resample Time

- aggregate (e.g., average, max, min, etc.) data to specified interval (e.g., hourly, daily, etc.)

Delta Dew Point

- Air Temp and RH from external (e.g., weather file) or internal source (e.g., HOBO sensor).
- calculating delta dew point value (i.e., difference between interior and exterior dew point temperature.)

New Column Names

- Ta [°C]: Ambient Air Temperature
- RH [%]: Relative Humidity
- CO2 [ppm]: Carbon Dioxide
- Tdpt [°C]: Dew Point Temperature
- etc.

Figure 2.2 – General data processing flow chart

3 Building Information

To quantify IEQ, sensors were installed within 25 individual suites across five social housing buildings planned for various retrofit measures. A summary of the building information is provided in the Table 3.1.

TABLE 3.1 SUMMARY OF STUDIED BUILDING INFORMATION

Location	**Building A**	**Building B**	**Building C**	**Building D**	**Building E**
Building Type	Multi-Unit Residential	Multi-Unit Residential	Multi-Unit Residential	Townhouse	Multi-Unit Residential
Storeys	3	3	8	2	4
Total # Suites	14	43	103	65	146
# Suites Monitored	5	6	6	2	6
# of Sensors	8	12	10	6	6
Sensor Installation Date	Feb. 15, 2017	May 11, 2017	Apr. 13, 2017	Feb. 16, 2017	Dec. 21, 2016
Retrofit Period	Jun 2017 – July 2018	Sep 2018 – Aug 2019	Jun 2017 – Nov 2018	Sep 2017 – Sep 2018	Feb 2017 – Jul 2017
Retrofit Description	· window and exterior door replacement · targeted washroom fan upgrade	· window and exterior door replacement · suite washroom fan replacements + motion sensors · new building CO_2 heat pumps (6)	· roof replacement · Seismic upgrade to brick cladding (including humidity control upgrade)	· window and exterior door replacement · roof shingle replacement · suite washroom fan replacement · attic insulation and air sealing	· window and exterior door replacement · low slope and metal roof replacement · suite washroom fan replacement · exterior bricks cleaned and sealed · building heating and ventilation system automation

3.1 Building A

Building A consists of a mixture of low-rise apartment and townhouse buildings. The building included in this study is a three-storey, wood-frame low rise apartment building with 14 suites that open to an exterior corridor on each level. All suites in the building are one-bedroom apartments with a living room, kitchen area, bedroom, and a washroom. Suite ventilation is provided by intermittent exhaust fans located in the kitchens and washrooms. The building renewal included replacement of the windows and sliding doors, and upgrades to some washroom exhaust fans.

Five suites of the original proposed six had CO_2 sensors installed during the site visit. The sixth suite did not wish to participate in the study. Additionally, two other suites indicated that they did not want sensors installed in bedrooms. The final sensor locations are shown in Figure 3.1. The suites layout is identical on all floors of the building.

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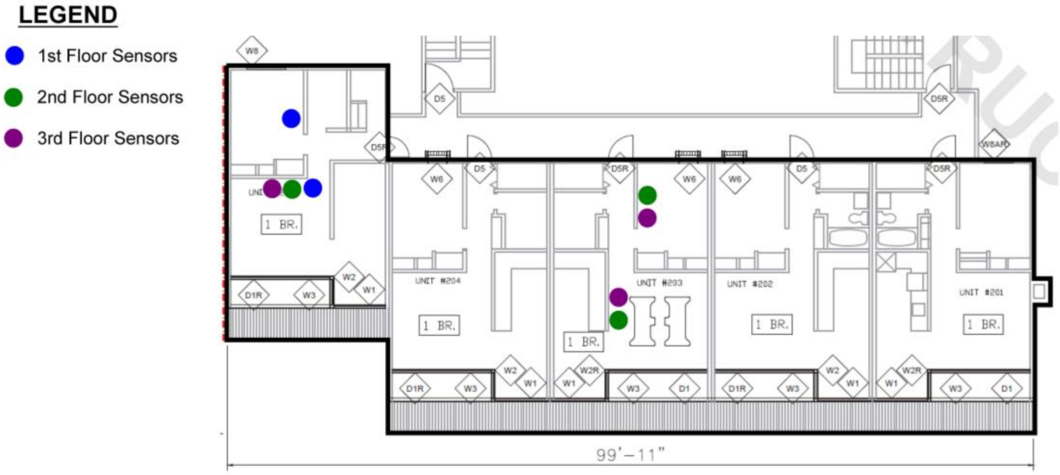


Figure 3.1 – Location of sensor installations at Building A

3.2 Building B

Building B consists of two three-storey wood-frame low-rise apartments. Only one of the two buildings was included in the study. The building consists of a mixture of one-bedroom and two-bedroom units with an interior corridor. Corridor ventilation is provided by dedicated fans in the stairwells at each end of the corridor on each floor to pressurize the common area. Suite ventilation is provided by intermittent exhaust fans located in the kitchen and washrooms. The building renewal included replacement of the windows and sliding doors.

Two suites on each floor of the building had sensors installed. Two CO_2 sensors were installed in the participating suites. The sensor locations within the building are shown on the floor plan in Figure 3.2. The suites layout is identical on floors one through three.

Figure 3.2 – Location of sensor installations at Building B

3.3 Building C

Building C consists of a high-rise apartment building and several townhouses. The building included in this study is an eight-storey, concrete high-rise apartment building with 149 suites with a mixture of SRO and one-bedroom designs. The building ventilation is provided by a make-up air unit located in the first-floor mechanical room that supplies to the corridor in the center of each floor. The suites do not have direct ventilation but are equipped with intermittent exhaust fans in the washroom and kitchen. The enclosure related building renewal included roof replacement and seismic upgrade of the brick cladding, and bathroom exhaust fan replacement including humidity controls.

Six suites, one SRO and a one-bedroom unit on each of levels 3, 5, and 7, agreed to participate in the study. One CO_2 sensor was installed in each of the three SRO units and two sensors in each of the one-bedroom units along with an additional sensor in the 5th floor corridor to capture common air background conditions. The sensor locations within the building are shown on the floor plan in Figure 3.3. The suites layout is identical on level 3 to level 7.

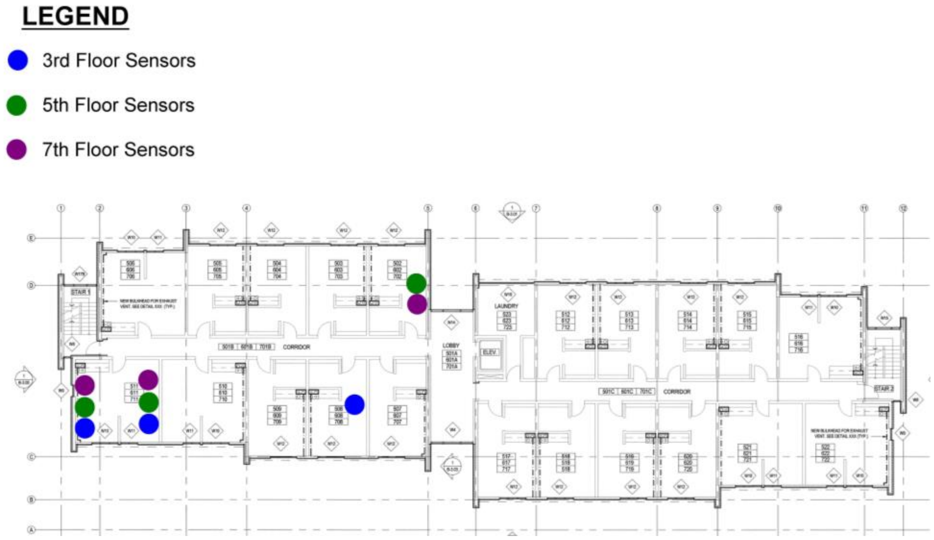


Figure 3.3 – Location of sensor installations at Building C

3.4 Building D

Building D is a townhouse development consisting of a total of 65 units in nine clusters. The buildings are wood frame construction with two to four bedrooms over two storeys. Building D is the only building where occupants have control of the heating, whereas the others rely on centralized heating systems. Ventilation is provided by intermittent exhaust fans located in the kitchen and washrooms. The floor plan for participating units at Building D is shown in Figure 3.4. The building renewal included replacement of the windows and sliding doors, new washrooms exhaust fans, improved attic ventilation and air sealing.

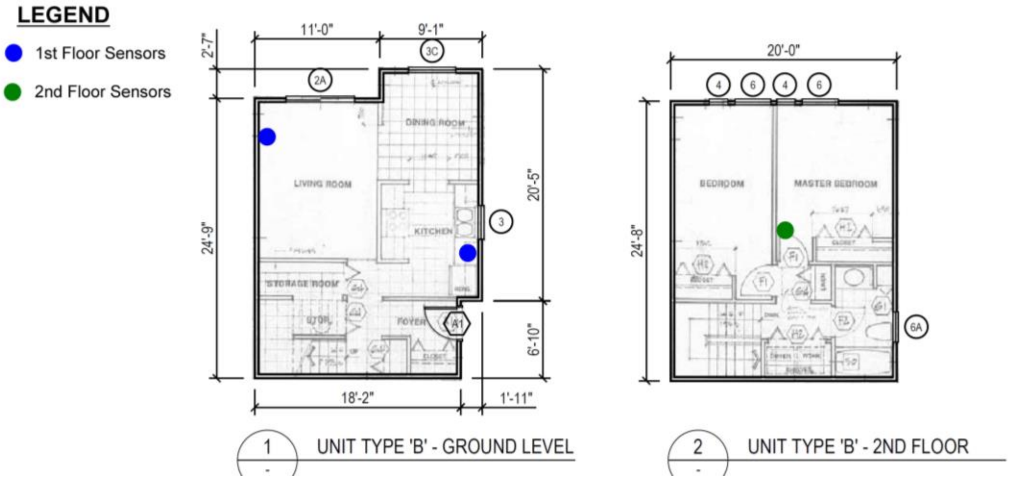


Figure 3.4 – Location of sensor installations at the Building D

Two units in the townhouse complex agreed to participate in the study. The townhouses were significantly larger than the suites at the other locations in the study and therefore warranted additional sensor coverage to determine a proper distribution. Three CO_2 sensors was installed in each of the suites to capture conditions in the living room, the bedroom and the kitchen. Locations of the sensors are indicated in Figure 3.4.

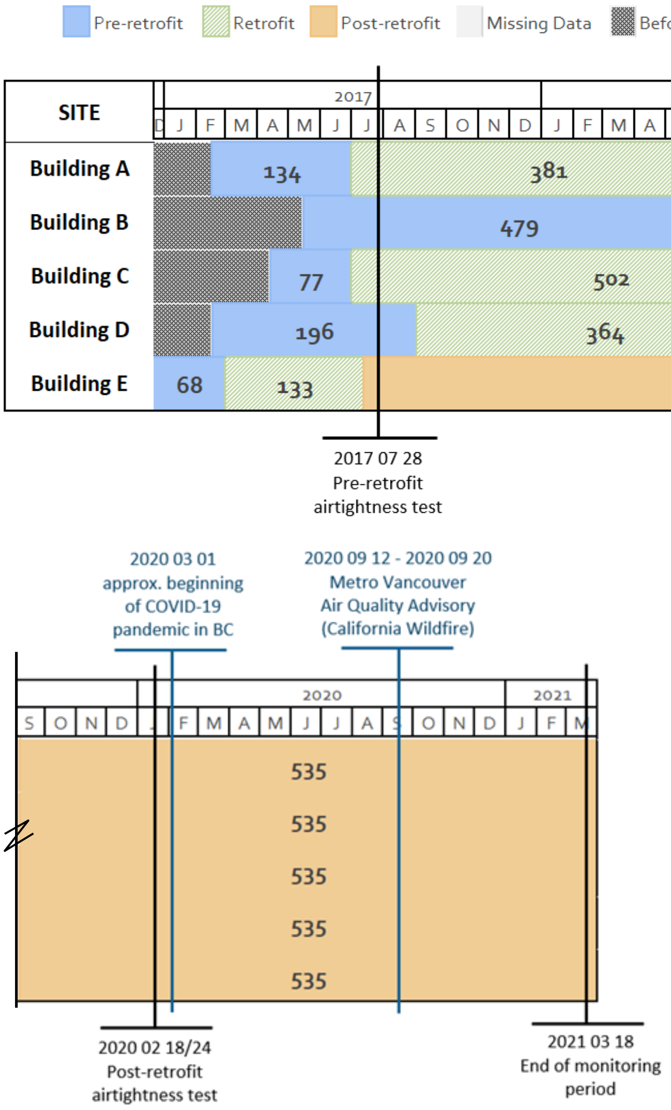
3.5 Building E

Building E is a four-storey concrete low-rise apartment. The building consists of two wings (West and East) off a central corridor (North). All suites in the building are SRO containing a living/sleeping area and a washroom. The building ventilation is provided by a rooftop make-up air unit that supplies in to the North and East wings and exhausts from the West wing. The suites do not have direct ventilation but are equipped with intermittent exhaust fans in the washroom. The building renewal included replacement of the windows in suites and common areas, replacement of exterior doors, sealing of bricks and a partial cladding replacement. One CO_2 sensor was installed in each of the six suites. The sensor locations within the building are shown on the floor plan in Figure 3.5.

Figure 3.5 – Location of sensor installations at Building E

4 Analysis & Discussion

This section provides an analysis and discussion of the measured parameters of this study, including suite airtightness, corridor pressurization, exhaust fan flow rates and IEQ. *Figure 4.1* is a Gantt chart of the study timeline including important dates and days monitored. Monitoring data was lost in the period of June to August 2019 as a result of suite access issues and the sensors losing power.



2017 07 28
Pre-retrofit
airtightness test

2020 03 01
approx. beginning
of COVID-19
pandemic in BC

2020 09 12 - 2020 09 20
Metro Vancouver
Air Quality Advisory
(California Wildfire)

2020 02 18/24
Post-retrofit
airtightness test

2021 03 18
End of monitoring
period

Figure 4.1 – Gantt chart of study timeline, important dates and number of days monitored

4.1 Suite Airtightness

A blower door test was performed on each unit within the study sample to allow for comparison of air leakage before and after the retrofit measures. Air leakage testing was performed with windows closed, but with all other openings including the bathroom and kitchen exhaust fans unsealed to represent the typical in-service conditions.

The suite level airtightness results, expressed as an air change rate at 50 Pa (ACH50) are presented for pre-retrofit and post-retrofit blower door testing, respectively in Figure 4.2 and Figure 4.3.

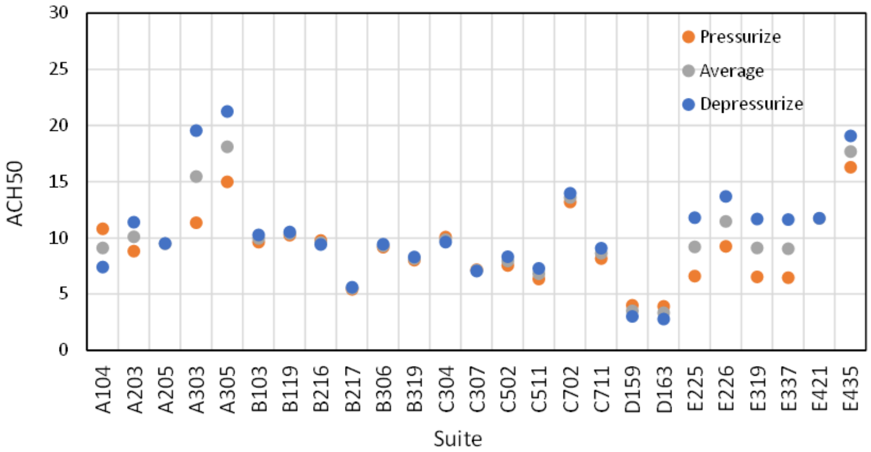


Figure 4.2 – Summary of suite air change rates at 50 Pa (ACH50) from pre-retrofit blower door testing

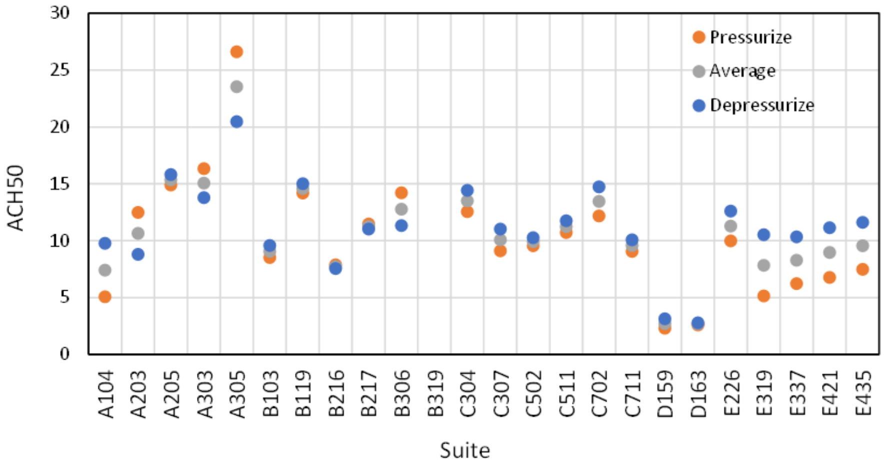


Figure 4.3 – Summary of suite air change rates at 50 Pa (ACH50) from post-retrofit blower door testing

Pre-retrofit, the ACH50 measurements across all of the buildings varied by an order of magnitude, ranging from 2.8 to 21.3 ACH50. This observed variability remained post-retrofit with airtightness values between 2.8 to 20.5 ACH50.

Figure 4.4 displays the average pre- and post-retrofit airtightness and percent difference for each suite. The measurements show that post-retrofit airtightness slightly improved for some suites and significantly worsened for others. For the units that became more

Figure 4.4 displays the average pre- and post-retrofit airtightness and percent difference for each suite. The measurements show that post-retrofit airtightness slightly improved for some suites and significantly worsened for others. For the units that became more airtight, the difference in pre- and post-airtightness was generally between 5% and 20%. For the units that became less airtight, the values varied significantly between 5% and 60%, with one suite measuring over 100%. As a result, the lack of suite separation allows for greater air-born contamination from adjacent suites (e.g., cigarette smoke, cooking pollutants) and the outdoors (e.g., urban pollutants, wildfire smoke, etc.).

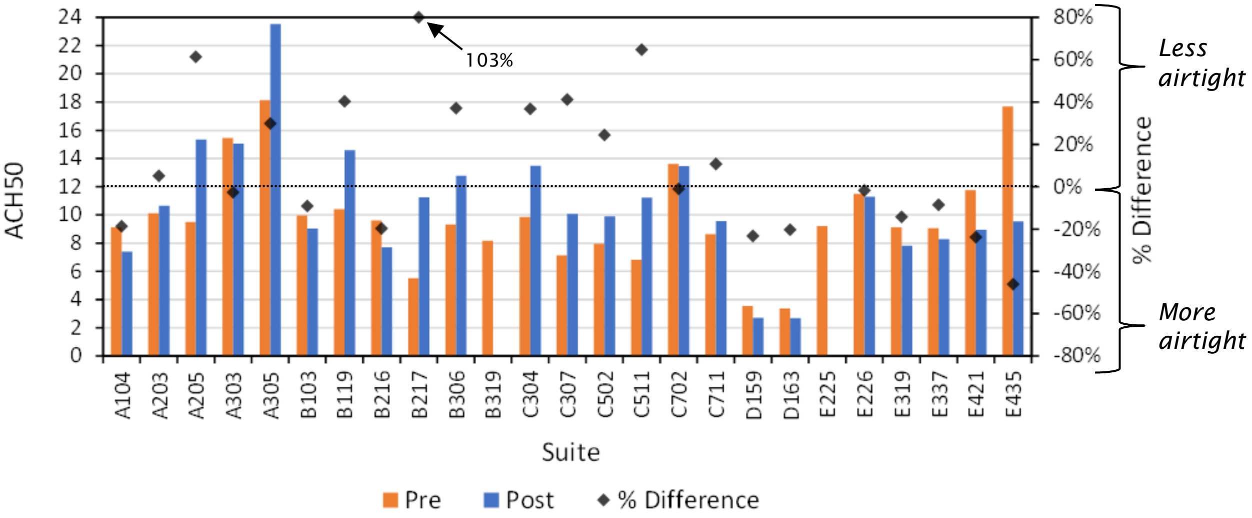


Figure 4.4 – Pre- and post-retrofit average airtightness test (ACH50) and percent difference.

4.2 Mechanical Ventilation

4.2.1 Corridor & Suite Pressurization

The intent of pressurized corridor ventilation is to deliver fresh air to suites by supplying fresh air into corridors and creating a positive pressure difference relative to the suites. The positive pressure drives the supply air into the suites through undercuts in the suite entrance doors. As three of the sites relied on pressurizes corridor ventilation the in-service suite pressurization was measured for each suite to understand the potential for fresh air to enter the suites. The two other sites opened directly to the exterior instead of a corridor. However, these sites also lacked direct outdoor air ventilation and instead relied on exhaust only ventilation to draw fresh air into the suite. The performance of pressurized corridor ventilation systems has been extensively monitored,[24] with the result being a shift away from their use. In BC, exhaust only ventilation has been unacceptable in Part 9 construction since 2014 and the BC Energy Step Code currently requires outdoor air to be supplied directly to each suite by mechanical ventilation.

Pressure measurements along with conditions during the test are shown in Table 4.1. The measurements were taken between the corridor and the suite. In the case of Building D and Building A, where there is no interior corridor, the pressure measurement was taken between the exterior and the suite (denoted with an asterisk).

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[24] Ricketts, L., & Straube, J. (2014). Corridor Pressurization System Performance in Multi-Unit Residential Buildings.

TABLE 4.1 IN-SERVICE CONDITIONS DURING PRE-RETROFIT BLOWER DOOR TEST

Label	Date	Suite Temp. (˚C)	Corridor/ Outdoor Temp. (˚C)	Δ Temp. (˚C)	Suite RH (%)	ΔP Corridor to Suite (Pa)†
A104	15-Feb-17	21	-/8	13	53	-1.5*
A203	15-Feb-17	23	-/8	15	43	-0.7*
A205	15-Feb-17	22	-/8	14	47	-0.9*
A303	15-Feb-17	21	-/8	13	43	0*
A305	15-Feb-17	22	-/8	14	49	1.2*
B103	15-May-17	25	24/-	1	38	0.9
B119	15-May-17	25	23/-	1	41	0.1
B216	15-May-17	24	26/-	-2	37	-0.4
B217	15-May-17	27	26/-	1	38	-0.1
B306	15-May-17	26	26/-	0	35	0.8
B319	15-May-17	24	26/-	-2	41	0.4
C304	13-Apr-17	21	20/-	1	46	-0.4
C307	13-Apr-17	22	20/-	2	46	0.3
C502	13-Apr-17	22	20/-	2	45	0.4
C511	13-Apr-17	22	20/-	2	45	1.7
C702	13-Apr-17	23	20/-	3	42	1.5
C711	13-Apr-17	19	20/-	-1	50	2.4
D159	15-Feb-17	21	-/10	11	44	0.8*
D163	15-Feb-17	22	-/10	12	50	0.5*
E225	21-Dec-16	25	25/-	0	36	0.4
E226	21-Dec-16	25	25/-	0	38	0
E319	21-Dec-16	24	23/-	1	34	0.5
E337	21-Dec-16	23	22/-	1	40	0.2
E421	21-Dec-16	23	22/-	1	35	0
E435	21-Dec-16	25	22/-	3	32	0.4

† positive values indicate that the corridor pressure is greater than the suite

* Suites without corridors (i.e., pressure difference is relative to outdoor environment)

The pressure measurements show that there is a very small pressure difference between the suites and corridors, less than 3 Pa.

The small pressure differences are likely the result of several factors including: open windows and non-operating exhaust fans along with wind and stack effect pressures competing against the mechanical system. While the pressure difference was measured at a single point in time, it is worth noting that the measured pressures would be insufficient to deliver fresh air to those suites.

4.2.2 Bathroom Exhaust

Rather than direct supply of outdoor air for ventilation, the suites in this study relied on either a combination or natural air infiltration though operable windows and/or the use of intermittent exhaust fans within the space, with make-up air coming from the corridor or other openings in the suite. The airflow rate provided by the intermittent washroom exhaust fans was measured and compared with code minimum values for each unit pre- (Figure 4.5) and post-retrofit (Figure 4.6). The measurements show that prior to the retrofits, most of the washroom exhaust fans provided airflow rates lower than the rates specified in the relevant codes and standards. Flow rates improved for many suites after the retrofits; however, around half of the measured units are still below code minimum rates. Note that four of five buildings underwent fan replacements or upgrades (Buildings A, B, D and E). Interestingly, Building A’s exhaust fan flow rates did not improve significantly overall whereas Building C exhaust fan flow rates improved despite no note of fan retrofits.

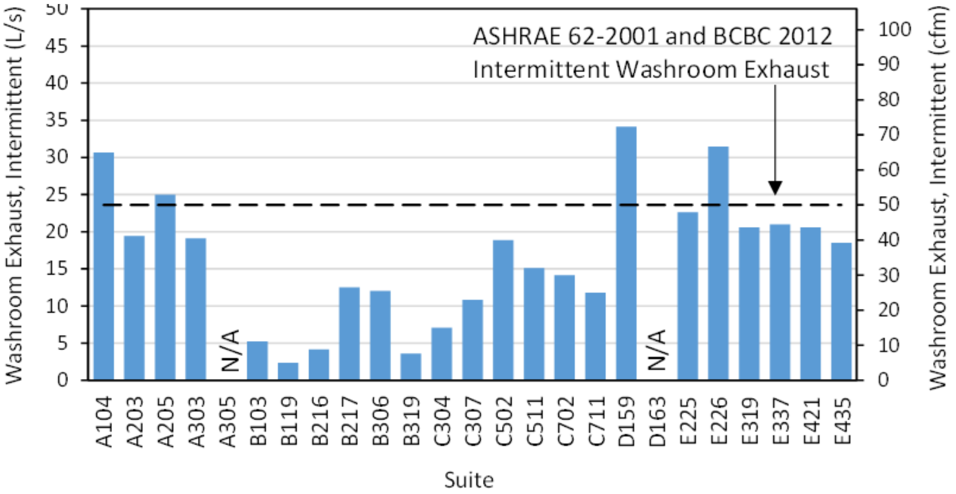


Figure 4.5 – Pre-retrofit washroom exhaust airflow rates (N/A indicates that no flow measurement was taken)

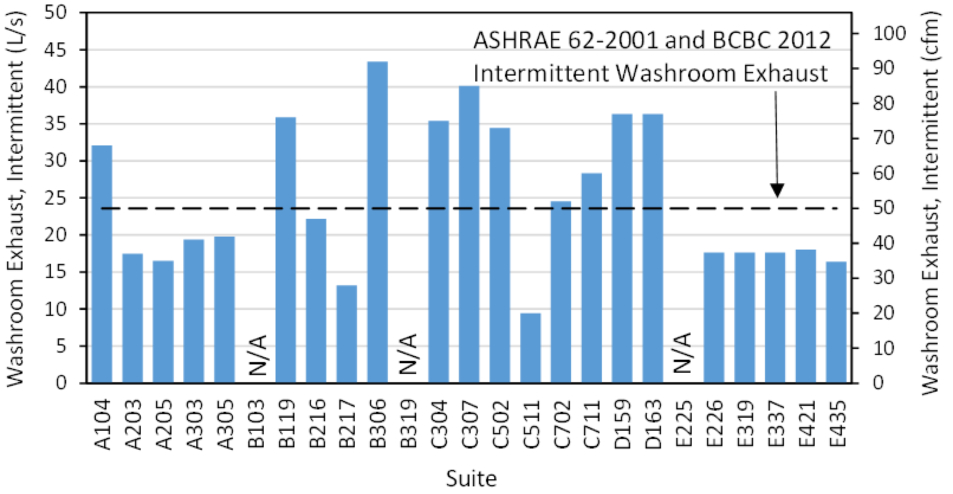


Figure 4.6 – Post-retrofit washroom exhaust airflow rates (N/A indicates that no flow measurement was taken)

In-service flow rates from exhaust fans can be reduced relative to their nominal rated performance value due to long ductwork, extensive duct fittings, wind pressures exerted on a building, insufficient fan power, blocked vents and/or debris build-up within the ducts. Regular cleaning can help to maintain the flow rate of exhaust fans.

In addition, occupants at many of the sites that exhibited low fan flow rates expressed concerns that the fans did not function properly (unable to remove moisture or smells) and were too noisy. These concerns from tenants can result in infrequent fan use, further reducing the effective suite ventilation.

4.3 Indoor Environmental Quality

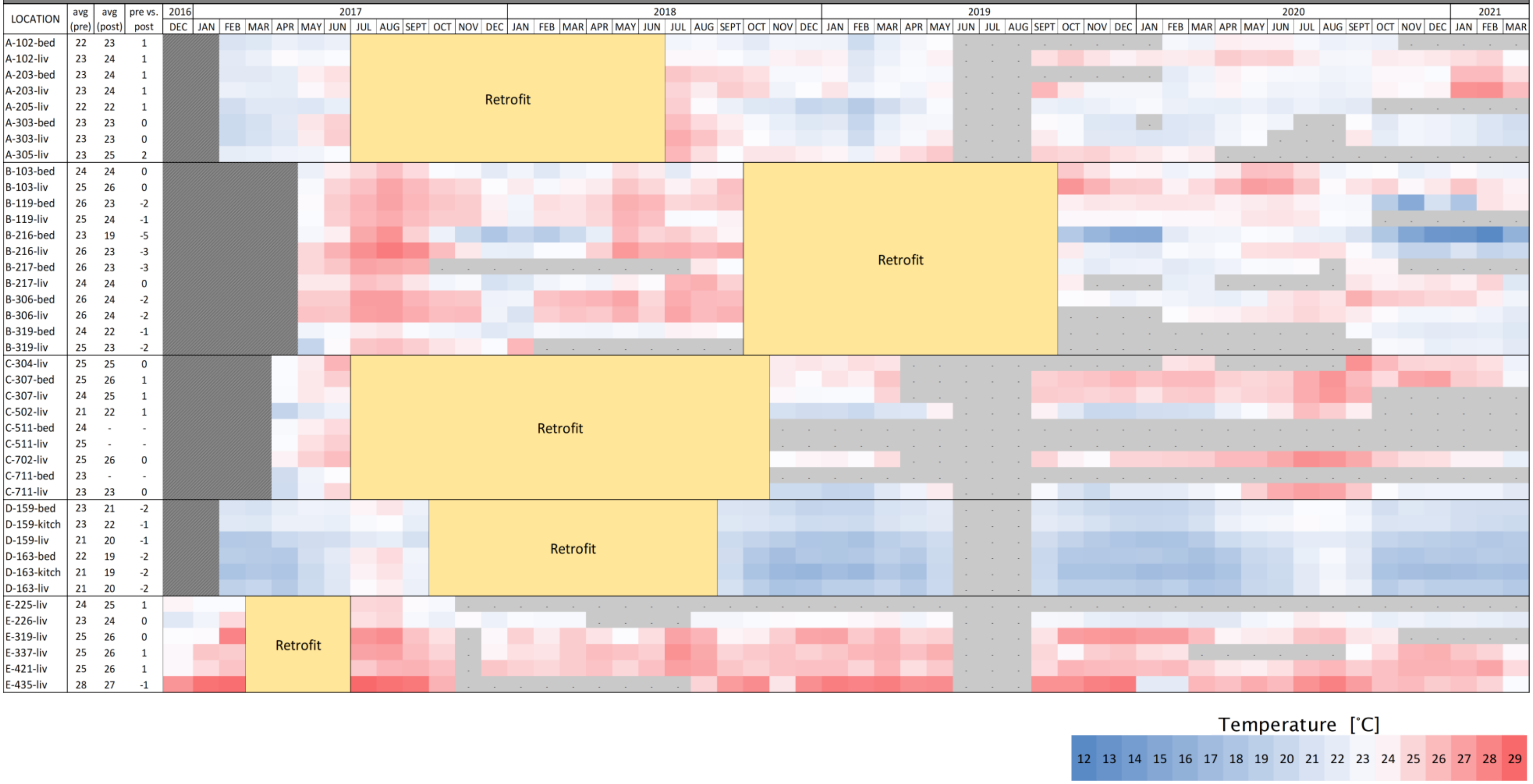
This section is an analysis and discussion of the measured IEQ and is divided into four sub-sections: air temperature, RH, dew point temperature and CO_2 concentrations.

4.3.1 Air Temperature

Pre-retrofit, four of the five sites were equipped with central hydronic heating system. The one exception, Building D, provided heat using electric baseboard heaters with dedicated thermostats in each room. Building C and Building A had in-suite thermostats to control the temperature. Building B and Building E relied on central controls and did not have in-suite thermostats to control the temperature. None of the suites included air-conditioning, so cooling was only possible through the use of open windows or portable fans and air conditioners.

To provide an overview of the measurements, Table 4.2 provides a heat map of the average monthly indoor temperature recorded in each suite during the pre- and post-retrofit monitoring periods. The data is coloured based on intensity, where residents are more likely to experience thermal discomfort as values become a darker red or darker blue. Note that, due to retrofit scheduling, some of the pre- and post-retrofit data do not align amongst all of the buildings. A heat map including the actual values and monthly average exterior air temperature is included in *Appendix D*. As the heat map shows, there were no observable trends in the average suite temperatures.

TABLE 4.2 SUMMARY TABLE: AVERAGE MONTHLY AIR TEMPERATURE (HEAT MAP)



LOCATION	avg (pre)	avg (post)	pre vs. post
A-102-bed	22	23	1
A-102-liv	23	24	1
A-203-bed	23	24	1
A-203-liv	23	24	1
A-205-liv	22	22	1
A-303-bed	23	23	0
A-303-liv	23	23	0
A-305-liv	23	25	2
B-103-bed	24	24	0
B-103-liv	25	26	0
B-119-bed	26	23	-2
B-119-liv	25	24	-1
B-216-bed	23	19	-5
B-216-liv	26	23	-3
B-217-bed	26	23	-3
B-217-liv	24	24	0
B-306-bed	26	24	-2
B-306-liv	26	24	-2
B-319-bed	24	22	-1
B-319-liv	25	23	-2
C-304-liv	25	25	0
C-307-bed	25	26	1
C-307-liv	24	25	1
C-502-liv	21	22	1
C-511-bed	24	-	-
C-511-liv	25	-	-
C-702-liv	25	26	0
C-711-bed	23	-	-
C-711-liv	23	23	0
D-159-bed	23	21	-2
D-159-kitch	23	22	-1
D-159-liv	21	20	-1
D-163-bed	22	19	-2
D-163-kitch	21	19	-2
D-163-liv	21	20	-2
E-225-liv	24	25	1
E-226-liv	23	24	0
E-319-liv	25	26	0
E-337-liv	25	26	1
E-421-liv	25	26	1
E-435-liv	28	27	-1

Of the five sites, only Building A (semi-detached homes) exhibited comfortable (according to ASHRAE Standard 55) average temperatures year-round. This trend is also apparent in *Figure 4.7* which shows the average monthly temperature for each building. The cooler temperatures measured in Building A are likely a result of greater control via the multiple thermostats and an increase in the number of operable windows allowing for improved cross-ventilation.

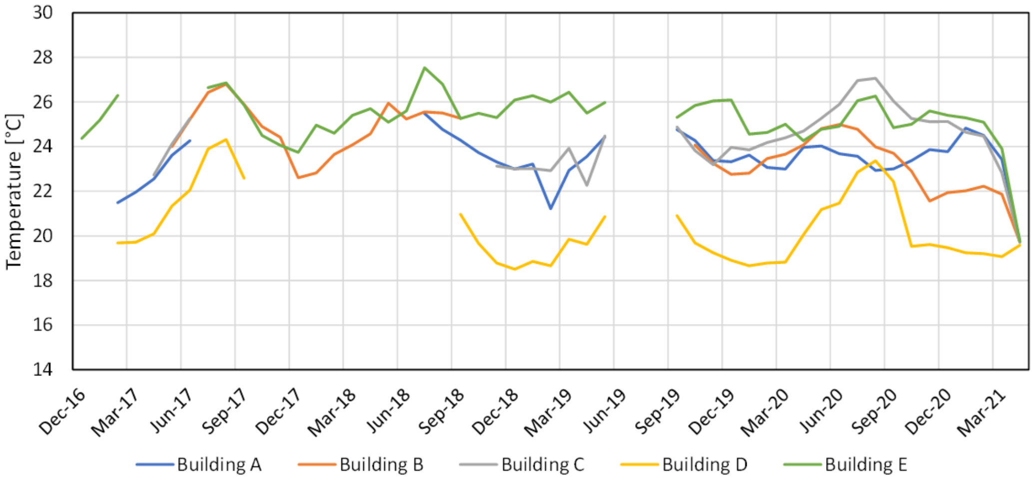


Figure 4.7 – Monthly average air temperature for each building. Gaps in data are either retrofit periods or missing data.

To understand if the air temperature may have been impacted by the retrofits, *Figure 4.8* compares the air temperature frequency distribution pre- and post-retrofit. The graph suggests that the ambient air temperature in the suites was not significantly affected by the retrofits. This finding is unsurprising as the retrofits did not add cooling or improve suite level control of the temperature.

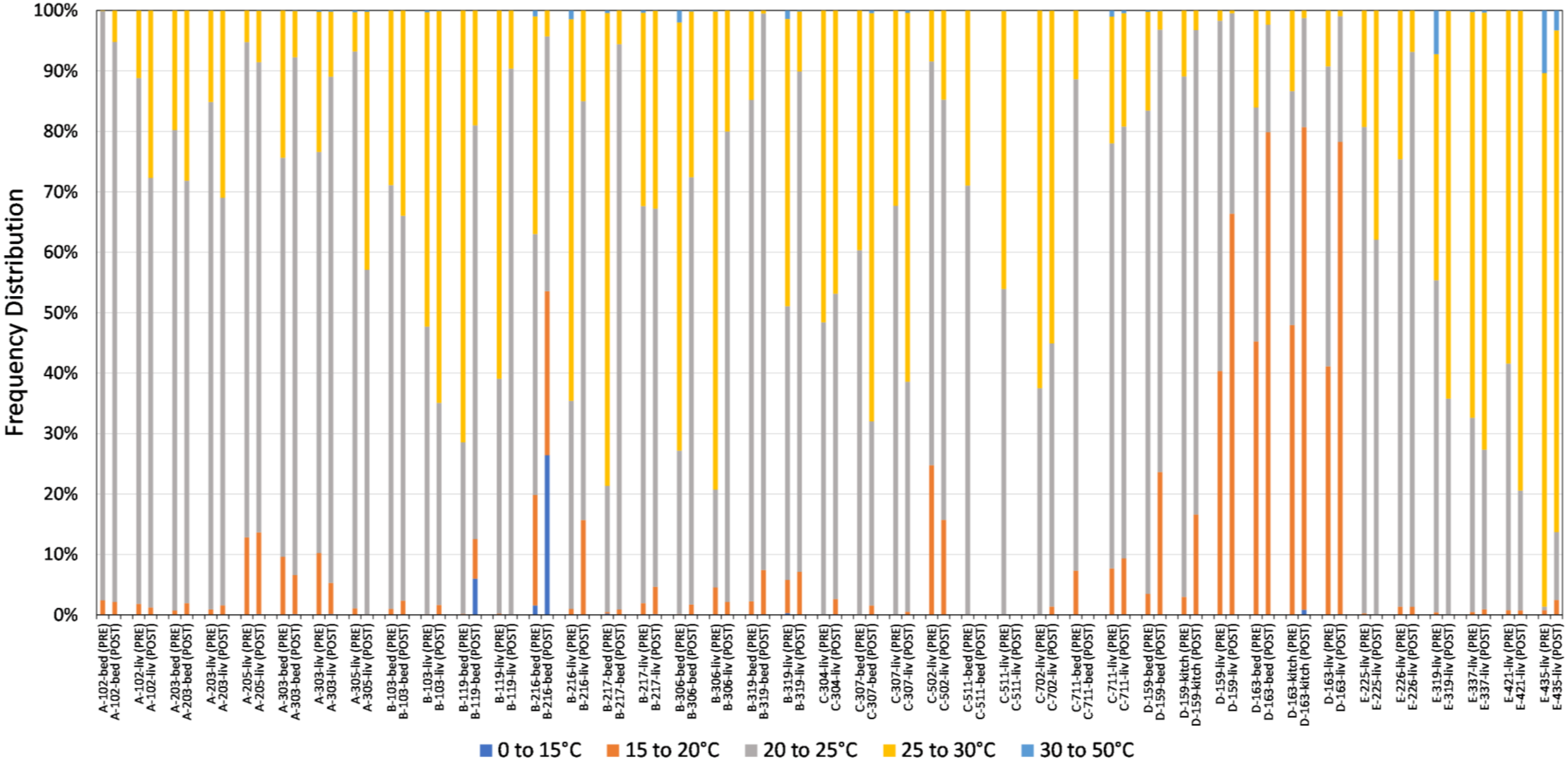


Figure 4.8 – Frequency distribution of air temperature (pre- vs. post-retrofit). Blank columns are the result of no measurements taken during the defined analysis period

To put the temperatures results into context, BC Housing requires new buildings to be designed to limit the number of hours with overheating. The requirements are based on the City of Vancouver's Energy Modelling Guidelines, which in turn reference ASHRAE Standard 55-2010 Section 5.3 as an acceptability limit for naturally cooled spaces. The City of Vancouver Energy Modelling Guideline requirement is:

> "For buildings that do not incorporate mechanical cooling, it must be demonstrated that interior dry bulb temperatures of occupied spaces do not exceed the 80% acceptability limits for naturally conditioned spaces, as outlined in ASHRAE 55-2010 Section 5.3, for more than 200 hours per year [or 5.5%] for any zone.
>
> For buildings or spaces with vulnerable groups (for example, seniors housing, shelter and supportive housing, daycares, schools, healthcare facilities, etc.), [...] it is recommended that projects target a more stringent threshold of not exceeding the 80% acceptability limits for more than 20 hours per year."

Note that the BC Housing Design Guidelines and Construction Standards are stricter than the City of Vancouver limits, targeting a maximum of 20 overheating hours for any zone.

The measured indoor temperatures during summer 2020 for all suites was compared against the overheating limit defined by BC Housing Design Guideline (COV Energy Modelling Guideline – Table 4). Figure 4.9 and Figure 4.10 are two examples of this comparison for Building C and Building D, respectively. See *Appendix C* for all overheating analysis plots. The plots show that the interior air temperatures in Building C exceed the overheating limit for a significant portion of the defined summer period. The suites in Building D, by comparison, exceeded the overheating limit far less. TABLE 4.3 lists all the measured suites and the number of overheating hours. Results suggest that overall, the suites across all buildings exceeded the overheating limit roughly 21% of the summer in 2020.

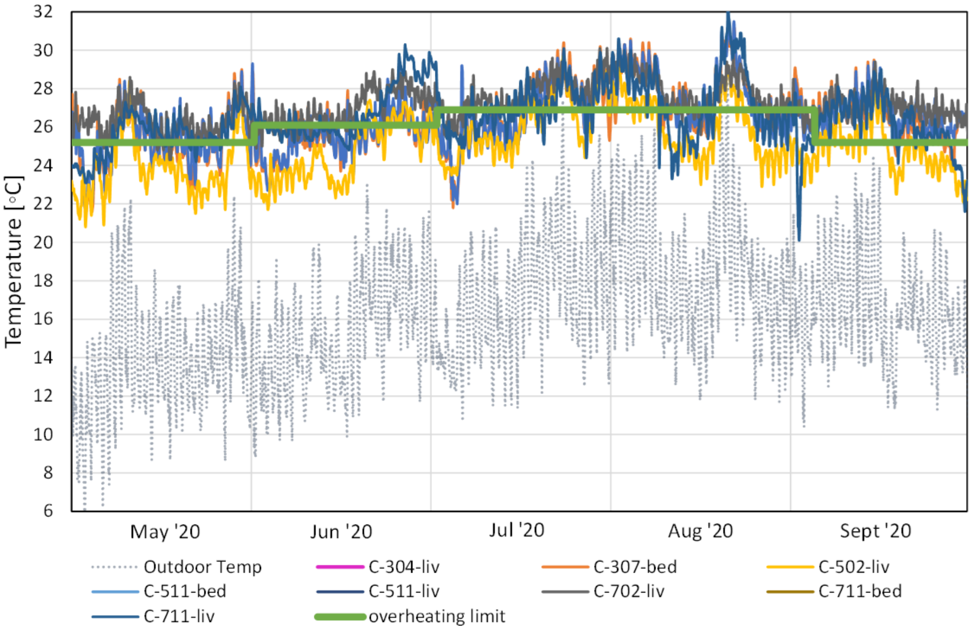


Figure 4.9 – Suite interior air temperature for Building C (2020, post-retrofit) against the summer overheating limit defined by BC Housing Design Guideline and City of Vancouver Energy Modelling Guidelines. Note that the acceptability limit varies by month.

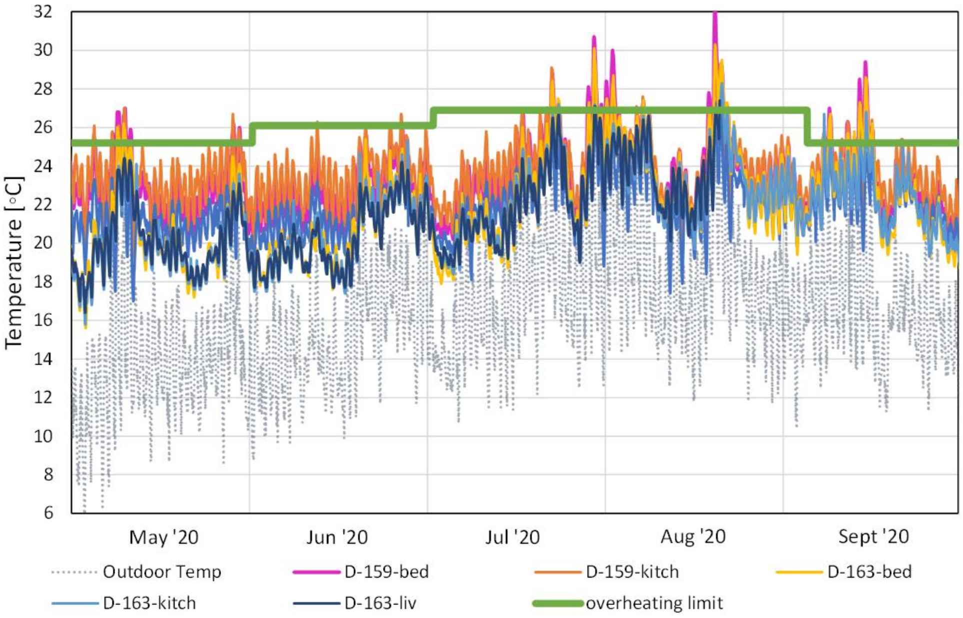


Figure 4.10 – Suite interior air temperature for Building D (2020, post-retrofit) against the summer overheating limit defined by BC Housing Design Guideline and City of Vancouver Energy Modelling Guidelines. Note that the acceptability limit varies by month.

TABLE 4.3 OVERHEATING HOURS IN 2020 DEFINED BY BC HOUSING GUIDELINES

Location	Hours Measured between May 1 – Sept 30	Total hours above limit	Percentage of time above limit between May 1 – Sept 30
A-102-bed	3672	169	5%
A-102-liv	3672	497	14%
A-203-bed	3672	160	4%
A-203-liv	3672	208	6%
A-205-liv	3663	157	4%
A-303-bed	1370	75	5%
A-303-liv	632	68	11%
A-305-liv	0	0	N/A
B-103-bed	3672	1114	30%
B-103-liv	3672	1787	49%
B-119-bed	3672	20	1%
B-119-liv	3658	54	1%
B-216-bed	3672	241	7%
B-216-liv	3672	701	19%
B-217-bed	1908	133	7%
B-217-liv	15	4	27%
B-306-bed	2661	135	5%
B-306-liv	3672	611	17%
B-319-bed	14	0	0%
B-319-liv	14	3	21%
C-304-liv	12	12	100%
C-307-bed	3672	1972	54%
C-307-liv	3660	2073	57%
C-502-liv	3660	929	25%
C-511-bed	0	0	N/A
C-511-liv	0	0	N/A
C-702-liv	3672	3108	85%
C-711-bed	0	0	N/A
C-711-liv	3672	2076	57%
D-159-bed	3672	280	8%
D-159-kitch	3672	207	6%
D-159-liv	3672	15	0%
D-163-bed	3672	206	6%
D-163-kitch	3672	34	1%
D-163-liv	2615	4	0%
E-225-liv	0	0	N/A
E-226-liv	3672	59	2%
E-319-liv	3672	782	21%
E-337-liv	16	2	13%
E-421-liv	3672	1142	31%
E-435-liv	3188	2434	76%
		Average	**21%**

Generally, an average monthly temperature of around 24°C within suites is considered comfortable based on the ASHRAE Standard 55 comfort range for occupants with typical indoor metabolic rates and clothing levels. However, thermal comfort is not only a function of air temperature and humidity. Other environmental factors such as draughts and direct solar radiation can affect how an occupant feels within a space. Personal factors can also influence thermal comfort, such as metabolic rate (activity level) and the type/amount of clothing they are wearing. It is also important to note that occupants, when exposed to a thermal environment for a prolonged period of time, can adapt to conditions that may initially be perceived as uncomfortable.

To provide a clearer understanding of the air temperature and RH conditions measured during the study, data was plotted on a psychrometric chart that includes an ASHRAE Standard 55 thermal comfort range. The comfort range assumes a typical occupant seated and relaxed (metabolic rate of 1 MET) and includes two clothing insulation levels: someone wearing pants and a long-sleeve shirt (0.6 clo) and someone wearing pants and a long-sleeve sweater (1 clo). Note that the following are sample plots for illustrative purposes. Additional plots are included in *Appendix B*.

Figure 4.11 and Figure 4.12 plot the air temperature and RH measured in two suites in Building A during summer and winter 2020, respectively. Results show that the conditions in both suites are similar and lie primarily within the ASHRAE comfort range. Figure 4.13 and Figure 4.14 plot two sample suites in Building E during summer and winter 2020, respectively. In summer, the bulk of the data lies on the edge of the upper limits of the comfort range, suggesting that the suites are too warm. In winter, suite 421 lies within the upper limit of the comfort range, whereas suite 435 is consistently outside the comfort range. Solar and internal heat gains are likely responsible for the upper points on the plots, whereas open windows in the winter are likely responsible for the lower points. It is important to note that people may in fact be comfortable in these environments despite the conditions laying outside of the ASHRAE Standard 55 comfort range either due to adaptation or changing clothing and activity levels. For this reason, thermal comfort surveys should be considered as a means of verifying these findings.

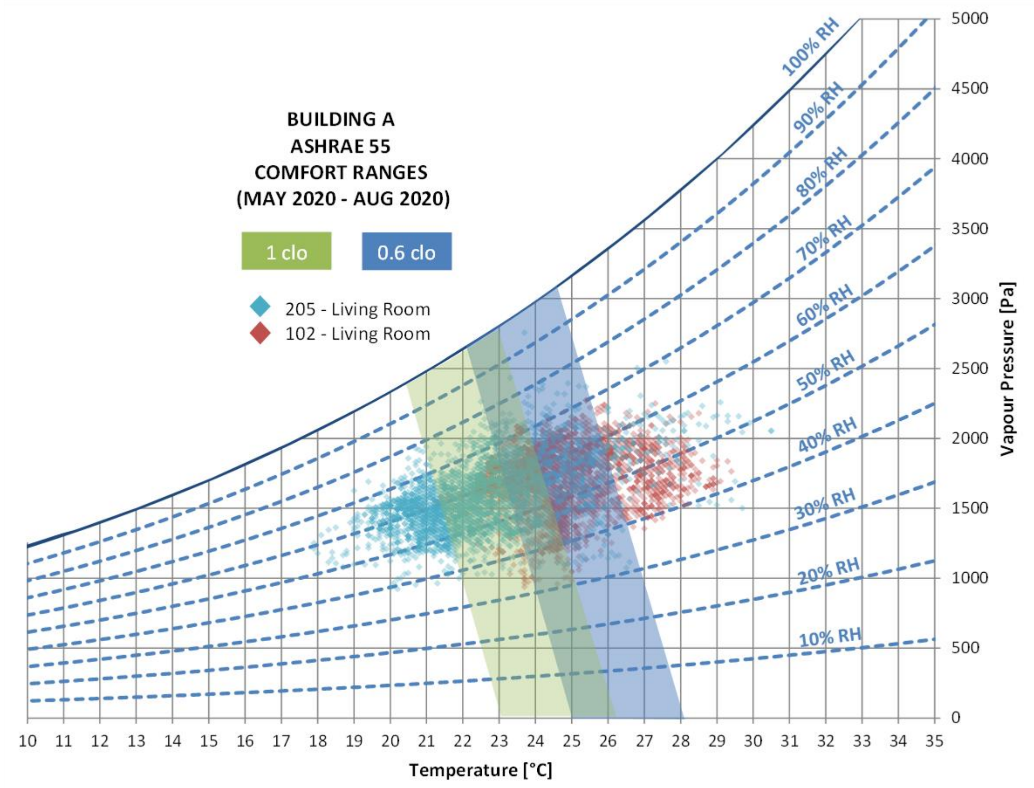


Figure 4.11 – Hourly air temperature measurements of two samples suites from Building A plotted on psychrometric chart (summer)

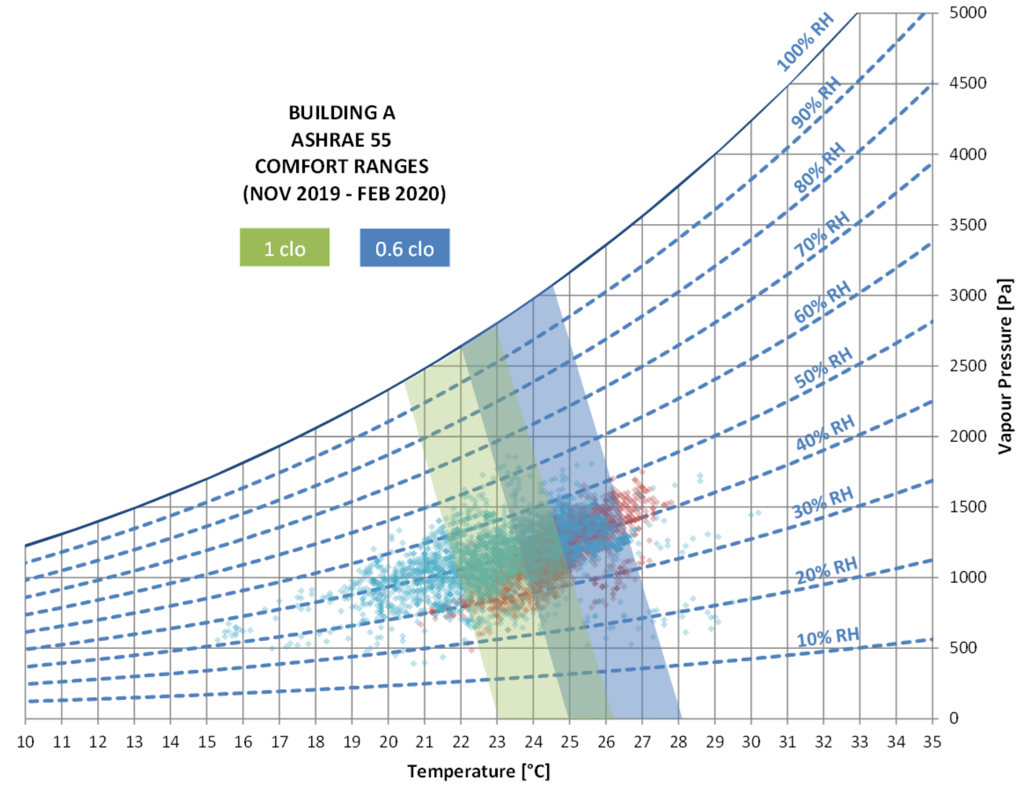


Figure 4.12 – Hourly air temperature measurements of two samples suites from Building A plotted on psychrometric chart (winter)

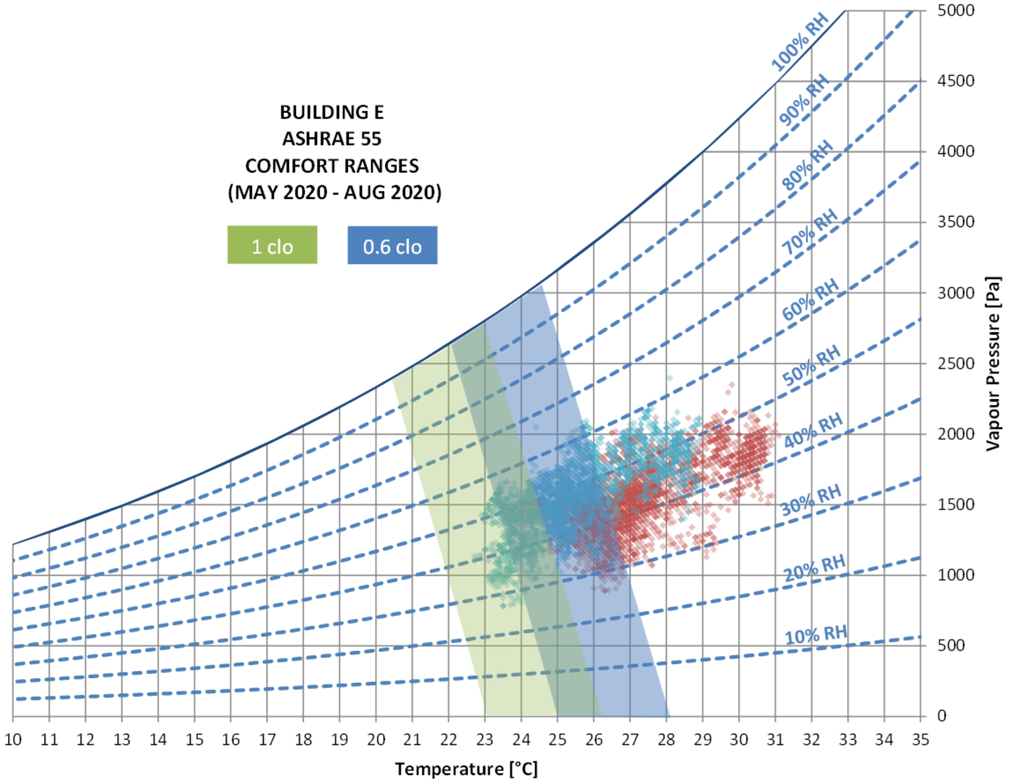


Figure 4.13 – Hourly air temperature measurements of two samples suites Building E plotted on psychrometric chart (summer)

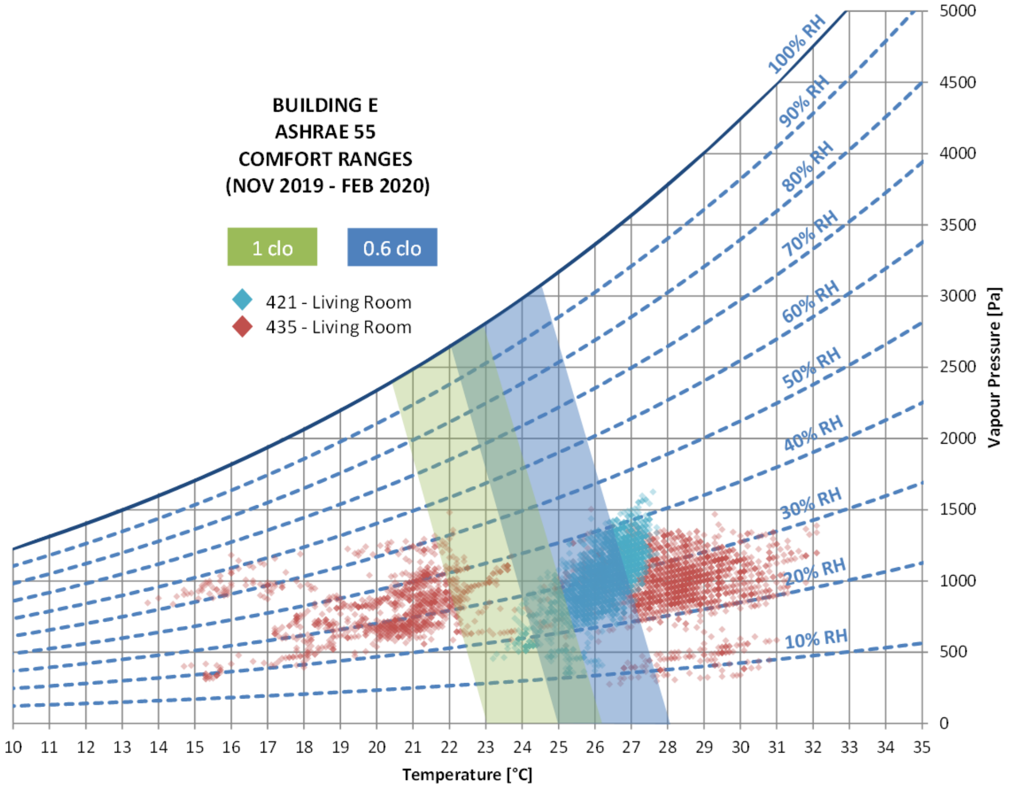


Figure 4.14 – Hourly air temperature measurements of two samples suites from Building E plotted on psychrometric chart (winter)

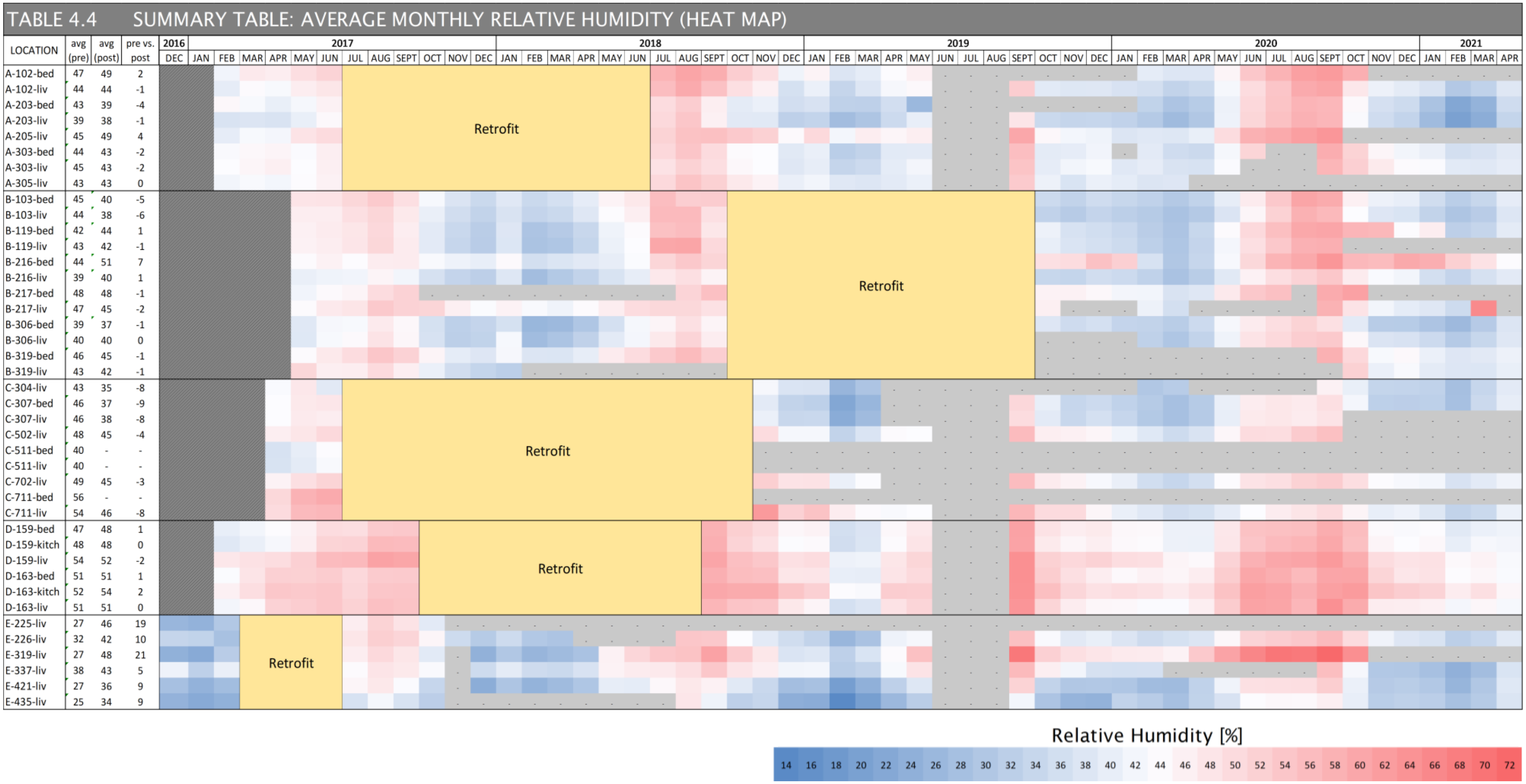
4.3.2 Relative Humidity

Figure 4.15 shows the average monthly RH for each building. Results show that RH is generally consistent for all buildings, with the exception of Building D, which experienced higher RH levels for the majority of the monitoring period. The monthly average RH readings are typically within the 30% to 60% design range for comfort. Generally, the reported monthly average RH levels did not reach above 60% (with the exception of a few cases), which indicates that the spaces do not typically experience excessive humidity. However, some of the spaces do show levels that are at the high end of the typical design scale and may be a concern. High RH is a concern in the winter due to potential condensation and is a concern in the summer because of the associated impacts on indoor comfort.

To provide a clearer overview of the measurements, the monthly RH recorded in each suite during the pre- and post-retrofit monitoring periods are shown as a heat map in Table 4.4. The monthly summary table also shows that the Building D suites tend to have generally higher RH. This is a result of the suites being relatively cooler than the other measured buildings in this study. In the following section, the dew point temperature was calculated and analyzed to assess the amount of moisture in the suites, which unlikely RH is independent of the ambient air temperature.

Figure 4.15 – Monthly average RH for each building. Gaps in data are either retrofit periods or missing data.

TABLE 4.4 SUMMARY TABLE: AVERAGE MONTHLY RELATIVE HUMIDITY (HEAT MAP)



LOCATION	avg (pre)	avg (post)	pre vs. post
A-102-bed	47	49	2
A-102-liv	44	44	-1
A-203-bed	43	39	-4
A-203-liv	39	38	-1
A-205-liv	45	49	4
A-303-bed	44	43	-2
A-303-liv	45	43	-2
A-305-liv	43	43	0
B-103-bed	45	40	-5
B-103-liv	44	38	-6
B-119-bed	42	44	1
B-119-liv	43	42	-1
B-216-bed	44	51	7
B-216-liv	39	40	1
B-217-bed	48	48	-1
B-217-liv	47	45	-2
B-306-bed	39	37	-1
B-306-liv	40	40	0
B-319-bed	46	45	-1
B-319-liv	43	42	-1
C-304-liv	43	35	-8
C-307-bed	46	37	-9
C-307-liv	46	38	-8
C-502-liv	48	45	-4
C-511-bed	40	-	-
C-511-liv	40	-	-
C-702-liv	49	45	-3
C-711-bed	56	-	-
C-711-liv	54	46	-8
D-159-bed	47	48	1
D-159-kitch	48	48	0
D-159-liv	54	52	-2
D-163-bed	51	51	1
D-163-kitch	52	54	2
D-163-liv	51	51	0
E-225-liv	27	46	19
E-226-liv	32	42	10
E-319-liv	27	48	21
E-337-liv	38	43	5
E-421-liv	27	36	9
E-435-liv	25	34	9

4.3.3 Dewpoint Temperature

Dewpoint temperature is the temperature at which air must be cooled to become saturated with water vapour. It can be used as an indicator of the potential for condensation and mold growth within a suite. Previous work by RDH has indicated that a wintertime dewpoint temperature of greater than 10°C results in an elevated risk of window condensation in Vancouver's climate.[25] Wintertime dewpoint temperatures in the range of 5 to 10°C represent a potential risk.

To provide an overview of the measurements, the monthly average dew point temperatures recorded in each suite during the pre- and post-retrofit monitoring periods are shown as a heat map in Table 4.5. Results show that dewpoint temperature measurements above 10˚C are generally found in summer and therefore pose less of a risk, say, compared to colder winter months when window frames which could go below the dewpoint temperature.

One particular suite to note is Building E 337 which had frequent readings with dewpoint temperature above 10°C throughout much of the monitoring period. This suite was also noted to have condensation on the windows during the site visit. All of the other buildings for which winter data was recorded show significant frequency of measurements above 10°C and most above 5°C. This data indicates that most of the suites in the study have a risk of condensation during winter months.

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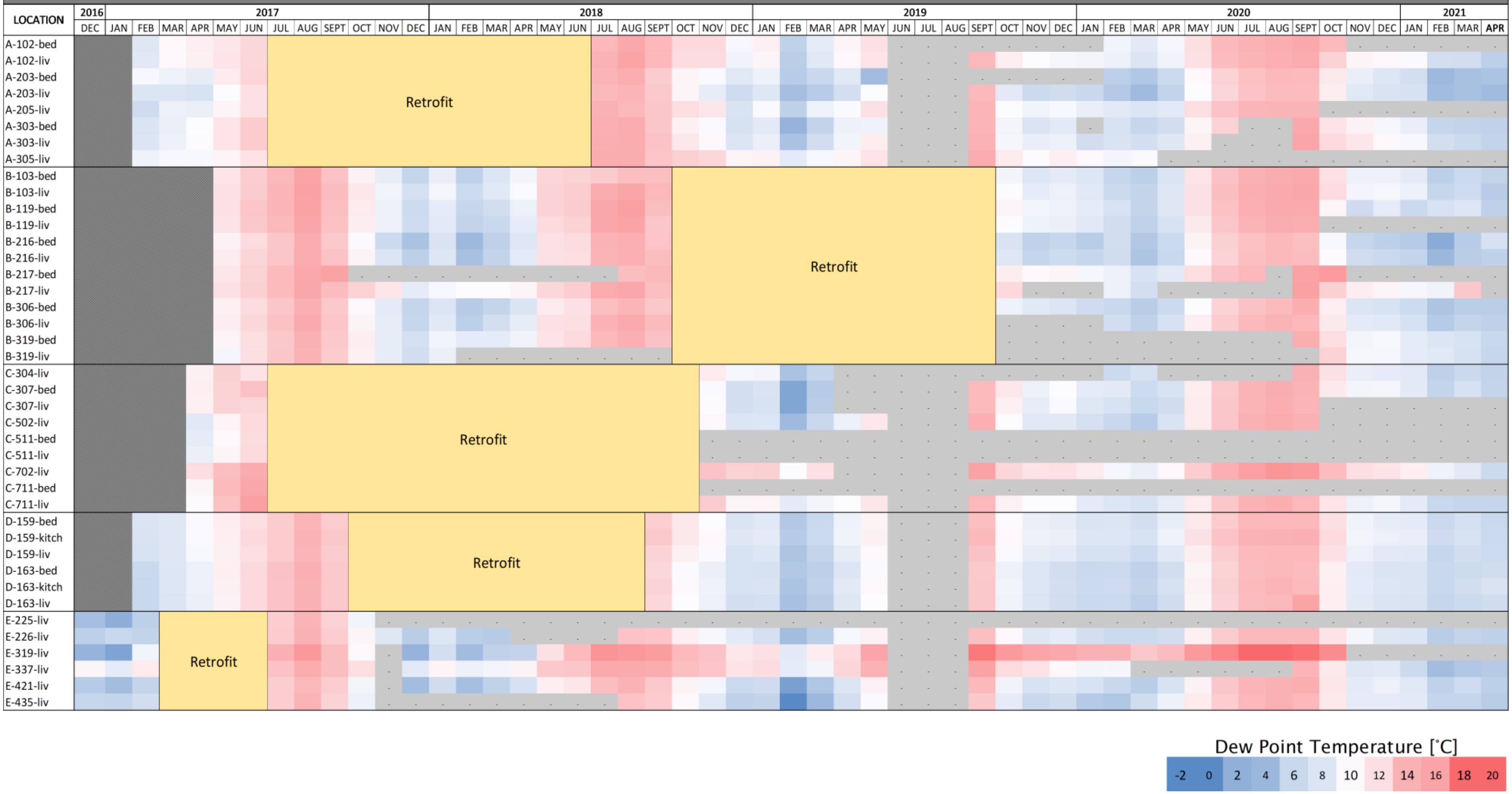
[25] RDH Technical Bulletin #9. http://rdh.com/wp-content/uploads/2015/09/TB-9-Air-Quality-in-MURBs-Technical-Bulletin-2015-08-25.pdf

TABLE 4.5 SUMMARY TABLE: AVERAGE MONTHLY DEW POINT TEMPERATURE (HEAT MAP)



The average monthly dewpoint temperature of buildings in the study are shown in Figure 4.16. The dewpoint temperatures show sharp increases and decreases in the summer and winter months, respectively. Higher dewpoint temperature in the summer months is expected and are generally less of a concern in heating dominated climates.

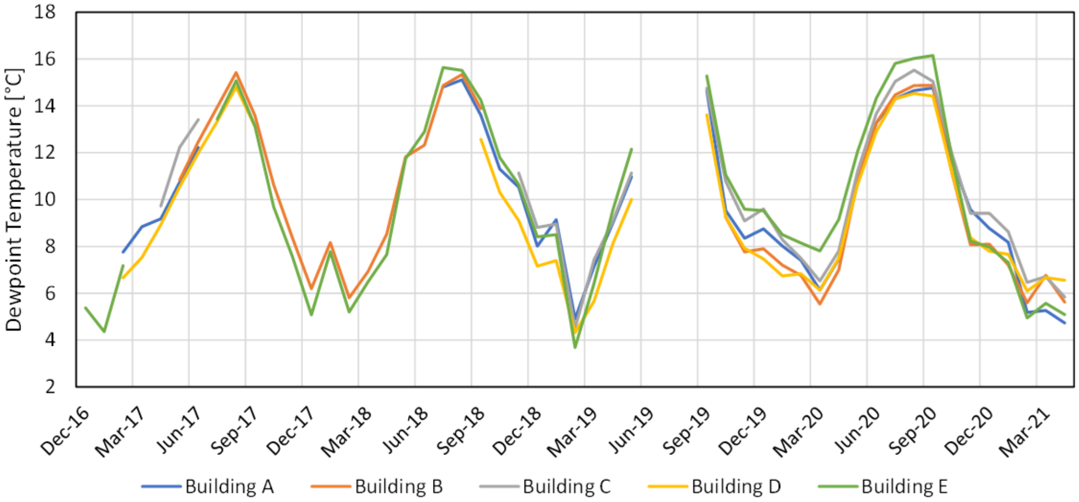


Figure 4.16 – Monthly average dewpoint temperature for each building. Gaps in data are either retrofit periods or missing data.

The distribution of dewpoint temperatures when condensation risk is greater (between October and March) is shown in *Figure 4.17*. The plot illustrates that the dew point temperature in the suites during cool outdoor conditions did not change significantly, other than a few cases such as Building E 319 living room and Building A 305 living room which show relatively greater distribution of dew point temperatures above 10°C compared to before the retrofits. These changes suggest that moisture build up in these suites is greater after the retrofits, perhaps a result of decreased ventilation or change in occupant behaviour.

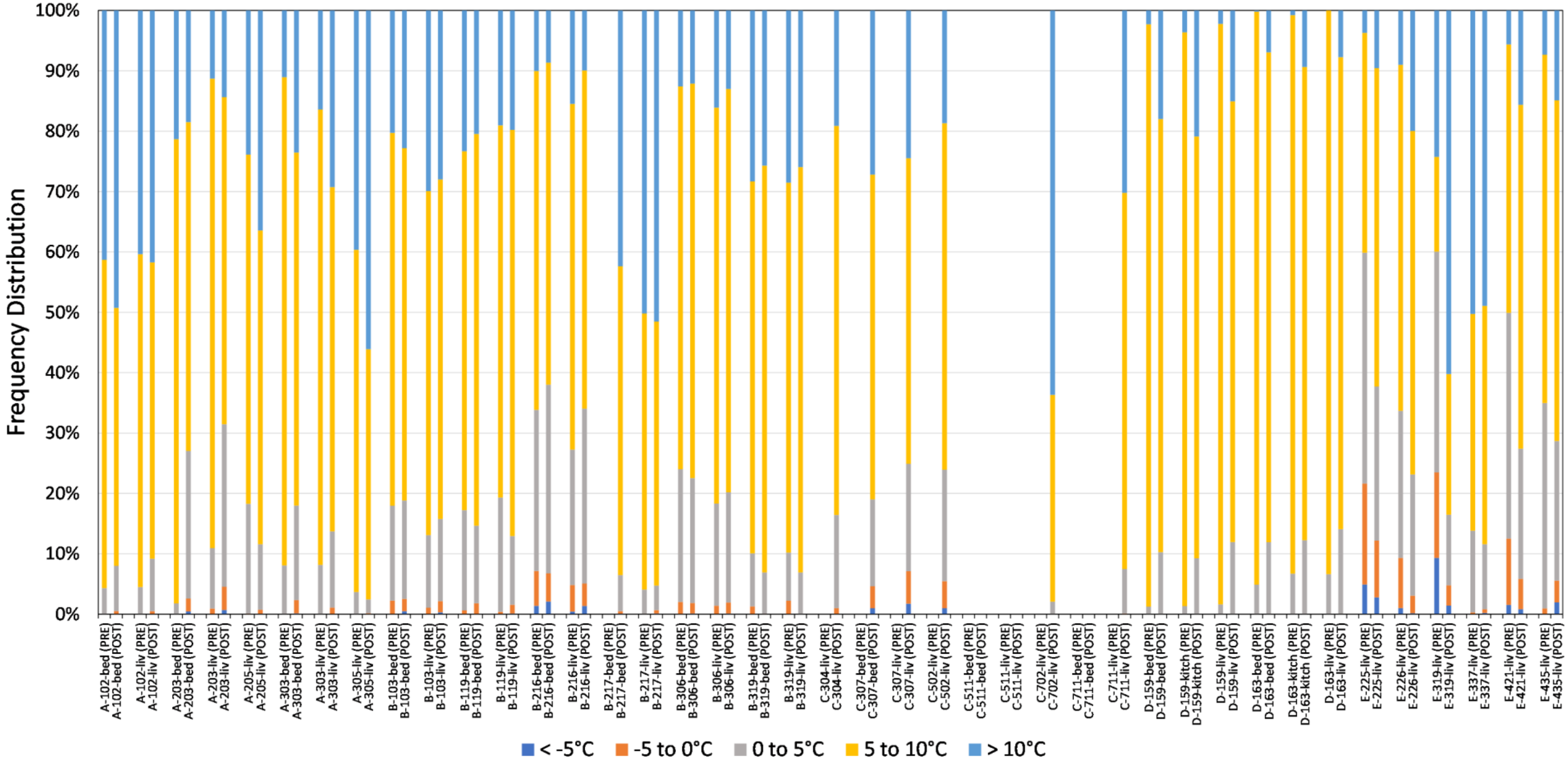


Figure 4.17 – Frequency distribution of dew point temperature between October and March (pre- vs. post-retrofit). Blank columns are the result of no measurements during the defined analysis period.

The delta dew point (or dew point rise) temperature metric is an indicator of the interior moisture generation and indoor ventilation effectiveness. This is the calculated difference in dewpoint temperature between the outdoor and indoor air. The delta dewpoint shows the relative increase in interior ambient moisture compared to the outdoors due to human activity (respiration, showering, etc.). A building that is perfectly ventilated will see a small difference in the interior and exterior dew points, as the indoor and outdoor are approaching the same moisture conditions. However, a building with relatively poor ventilation will experience a build-up of moisture related to indoor moisture sources such as occupant activity (breathing, cooking, etc.), plants, pets, etc. Although perfect ventilation is not generally possible, one of the objectives of an effective ventilation system is to reduce the buildup of indoor moisture, from both a building durability and IEQ perspective.

The average monthly delta dewpoint temperature of buildings in the study are shown in Figure 4.18. Results show that build-up of moisture relative to outdoor conditions is greatest during cooler months. This is likely due to the relatively dryer winter air and more frequent closing of windows which would reduce ventilation.

The monthly average dew point temperatures recorded in each suite during the pre- and post-retrofit monitoring periods are shown as a heat map in Table 4.6. The table shows similar results from Figure 4.18, though shows a significant build up of moisture for suite Building E 337 during winter of 2019/2020. Also, significant increase in moisture is noted in nearly all measured suites during February of 2019.

The distribution of delta dewpoint temperatures when condensation risk is greater (between October and March) is shown in *Figure 4.19*. The plot illustrates that the delta dew point temperature in the suites during cool outdoor conditions did not change significantly, with the exception of Building E 319 living room.

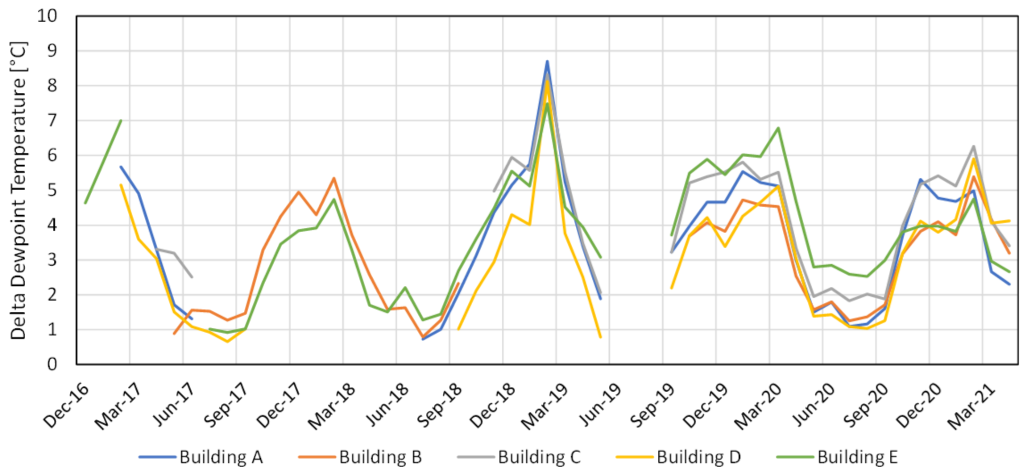
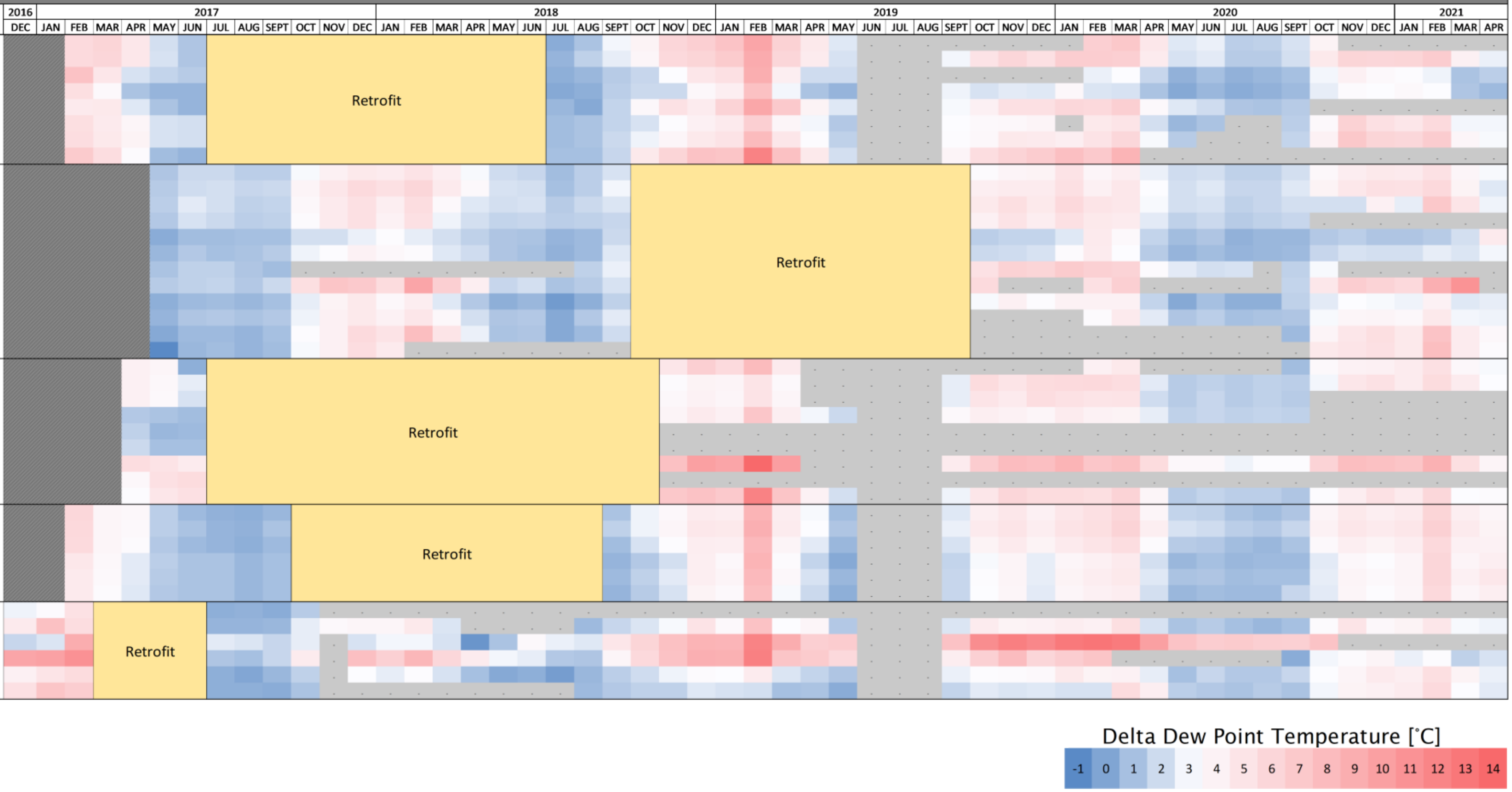


Figure 4.18 – Monthly average delta dewpoint temperature for each building. Gaps in data are either retrofit periods or missing data.

TABLE 4.6 SUMMARY TABLE: AVERAGE MONTHLY DELTA DEW POINT TEMPERATURE (HEAT MAP)

LOCATION	avg (pre)	avg (post)	pre vs. post
A-102-bed	4.0	4.2	0.2
A-102-liv	4.0	4.4	0.5
A-203-bed	3.5	2.6	-1.0
A-203-liv	2.3	2.2	-0.1
A-205-liv	2.7	3.8	1.1
A-303-bed	3.6	3.3	-0.3
A-303-liv	3.7	4.0	0.3
A-305-liv	3.4	5.5	2.1
B-103-bed	2.7	3.5	0.8
B-103-liv	3.1	3.8	0.7
B-119-bed	2.9	3.6	0.7
B-119-liv	2.7	3.3	0.6
B-216-bed	1.6	1.9	0.2
B-216-liv	2.0	2.1	0.1
B-217-bed	1.6	4.3	2.7
B-217-liv	3.7	6.1	2.5
B-306-bed	1.8	2.6	0.8
B-306-liv	2.3	2.8	0.5
B-319-bed	2.5	4.3	1.8
B-319-liv	2.2	5.0	2.8
C-304-liv	2.8	4.4	1.7
C-307-bed	3.5	3.8	0.4
C-307-liv	3.3	3.5	0.2
C-502-liv	1.2	3.4	2.2
C-511-bed	1.1	-	-
C-511-liv	1.4	-	-
C-702-liv	4.9	6.7	1.7
C-711-bed	4.8	-	-
C-711-liv	4.4	4.6	0.1
D-159-bed	2.2	3.7	1.5
D-159-kitch	2.3	3.9	1.7
D-159-liv	2.1	3.4	1.3
D-163-bed	2.1	2.9	0.8
D-163-kitch	2.1	3.1	1.0
D-163-liv	2.0	2.9	0.9
E-225-liv	3.8	0.8	-3.1
E-226-liv	5.8	3.0	-2.7
E-319-liv	4.4	6.3	1.9
E-337-liv	9.9	4.8	-5.1
E-421-liv	4.8	2.5	-2.4
E-435-liv	6.3	2.2	-4.1



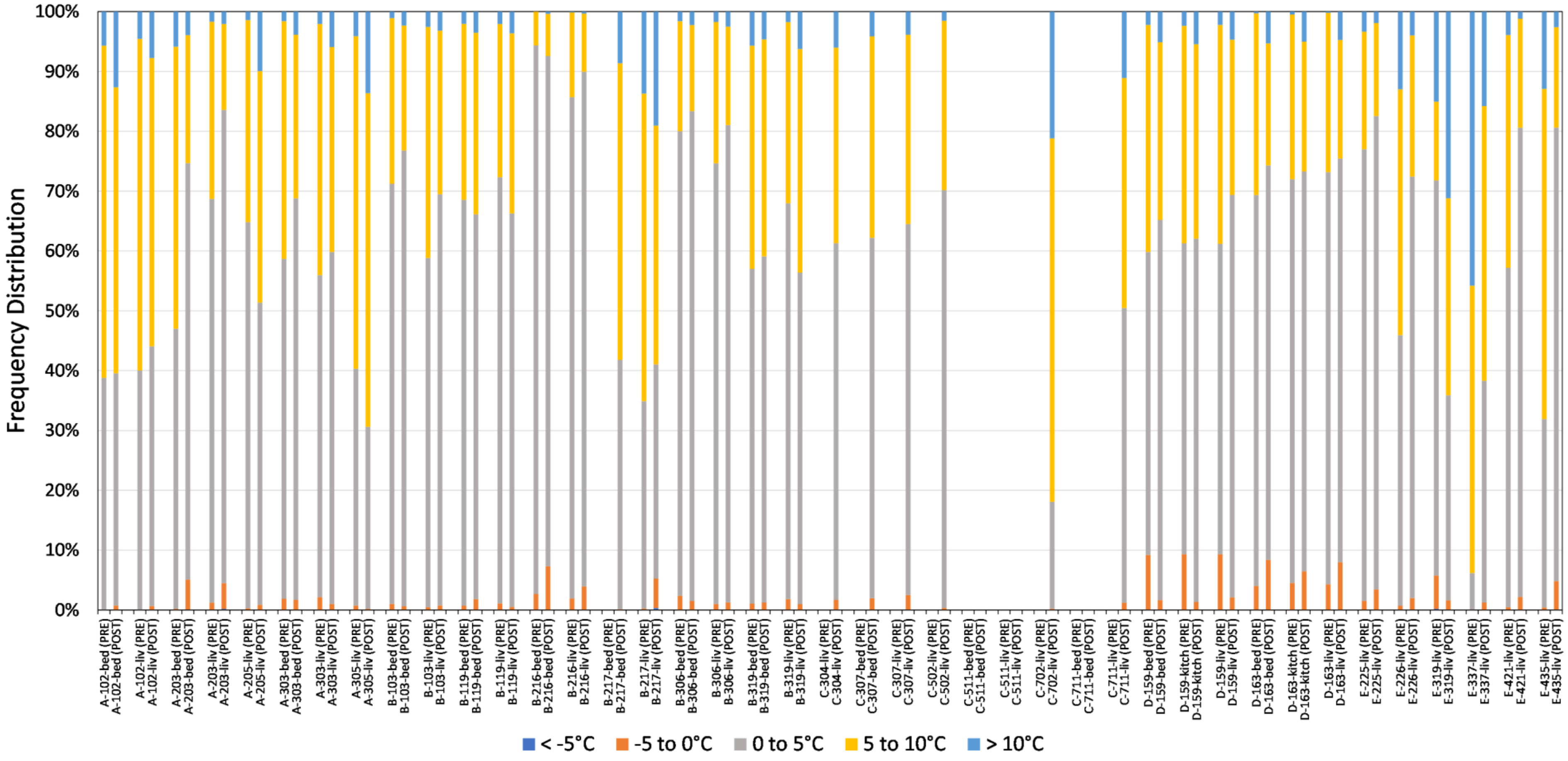


Figure 4.19 – Frequency distribution of delta dew point temperature between October and March (pre- vs. post-retrofit). Blank columns are the result of no measurements taken during the defined period.

4.3.4 Carbon Dioxide Concentrations

As described in Section 1.1, several studies have linked high CO_2 concentrations and negative health outcomes such as fatigue, headaches, dizziness, cognitive decline, etc. and the importance of proper ventilation in order to avoid the buildup of CO_2 concentrations. To provide an overview of the measurements, the monthly average CO_2 concentrations recorded in each suite during the pre- and post-retrofit monitoring periods are shown as a heat map in Table 4.7.

The average indoor CO_2 concentration during the pre-retrofit period varied significantly, between roughly 400 ppm and 4,800 ppm. As the heat map shows, there are no distinct trends in the overall average suite CO_2 concentrations other than suite 217 from Building B having significantly higher concentrations of CO_2 after the retrofit period. Interestingly, the blower door test results for this suite showed an increase in the air leakage rate (5.5 to 11.2 ACH50), therefore it is unlikely that the retrofit measures are responsible for the high concentrations of CO_2.

Figure 4.20 shows that the average CO_2 concentration in most suites was in the range of 500 to 1300 ppm, which is generally within normal design conditions. However, most monitored suites experienced CO_2 concentrations in excess of 1,100 ppm for more than 20% of the monitoring period. Examining the hourly data in a sample of the suites showed that the CO_2 concentrations typically increased in the evening and overnight with a decrease the following morning. This finding is generally consistent with standard occupancy patterns, where CO_2 steadily rises when occupants are present in the evening and sleep.

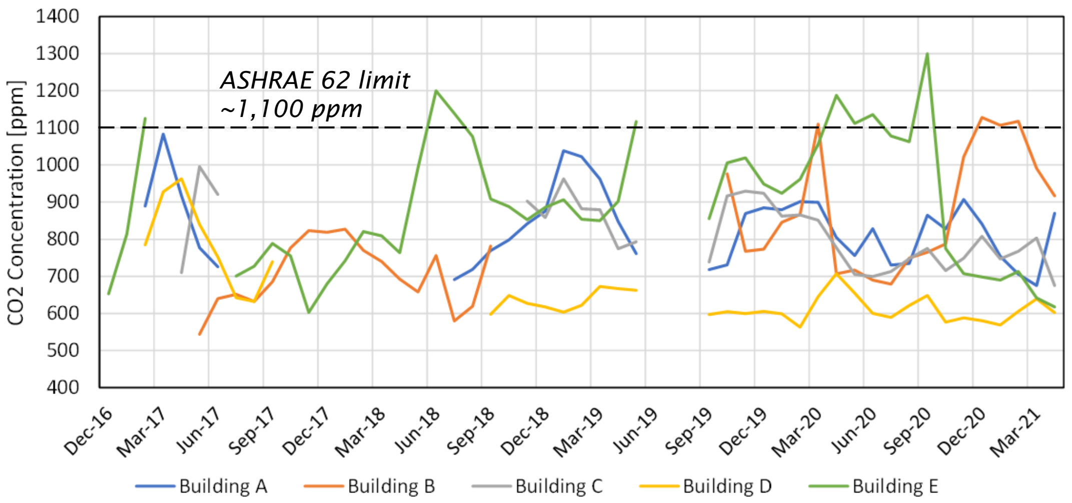
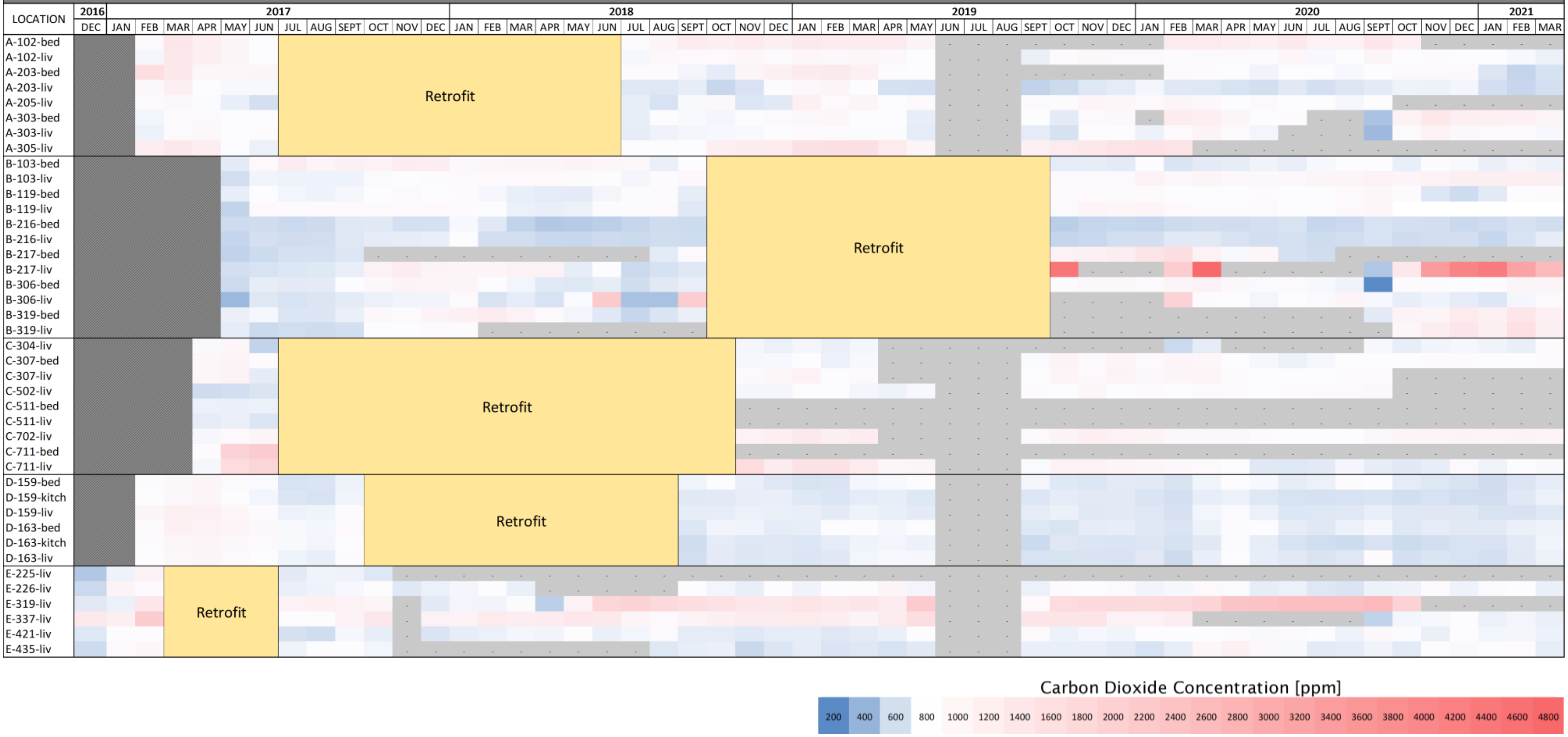


Figure 4.20 – Monthly average carbon dioxide concentrations for each building. Gaps in data are either retrofit periods or missing data

TABLE 4.7 SUMMARY TABLE: AVERAGE MONTHLY CARBON DIOXIDE CONCENTRATIONS (HEAT MAP)



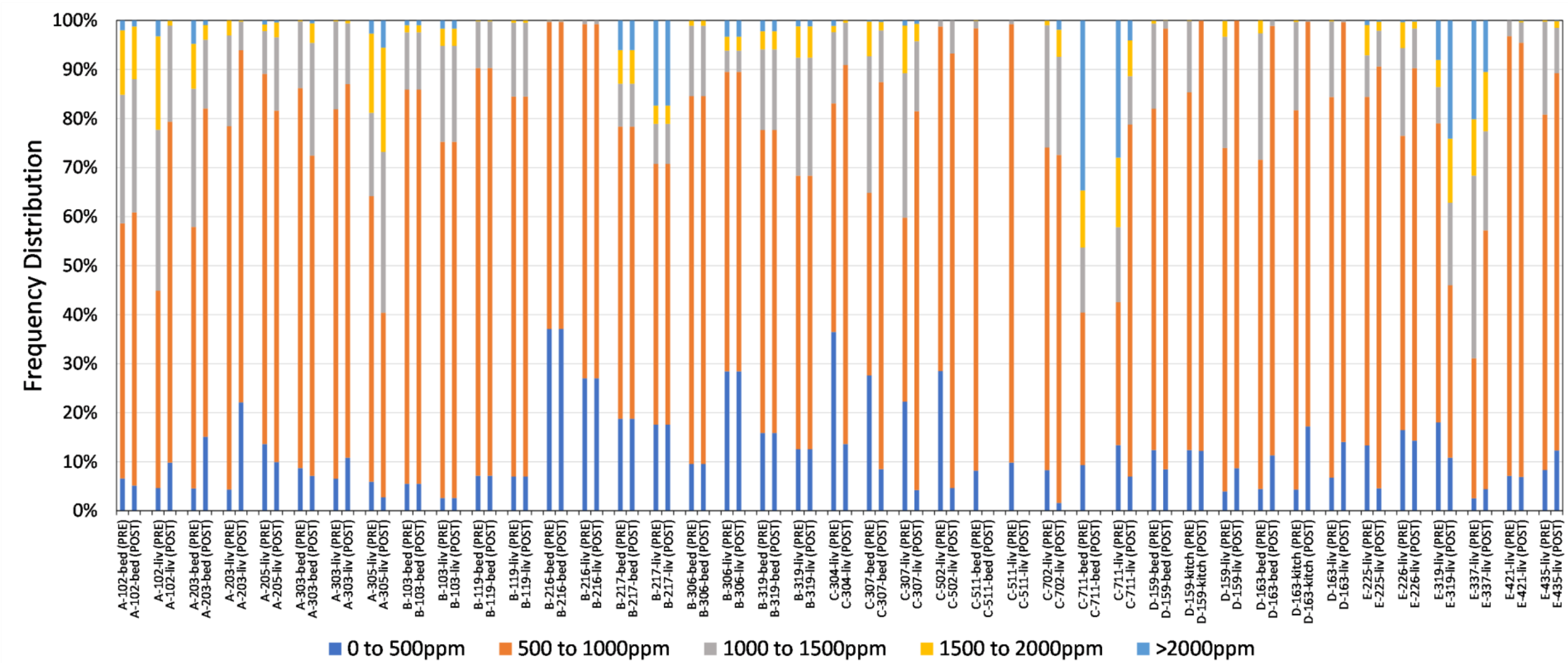


Figure 4.21 – Frequency distribution of CO_2 concentrations (pre- vs. post-retrofit). Blank columns are the result of no measurements taken during the defined analysis period.

4.4 Special Events

During the monitoring period, two notable special events occurred including a City of Vancouver Air Quality Advisory due to wildfires in the interior along with the beginning of the COVID-19 lockdown. This section specifically looks at possible trends during these events.

4.4.1 COVID-19

The Province of British Columbia declared a public health emergency related to the COVID-19 pandemic on March 17, 2020, with the closure of restaurants, personal service establishments, and physical distancing requirements starting shortly thereafter. These public health measures were anticipated to result in increased occupancy of the suites due to people remaining indoors. Similar increases in cooking and other indoor activities were expected.

Figure 4.22 and *Figure 4.23* are samples of the air temperature and CO_2 concentrations for the entire monitoring period for Building B and Building A, respectively. For similar plots of other measured buildings, see *Appendix A*. Based on an analysis of the data immediately before and after the Provincial lock-down orders, there were no significant changes in the measured IEQ parameters due to COVID-19 policies.

The lack of observable trends pre- and post-lockdown is likely the result of the elevated pre-lockdown trends in temperatures, CO_2, and interior moisture along with the 15-min monitoring interval being too long to capture short-term events less than 30-min in duration.

4.4.2 Wildfire Season

Wildfires are increasingly resulting in air quality advisories in the Lower Mainland due to elevated concentrations of outdoor particulate matter. During air quality advisories, public health guidance is to remain sheltered indoors with windows closed. As operable windows were often the main source of fresh air ventilation and cooling in the suites, the wildfires were expected to result in a measurable increase in the indoor air temperature, RH, and CO_2 concentrations.

Figure 4.24 and *Figure 4.25* plot the air temperature and CO_2 concentrations during the September 2020 Metro Vancouver Air Quality Advisory for Building B and Building A, respectively. The plots include data from one week before and one week after the advisory for comparative purposes. The results show that the temperature in Building B did not significantly change as a result of the advisory; however, the CO_2 concentrations in Building A appear to have increased suddenly at the beginning of that period. This agrees with the public health recommendations to stay indoors with windows and doors closed. For similar plots of other measured buildings, see *Appendix F*.

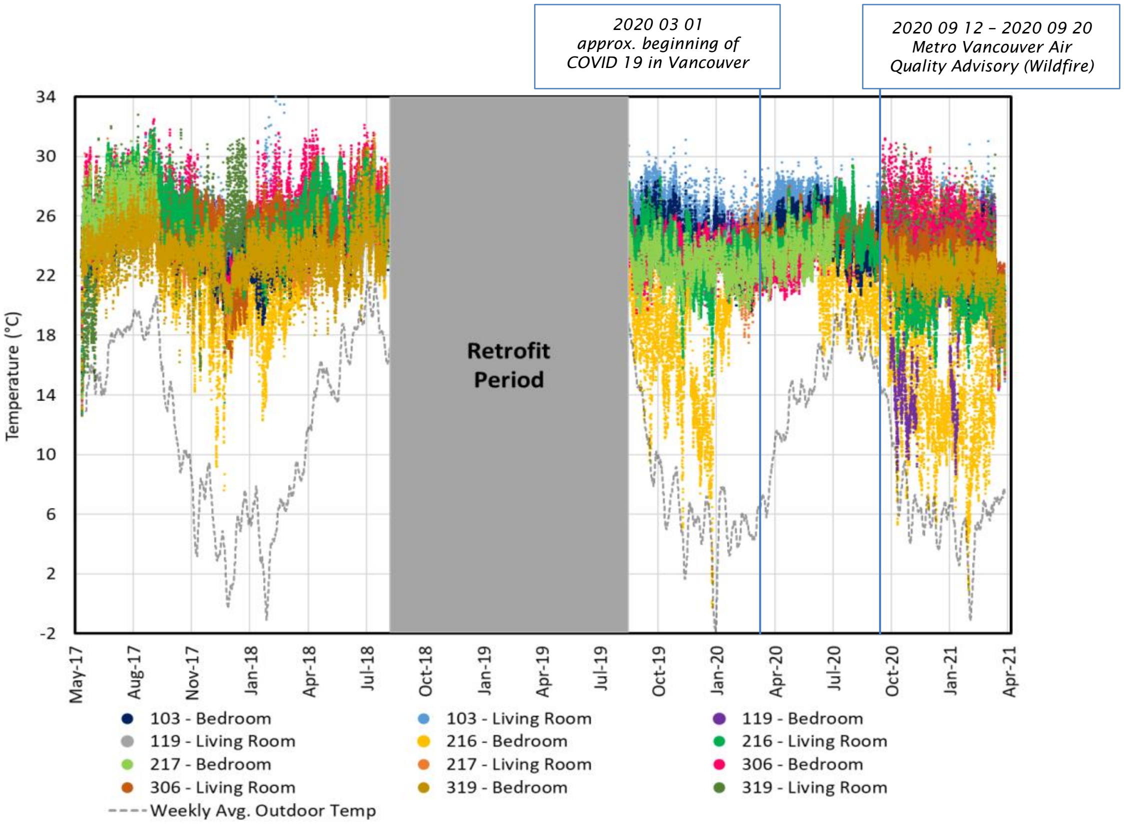


Figure 4.22 – Air temperature measurements throughout monitoring period (Building B)

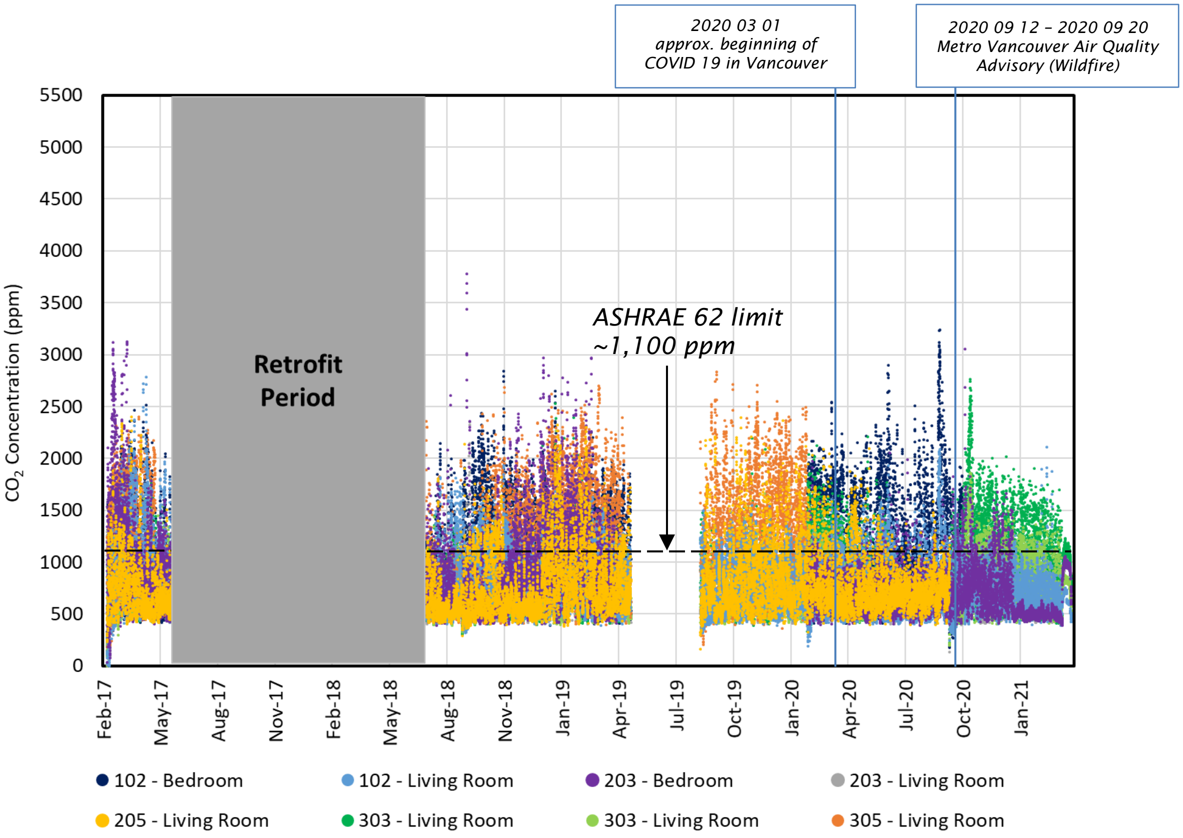


Figure 4.23 – CO$_2$ concentration measurements throughout monitoring period (Building A)

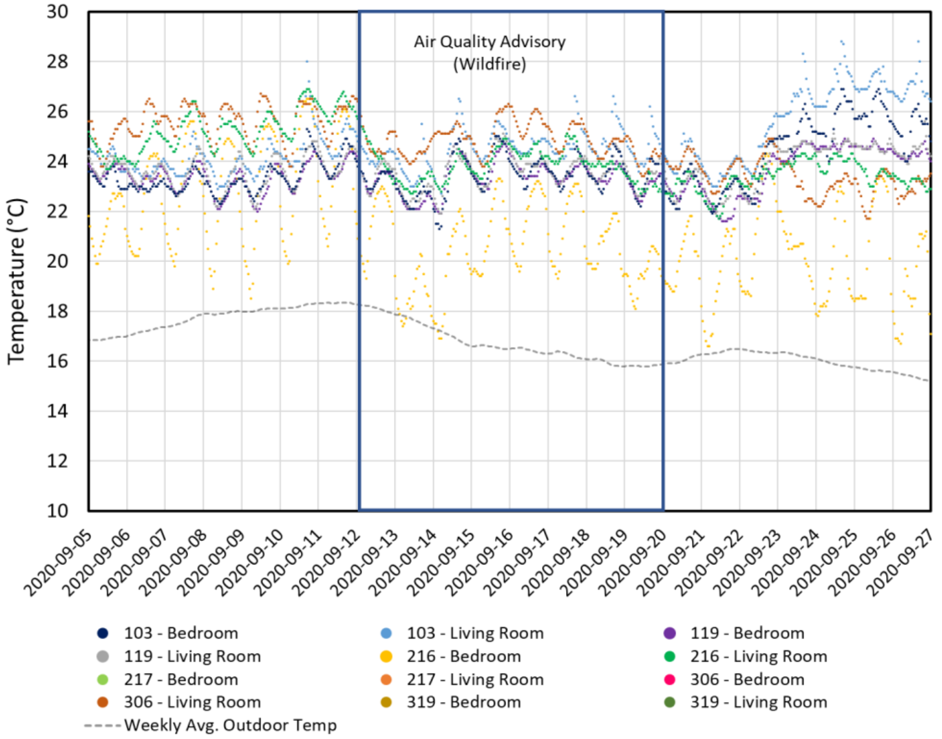


Figure 4.24 – Air temperature measurements during the Metro Vancouver Air Quality Advisory (Building B)

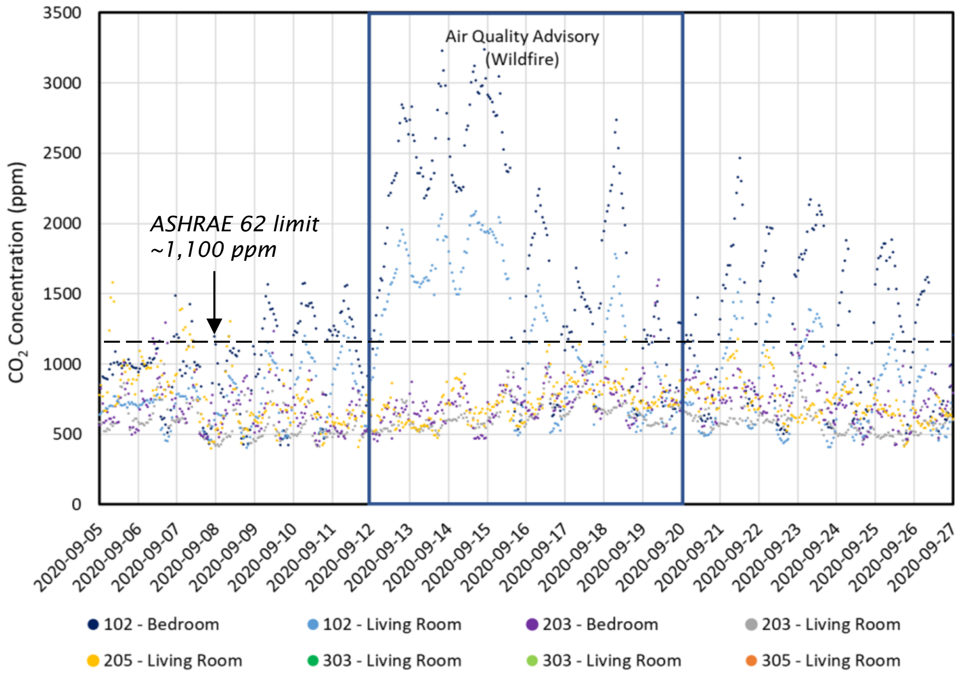


Figure 4.25 – CO_2 concentration measurements during the Metro Vancouver Air Quality Advisory (Building A)

4.5 Other Considerations

Some IEQ variables beyond the those measured in this study were noted during site visits. As previously stated, IEQ includes a broader assessment of the indoor conditions (e.g., lighting, acoustics, ergonomics, smells, etc.). The following general observations were noted as additional considerations and/or concerns with the suite-level IEQ:

Tobacco Smoke & Odours

The smell of tobacco smoke was heavy in public spaces, corridors, and the suites of tenants who reported being non-smokers. Efforts to open windows, use exhaust fans, and close/seal around doors was ineffective at preventing odours entering the suites.

Use of the exhaust fans pulled smoke from the corridors into the suite, and opening windows provided another path for smoke and odours to pass between the suites.

In the absence of a no-smoking policy for indoor spaces, effective control of tobacco smoke and other air contaminants would require:

1. Exhaust ventilation in spaces where smoking is permitted, with the exhaust air discharging away from nearby fresh air intakes (e.g., adjacent open windows)
2. Suite-level compartmentalization to provide an air barrier between suites
3. Continuous fresh air ventilation

Bugs & Pests

Anecdotally, insects (e.g., bed bugs, cockroaches, etc.) were a significant problem reported by the tenants. In one case, a tenant had blocked their exhaust fan as they claimed bugs were entering their suite through the duct work. During the sensor take-down at the end of the study, three sensors were damaged by the excessive accumulation of insects inside the hardware.

While the buildings had on-going pest control plans, it is worth noting that suite-level compartmentalization would have an added benefit of reducing the spread of pests between suites.

Mould & Mildew

Mould and mildew were noted in several suites, particularly in bathrooms where exhaust fans were observed to be poor performing or non-functional.

5 Key Findings

The intended outcomes of this study were to understand the indoor environmental quality in existing multi-unit social housing buildings in BC. These objectives were met through long-term monitoring of several IEQ parameters. Additionally, the potential impacts of building enclosure and mechanical system upgrades were assessed through pre- and post-retrofit monitoring. The measured IEQ parameters included ambient air temperature, RH, dewpoint temperature, and CO_2 concentrations. The key findings and discussion are summarized below.

- Four of the five monitored buildings experienced significant periods of overheating. On average, across all buildings, the suites experienced more than 700 hours with the indoor air temperature exceeding 26°C. The peak indoor air temperature was in excess of 31°C.
    - Suite-level control of the heating system was inconsistent and likely contributed to overheating in the shoulder seasons
    - Cooling is only provided through natural ventilation of the open windows, and the findings show that this is insufficient to meet BC Housing's overheating guidelines
    - Relying on open windows will reduce the effectiveness of possible future IEQ or energy upgrades
- With a few exceptions, the RH remained within 30% - 60%, with the elevated humidity periods experienced in the summer months. This observation is consistent with open windows.
- CO_2 concentrations generally remained below 1,100 ppm with elevated concentrations overnight. This trend is consistent with reduced ventilation (i.e., closed windows) and/or sustained occupancy overnight.
- No significant trends were observed in the monitored IEQ parameters pre- and post-retrofit. Continued reliance on open windows for ventilation and the lack of IEQ specific upgrades likely contributed to this finding. Refer to Part 6 *Recommendations* for additional discussion.
- In general, the pre-retrofit airflow rates through the exhaust fans were lower than the rates specified in the relevant codes and standards. Post-retrofit measurements of the airflow rates were higher than the pre-retrofit measurements but remained below specified rates in nearly half the suites. Building upgrades included new exhaust fans in some, but not all units.
- Improved exhaust fan performance had no significant impact on the monitored IEQ parameters. This is likely the result of lack of use, which may be due to fan noise or other factors.
- Pre- and post-retrofit airtightness measurements of the suites in buildings that underwent a window replacement generally showed an improved airtightness between 5% to 20%. The air leakage testing did not control for air leakage between suites due to lack of adjacent suite access. Building C, which did not undergo a window replacement, saw a consistent increase in the air leakage post-retrofit.

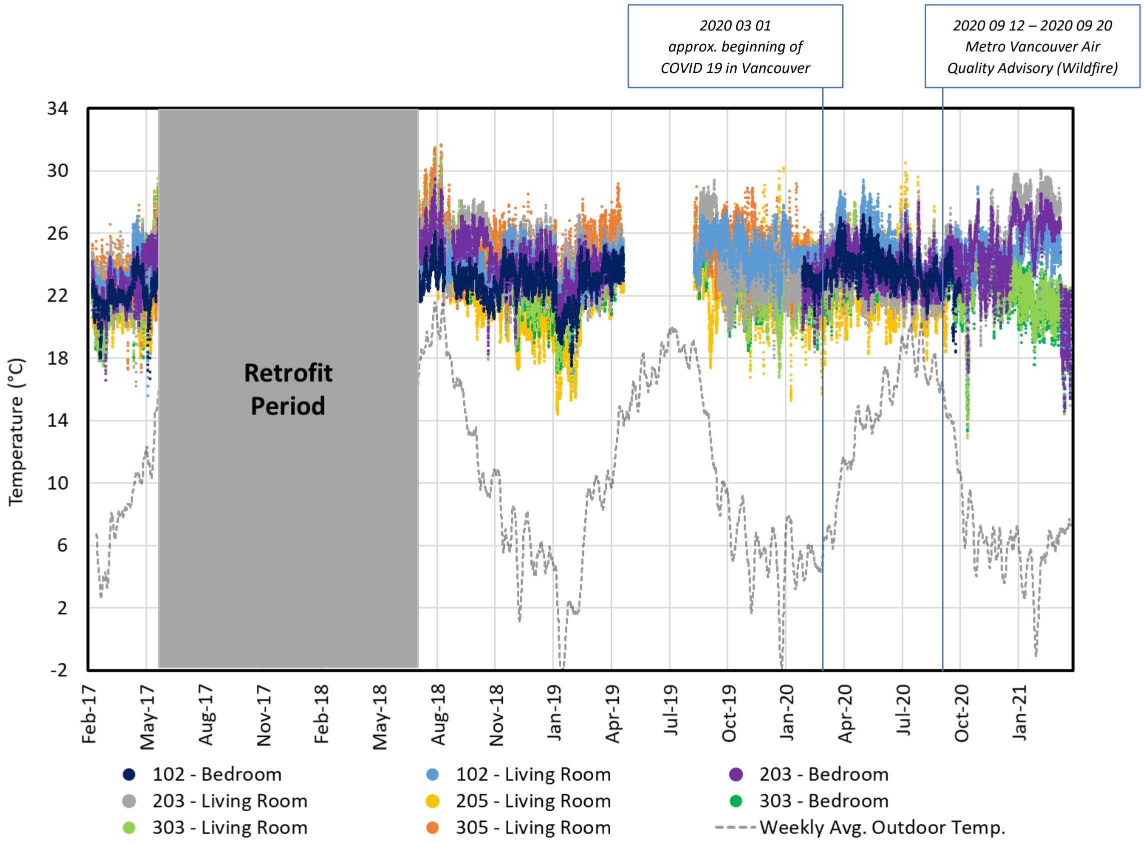
6 Recommendations

The key finding of this study was significant periods of overheating. Relying on open windows was generally ineffective as a cooling strategy for the monitored suites and led to negative IEQ consequences such as transfer of odours and exposure to outdoor contaminants (e.g., wildfires). The building retrofit measures from this study were largely focused on building enclosure and mechanical upgrades. While for example, window replacements and repairs to damaged equipment could have an impact on IEQ, no impacts were observed in this study. For future building retrofits, we recommend that specific strategies be considered for improving IEQ. These strategies could include:

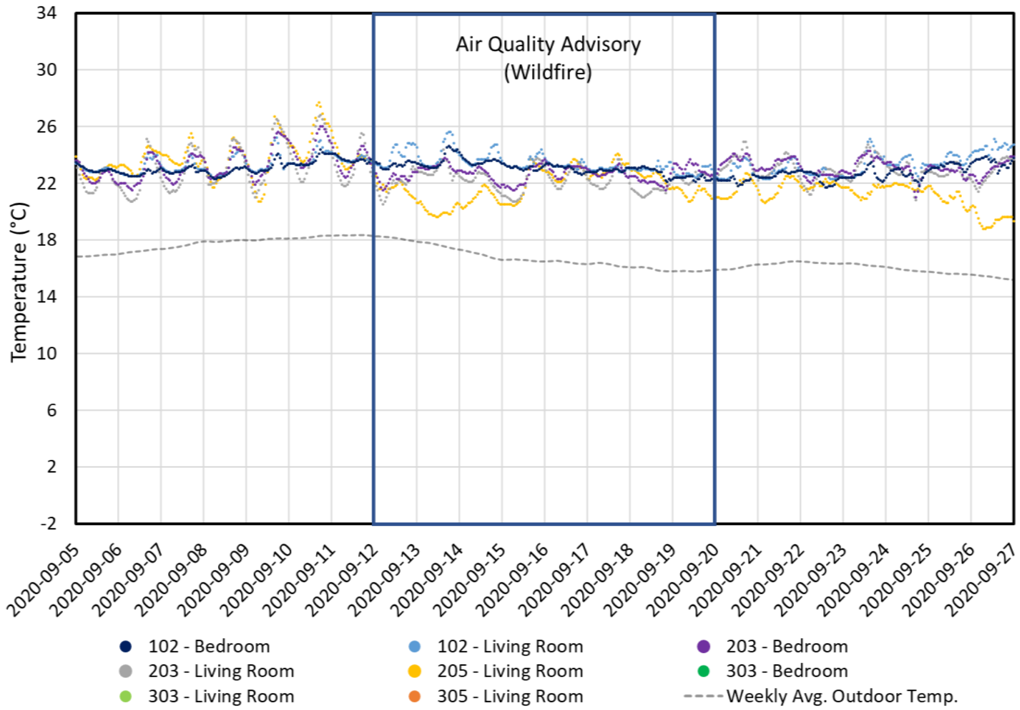
- → Addition of suite-level ventilation to provide consistent supply of fresh air to suites instead of relying on exhaust only ventilation and windows (e.g., heat-recovery ventilators)
- → Addition of suite-level control of space heating equipment
- → Suite compartmentalization to improve air sealing between suites and to reduce contaminant transfer (e.g., odours, pests, etc.)
- → Addition of active cooling (e.g., centralized air-source or ductless mini-split heat pumps)
- → Installation of windows with low solar heat gain coefficients (SHGC) or exterior shading to reduce incoming solar radiation

When these upgrades are considered in conjunction with more conventional building enclosure upgrades focused on thermal efficiency of walls and windows, reductions in unwanted solar gains, and improved airtightness, it is possible to meaningfully improve IEQ. Providing an airtight enclosure with adequate ventilation can also improve resilience to extreme events, such as those experienced during this study. IEQ retrofits will be an important aspect of adapting to a changing climate.

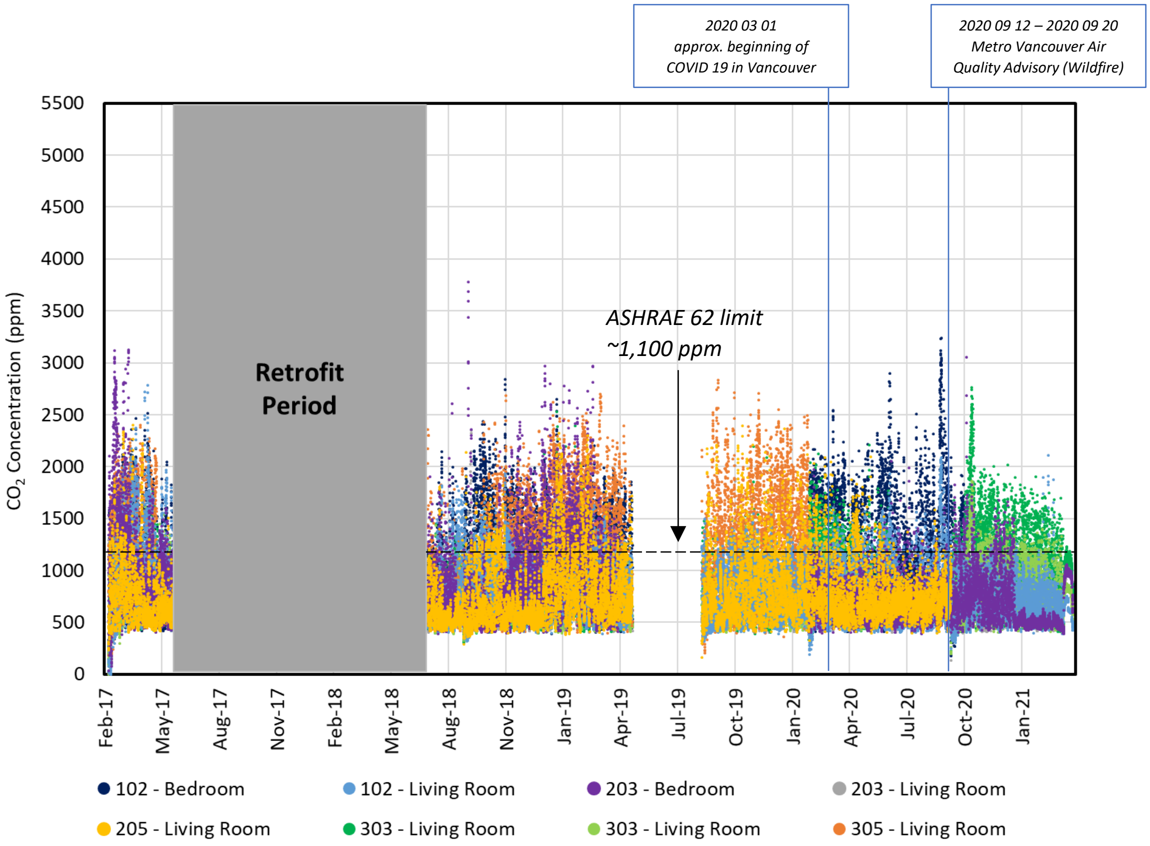
Appendix A
Air Temperature & Carbon Dioxide Scatter Plots



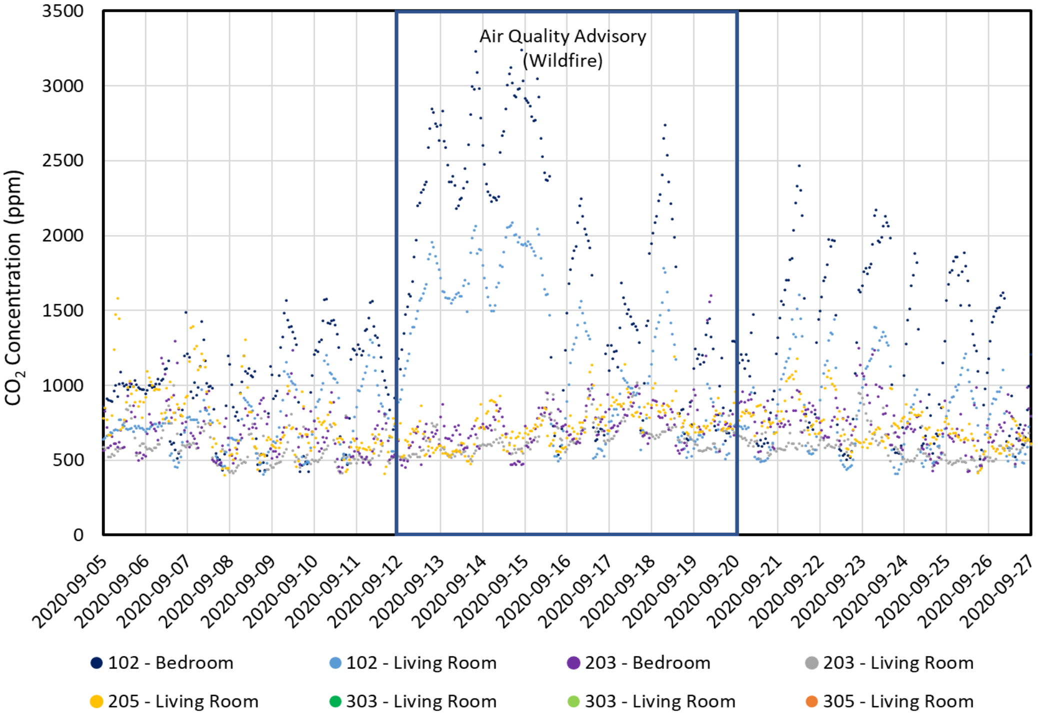
Appendix A.1 – Air temperature measurements throughout monitoring period (Building A)



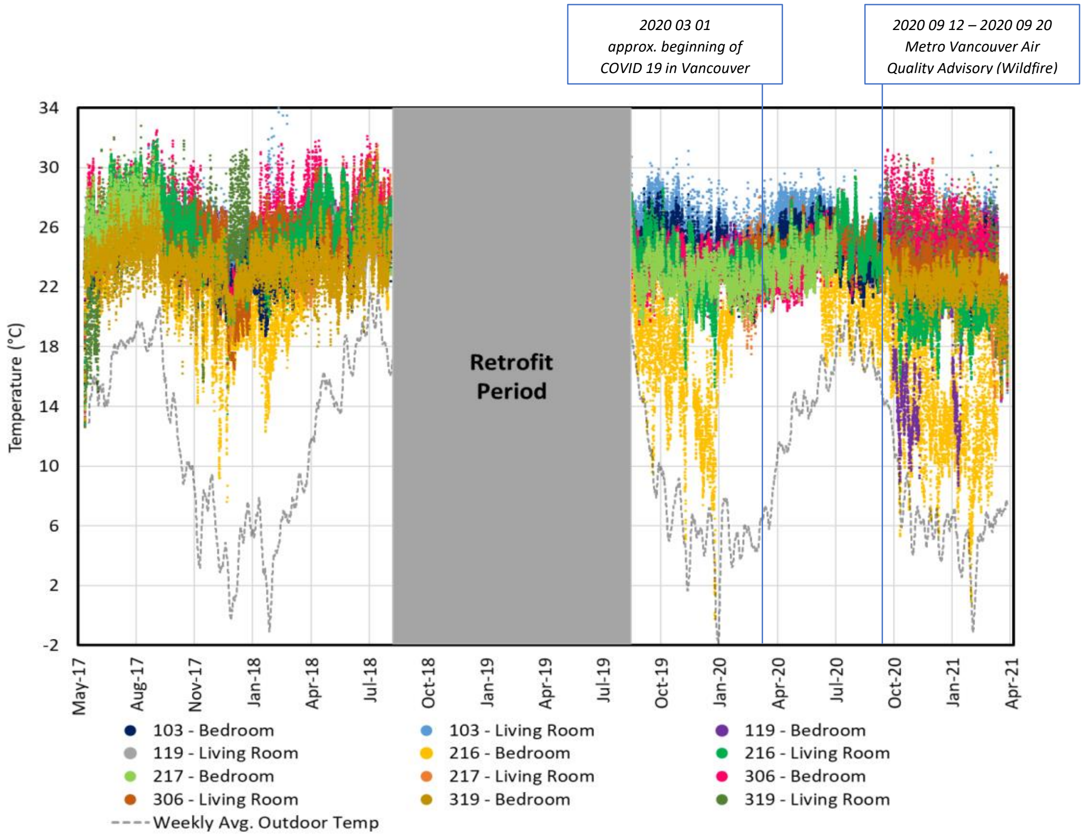
Appendix A.2 – Air temperature one week before, during and after the 2020 wildfire air quality advisory (Building A)



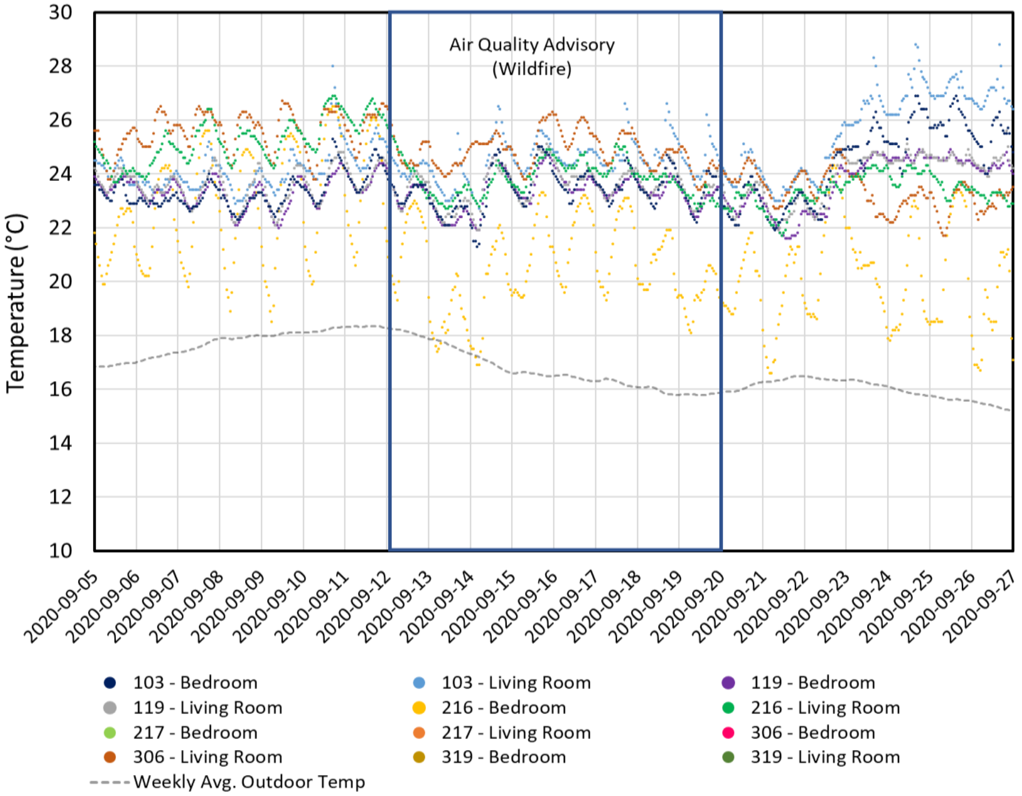
Appendix A.3 – CO_2 concentration measurements throughout monitoring period (Building A)



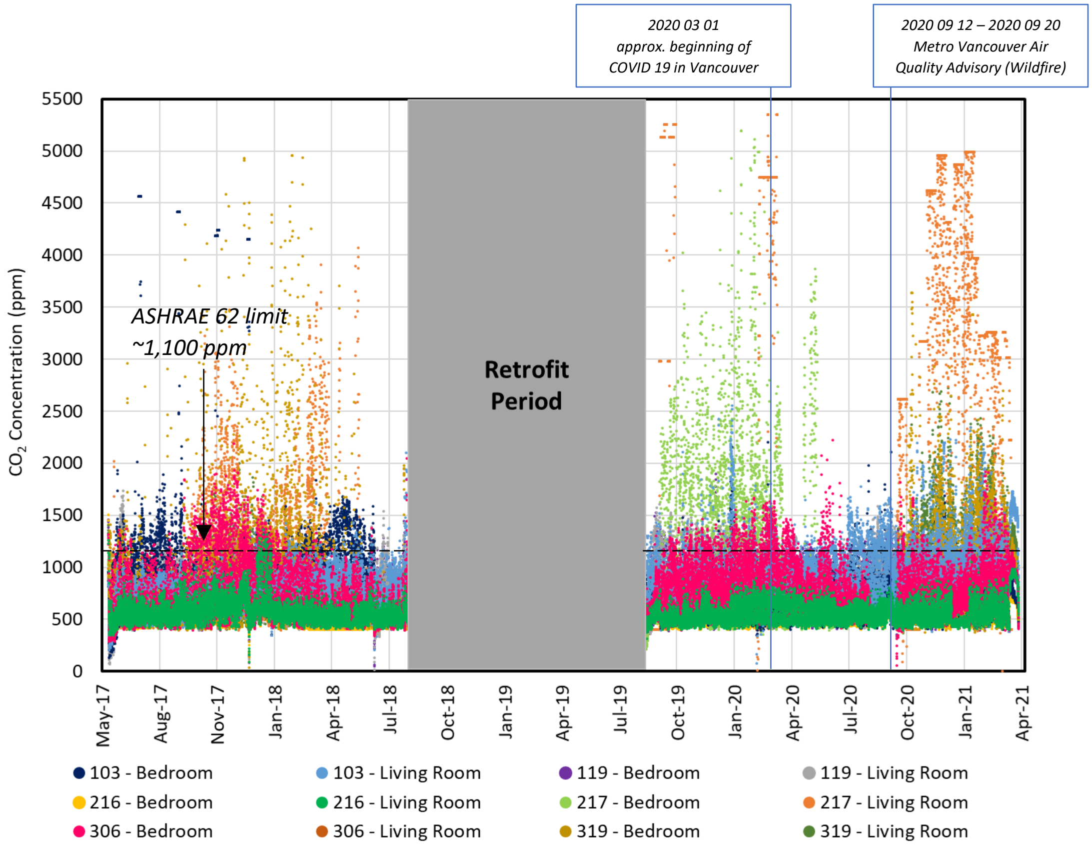
Appendix A.4 – CO_2 concentration one week before, during and after the 2020 wildfire air quality advisory (Building A)



Appendix A.5 – Air temperature measurements throughout monitoring period (Building B)

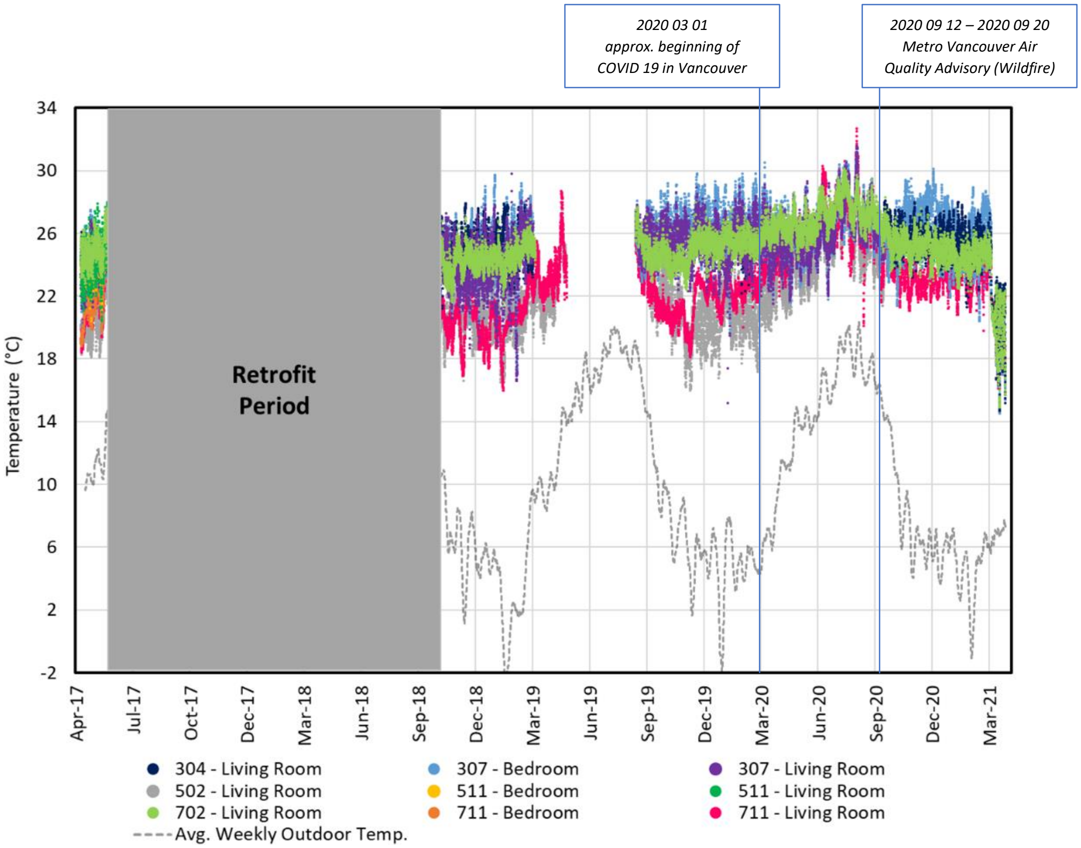


Appendix A.6 – Air temperature one week before, during and after the 2020 wildfire air quality advisory (Building B)

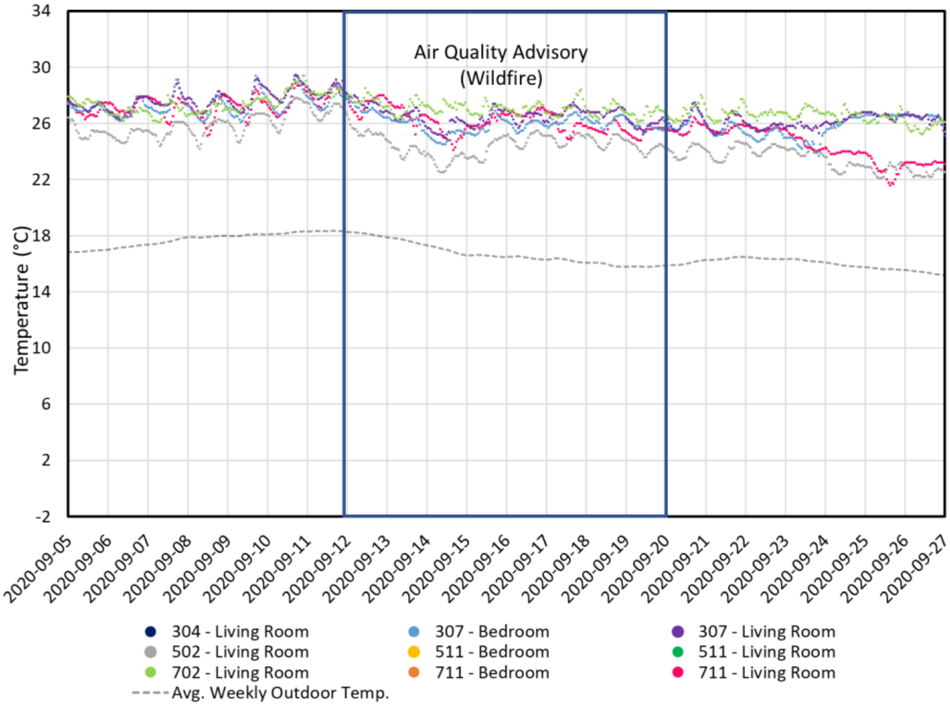


Appendix A.7 – CO$_2$ concentration measurements throughout monitoring period (Building B)

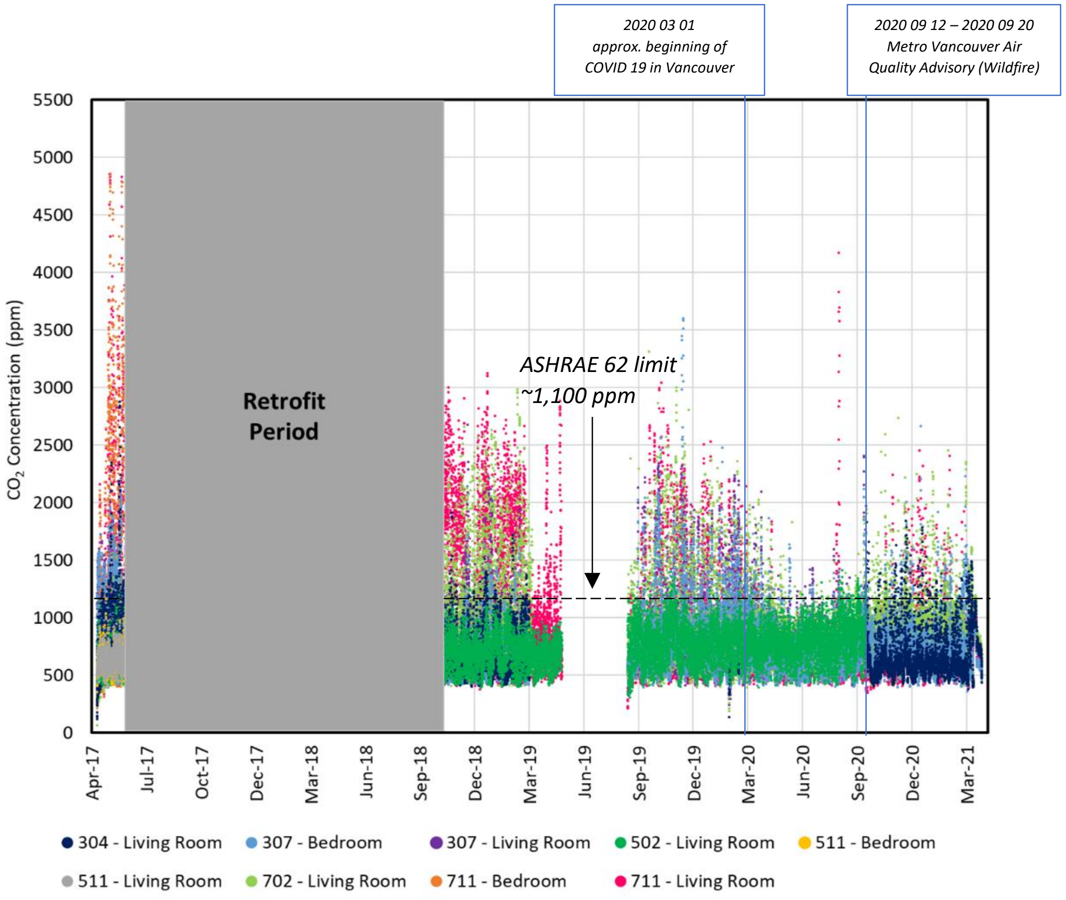
Appendix A.8 – CO$_2$ concentration one week before, during and after the 2020 wildfire air quality advisory (Building B)



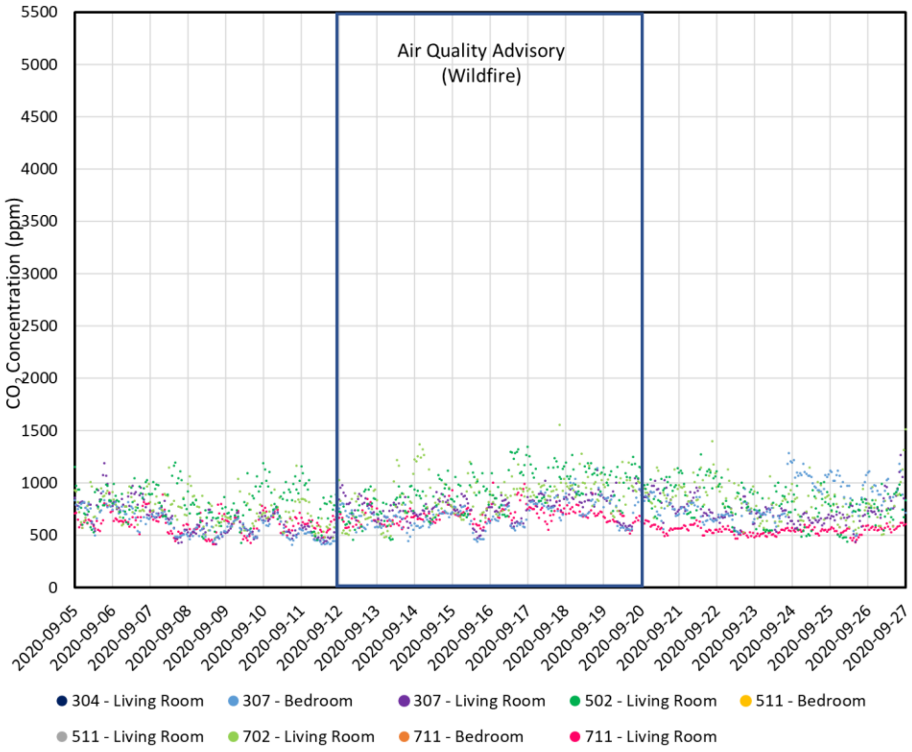
Appendix A.9 – Air temperature measurements throughout monitoring period (Building C)



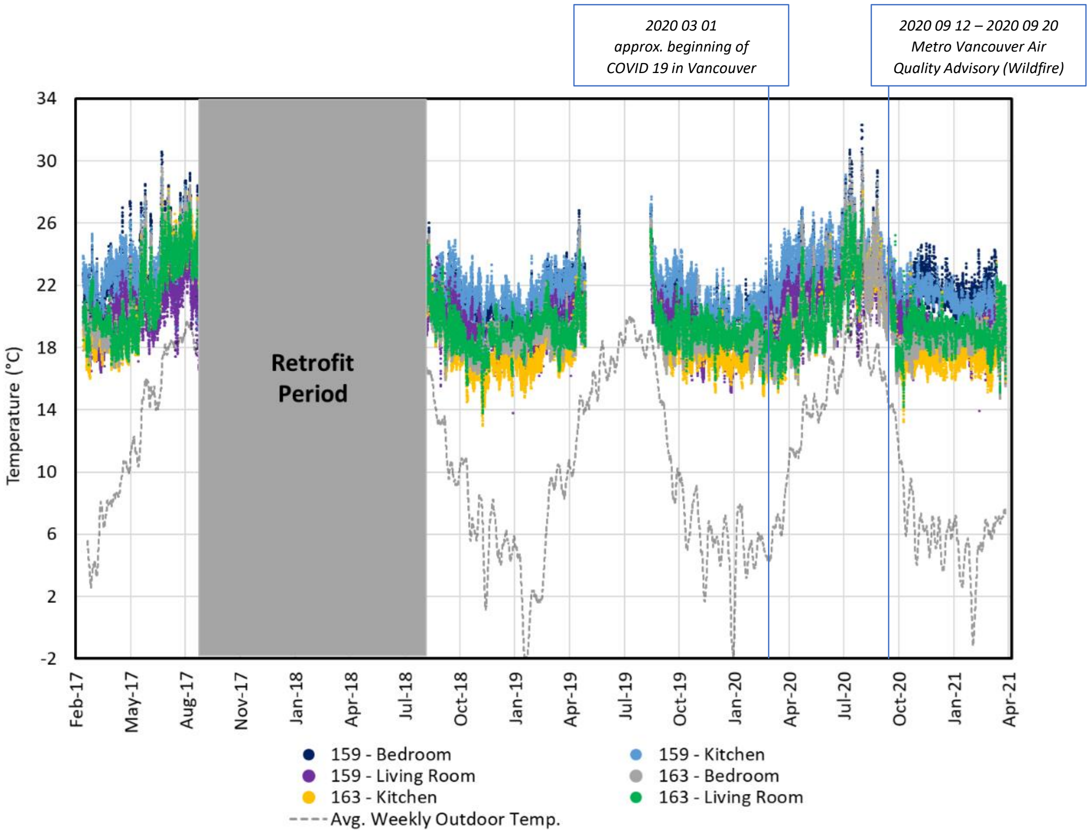
Appendix A.10 – Air temperature one week before, during and after the 2020 wildfire air quality advisory (Building C)



Appendix A.11 – CO_2 concentration measurements throughout monitoring period (Building C)



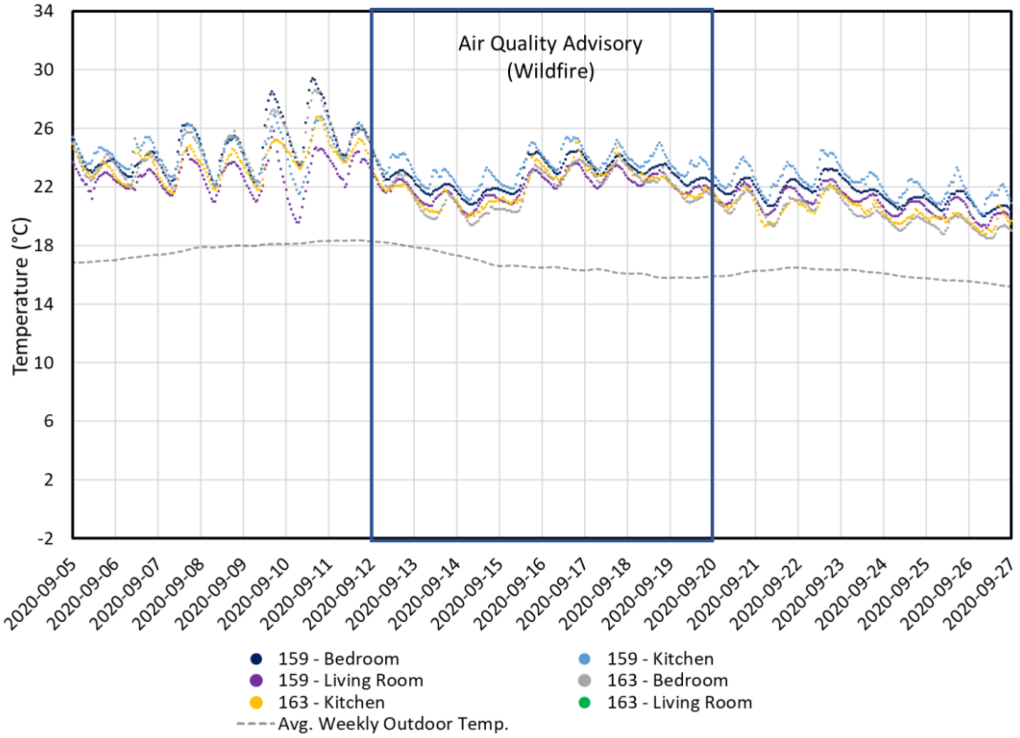
Appendix A.12 – CO_2 concentration one week before, during and after the 2020 wildfire air quality advisory (Building C)



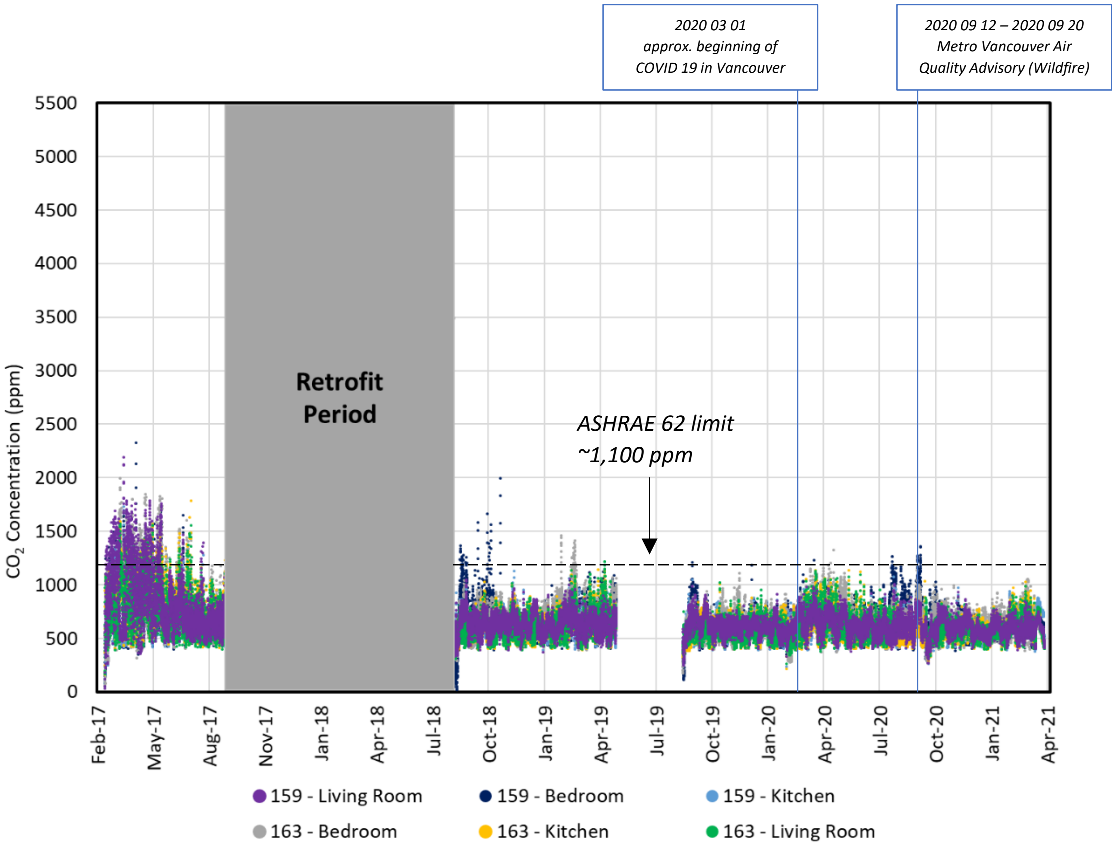
2020 03 01
approx. beginning of
COVID 19 in Vancouver

2020 09 12 – 2020 09 20
Metro Vancouver Air
Quality Advisory (Wildfire)

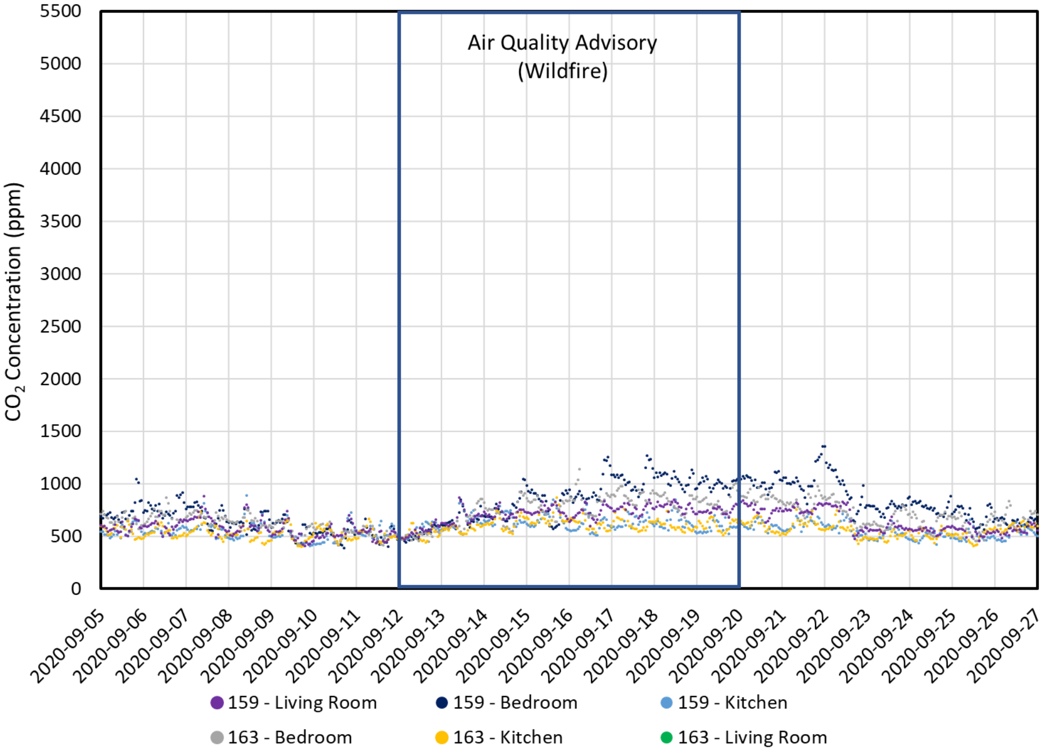
Appendix A.13 – Air temperature measurements throughout monitoring period (Building D)



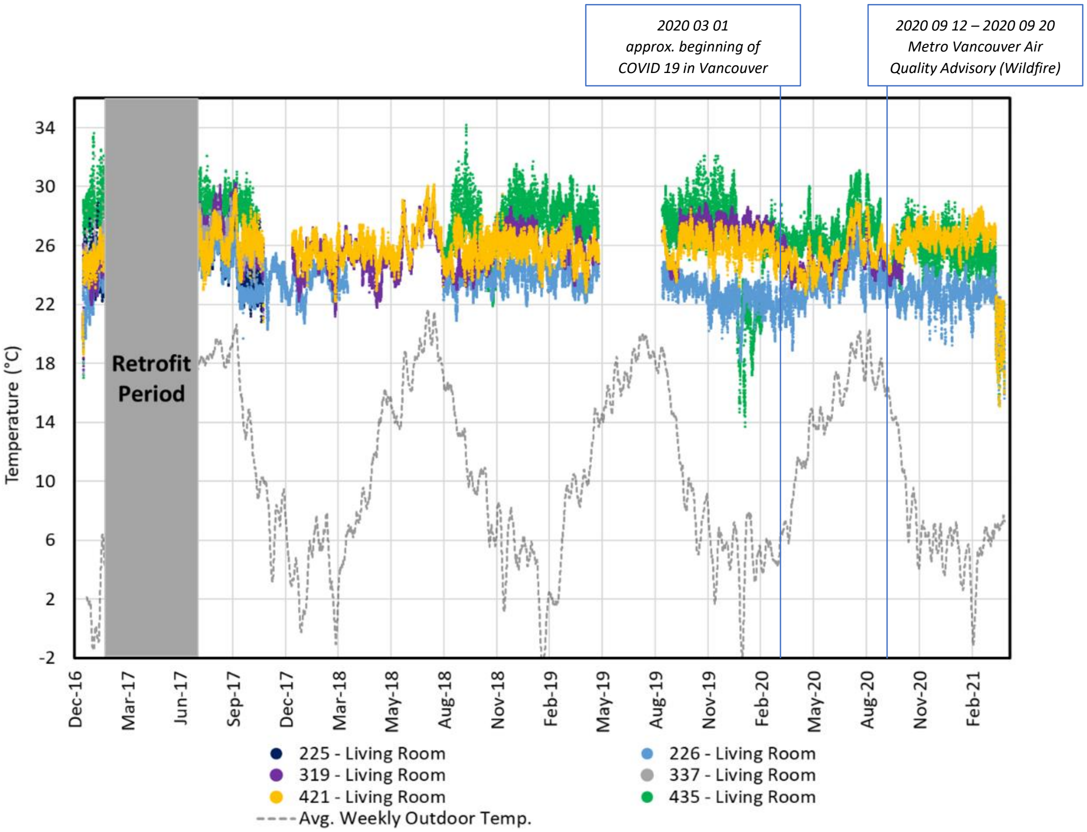
Appendix A.14 – Air temperature one week before, during and after the 2020 wildfire air quality advisory (Building D)



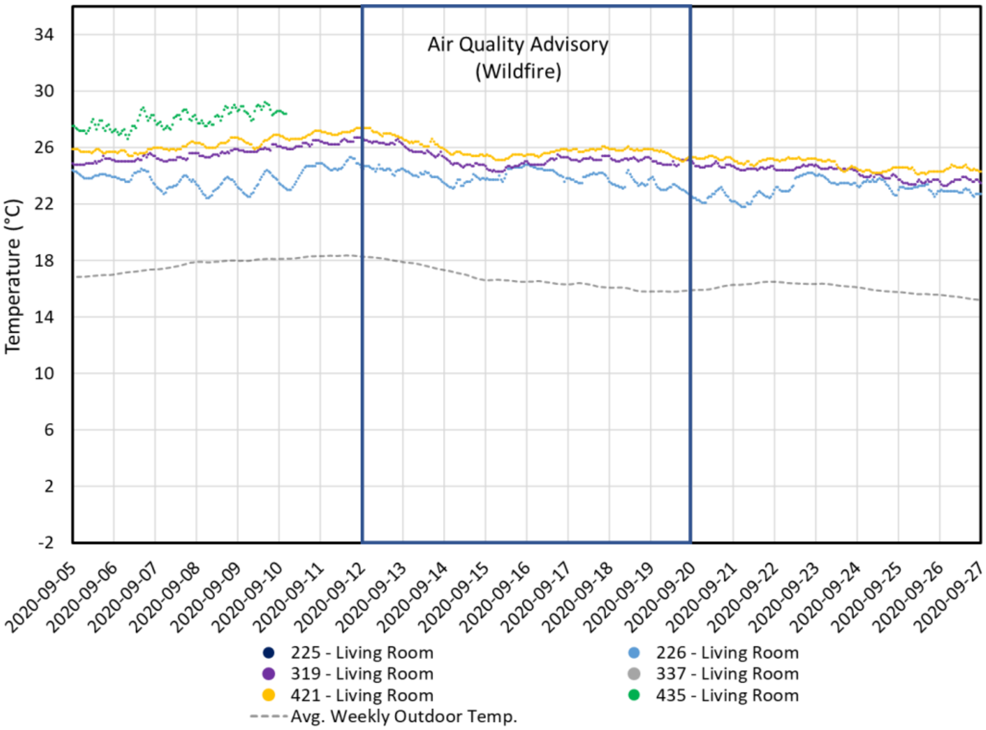
Appendix A.15 – CO_2 concentration measurements throughout monitoring period (Building D)



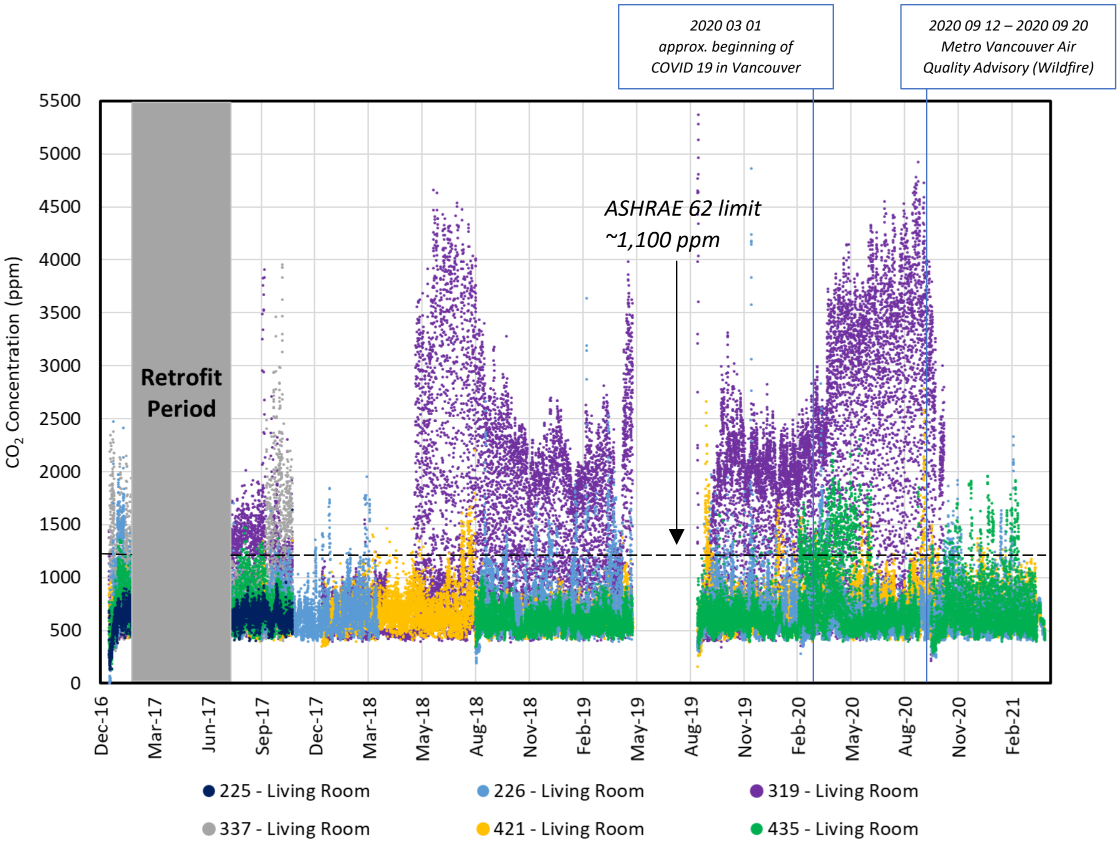
Appendix A.16 – CO_2 concentration one week before, during and after the 2020 wildfire air quality advisory (Building D)



Appendix A.17 – Air temperature measurements throughout monitoring period (Building E)



Appendix A.18 – Air temperature one week before, during and after the 2020 wildfire air quality advisory (Building E)

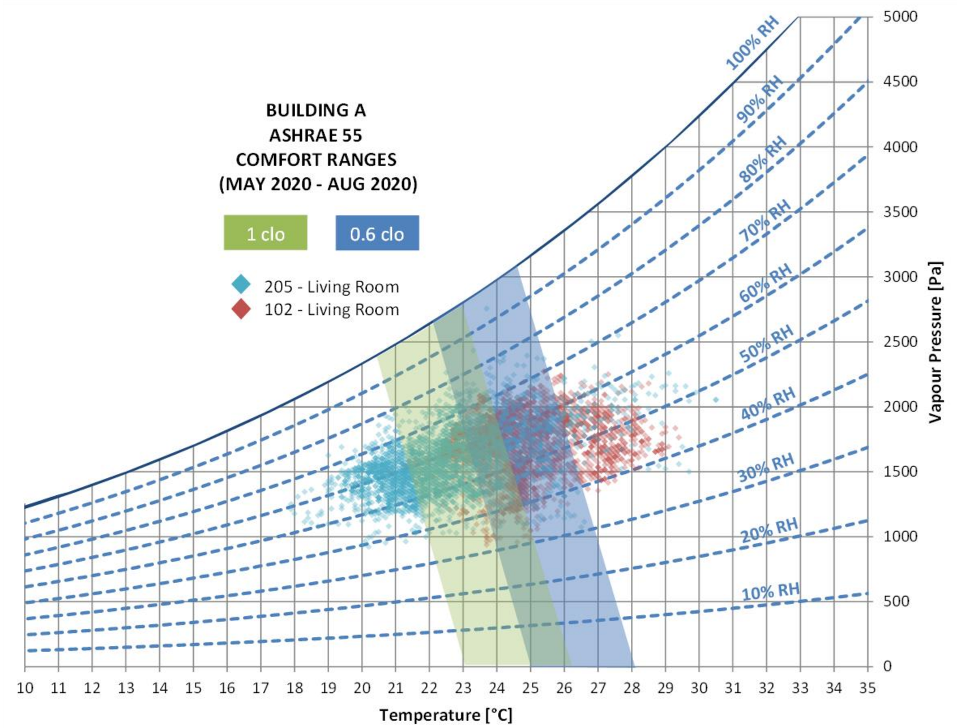


Appendix A.19 – CO_2 concentration measurements throughout monitoring period (Building E)

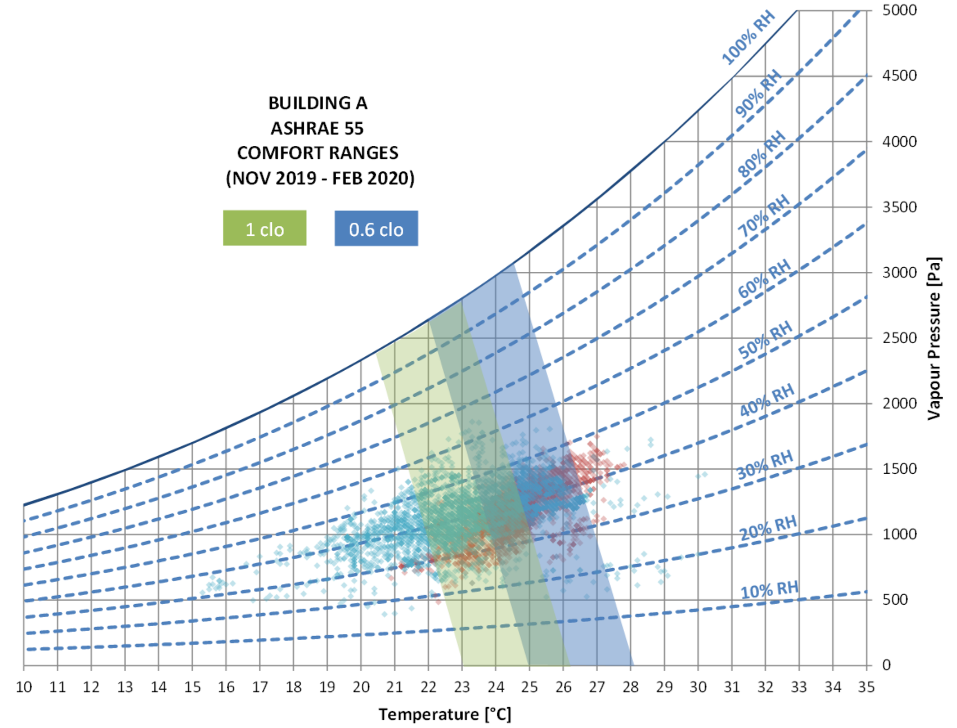
Appendix A.20 – CO_2 concentration one week before, during and after the 2020 wildfire air quality advisory (Building E)

Appendix B

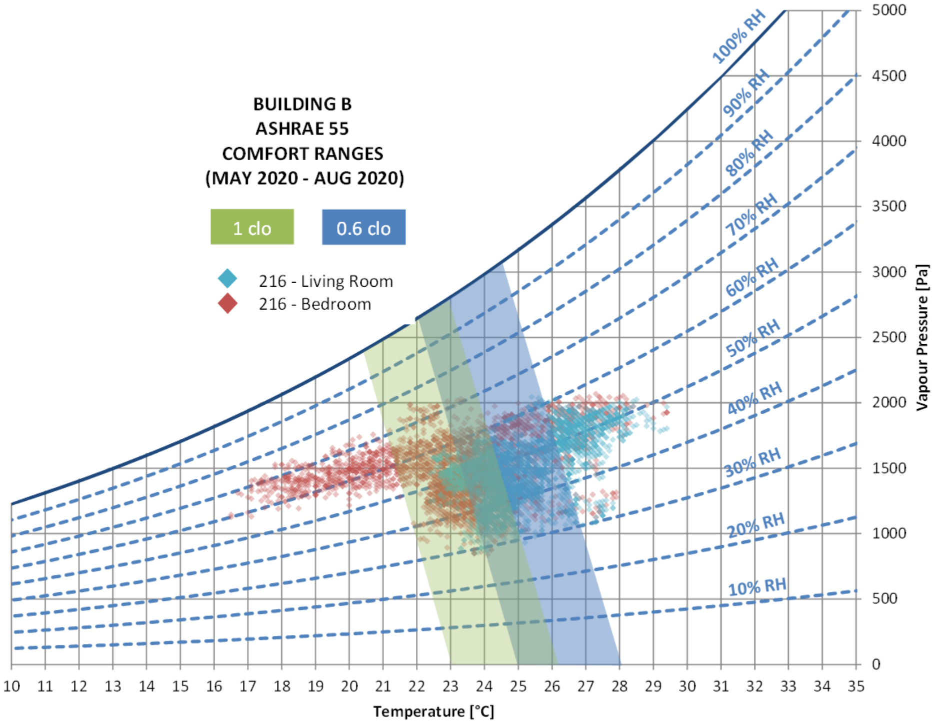
ASHRAE 55 - Psychrometric Chart Analysis



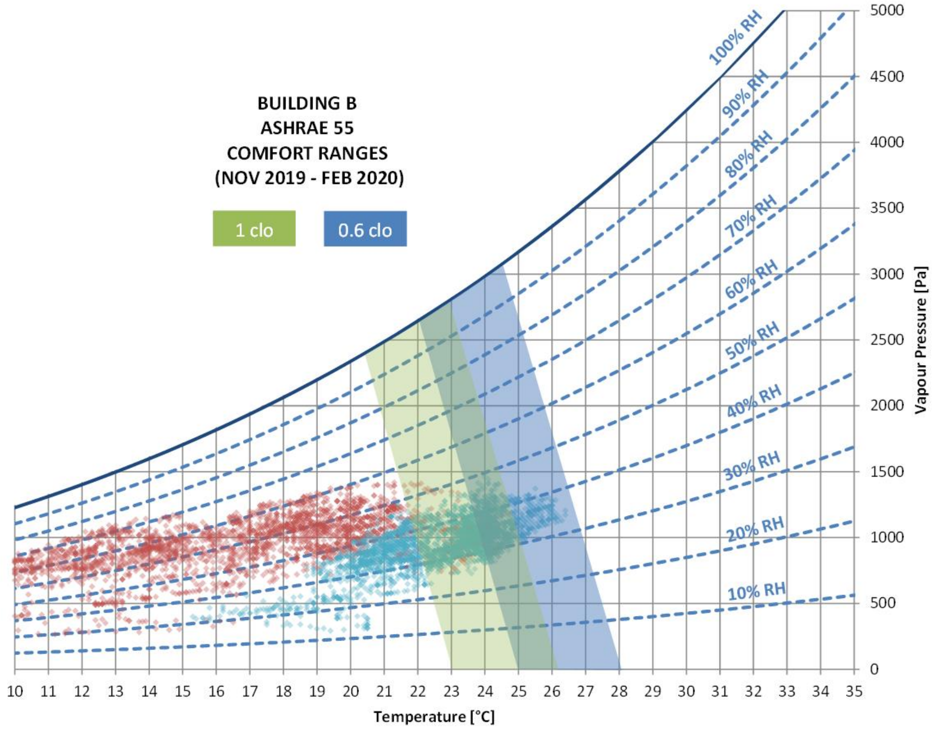
Appendix B.1 – Hourly air temperature measurements of two samples suites from Building A plotted on psychrometric chart (summer)



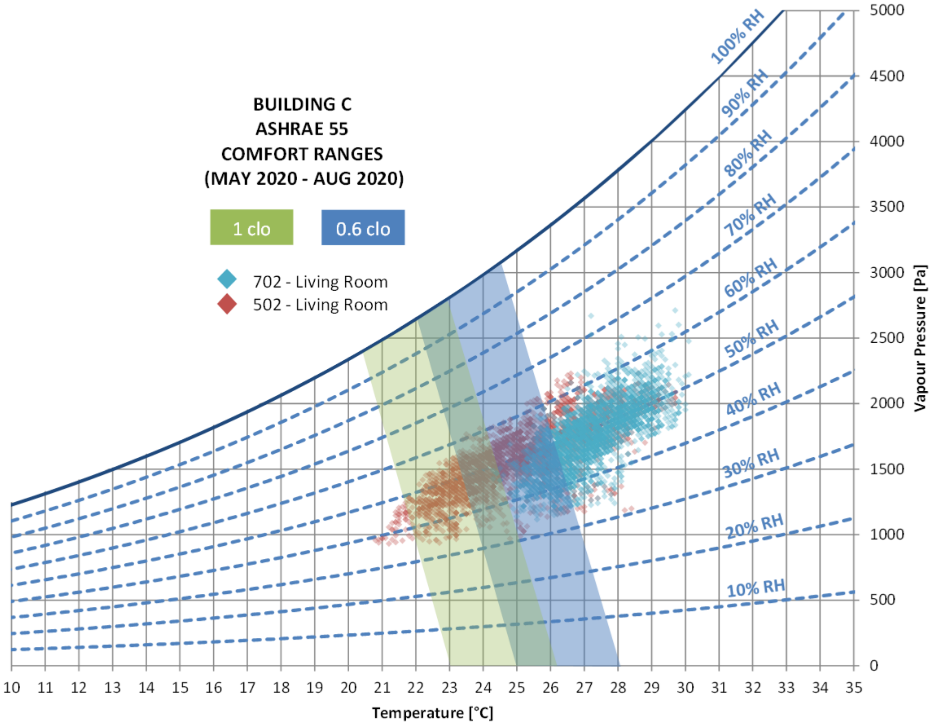
Appendix B.2 – Hourly air temperature measurements of two samples suites from Building A plotted on psychrometric chart (winter)



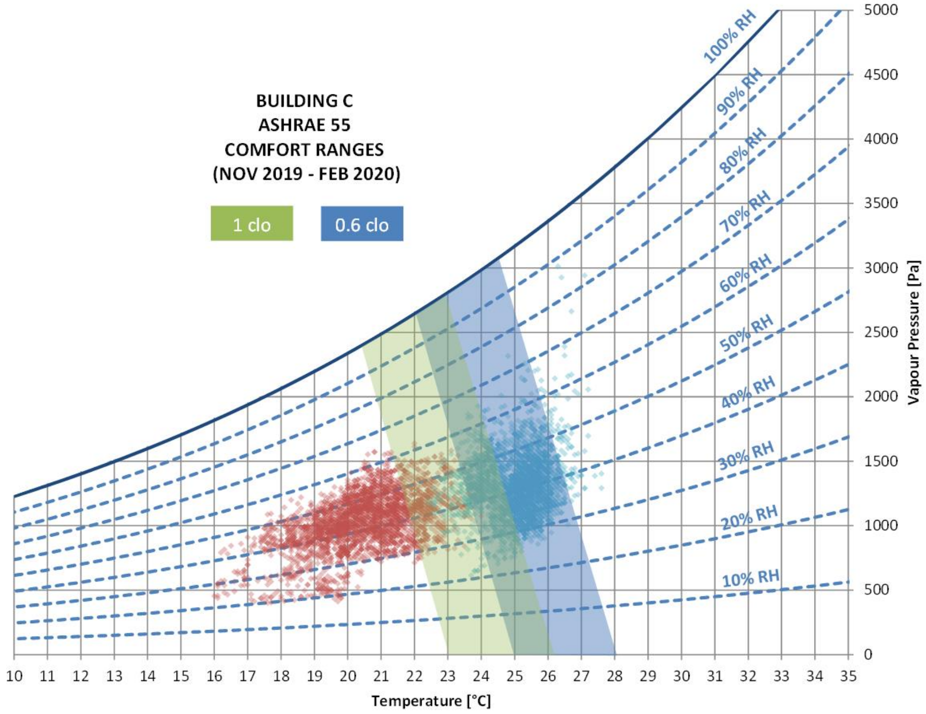
Appendix B.3 – Hourly air temperature measurements of two samples suites from Building B plotted on psychrometric chart (summer)



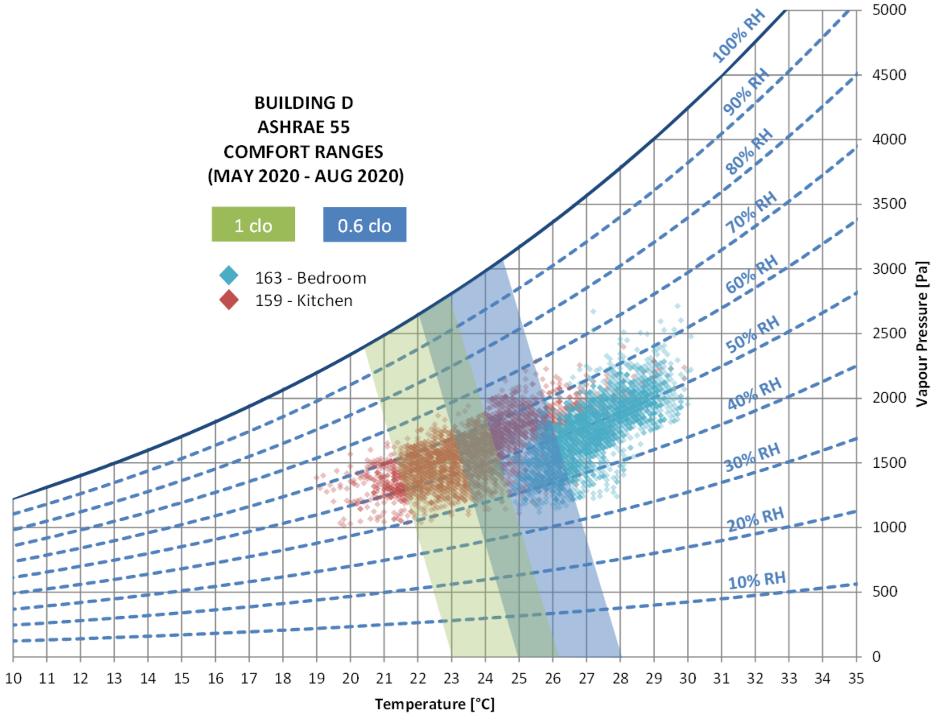
Appendix B.4 – Hourly air temperature measurements of two samples suites from Building B plotted on psychrometric chart (winter)



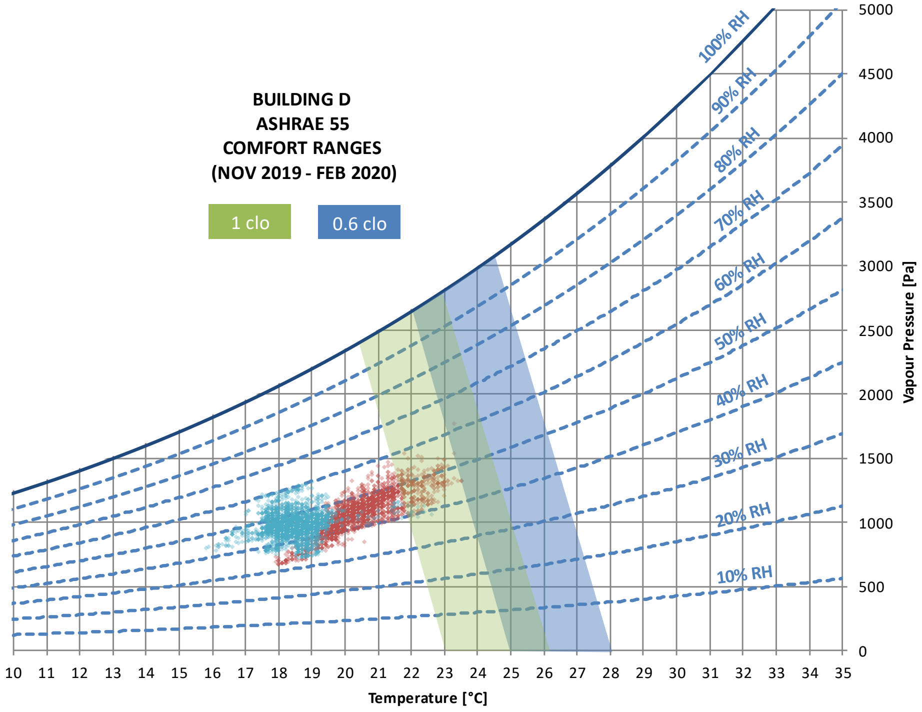
Appendix B.5 – Hourly air temperature measurements of two samples suites Building C plotted on psychrometric chart (summer)



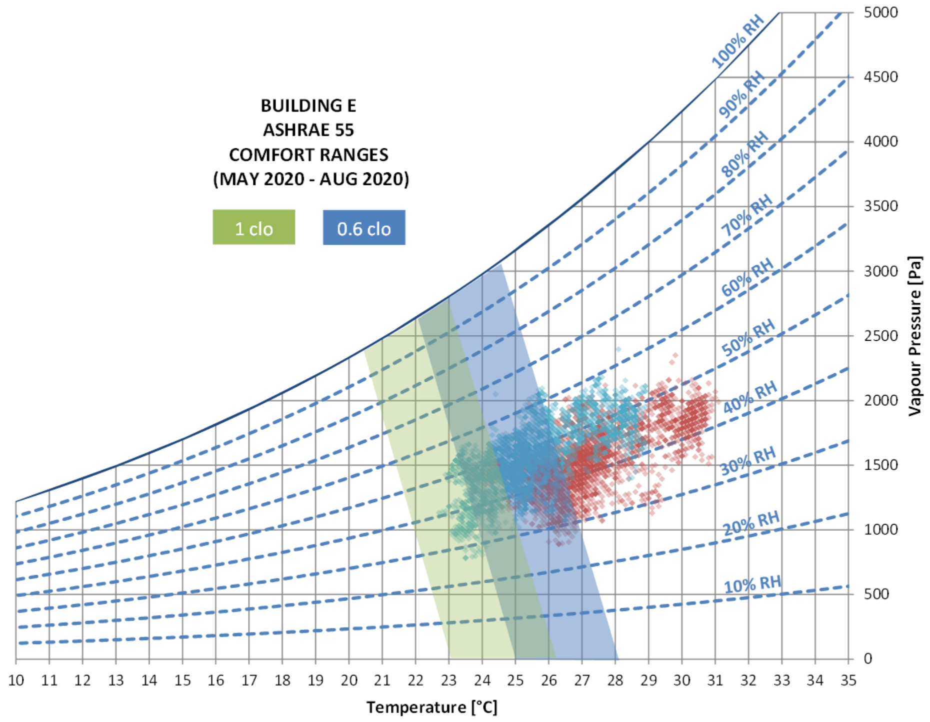
Appendix B.6 – Hourly air temperature measurements of two samples suites from Building C plotted on psychrometric chart (winter)



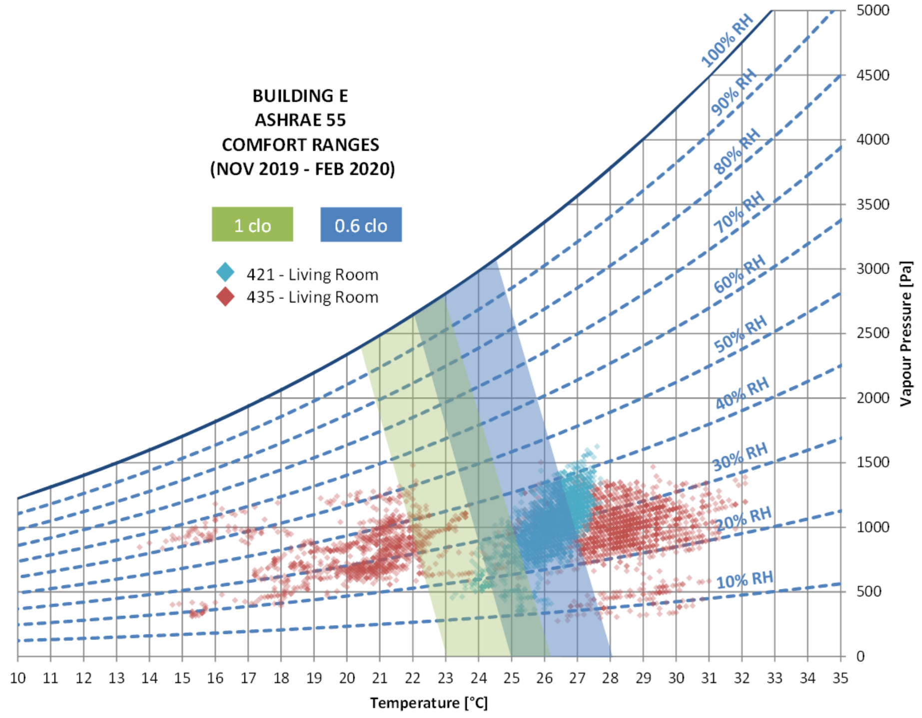
Appendix B.5 – Hourly air temperature measurements of two samples suites Building D plotted on psychrometric chart (summer)



Appendix B.6 – Hourly air temperature measurements of two samples suites from Building D plotted on psychrometric chart (winter)



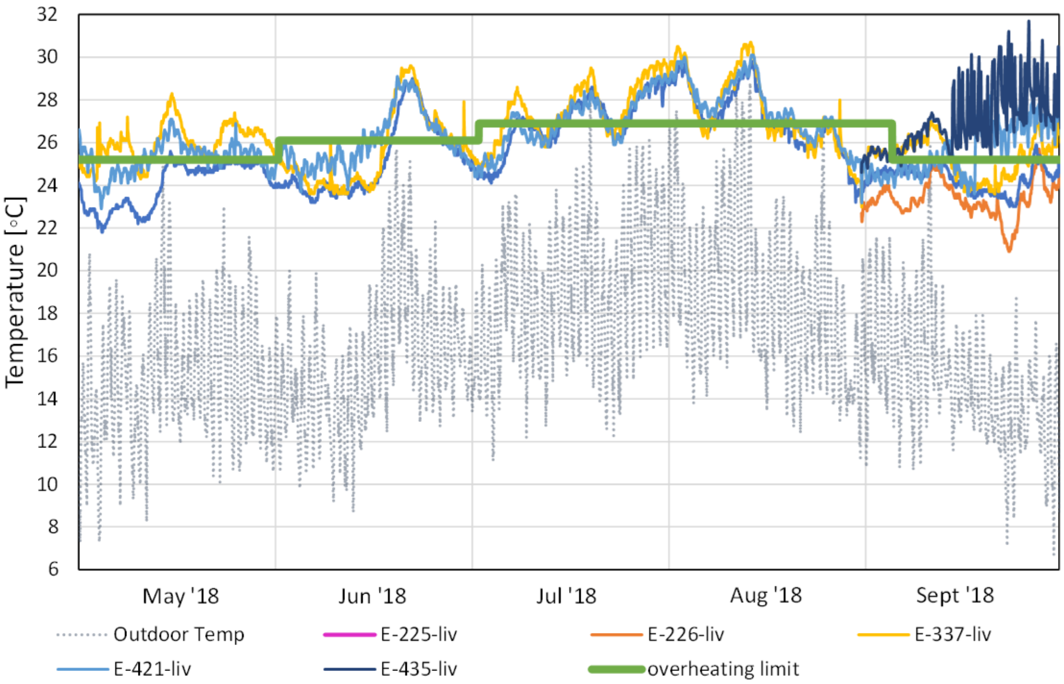
Appendix B.5 – Hourly air temperature measurements of two samples suites Building E plotted on psychrometric chart (summer)



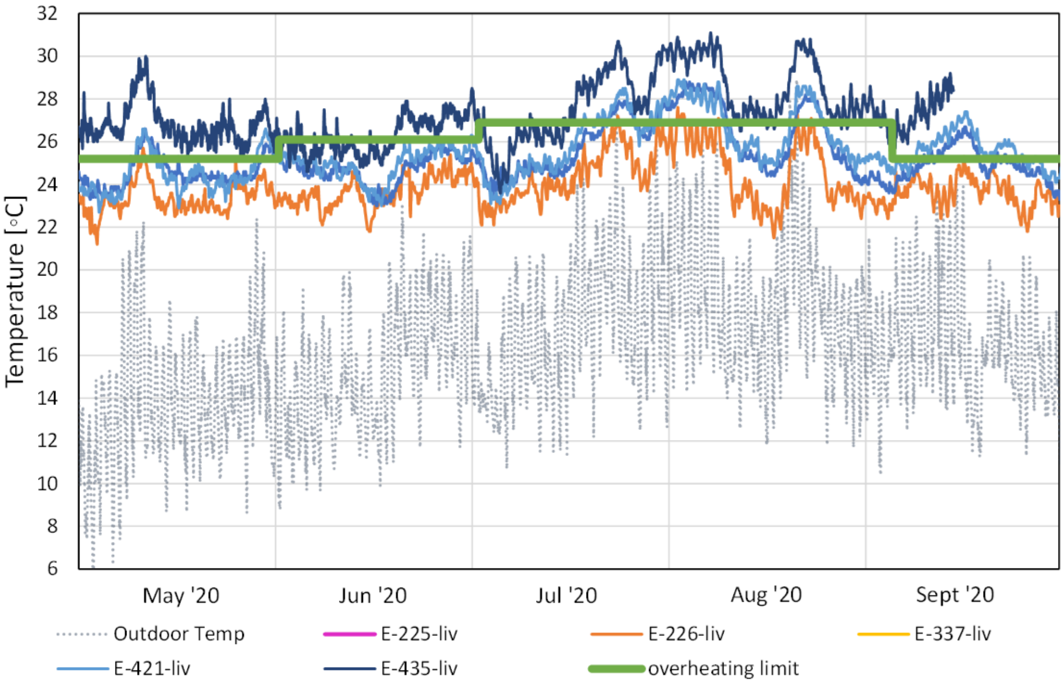
Appendix A.B – Hourly air temperature measurements of two samples suites from Building E plotted on psychrometric chart (winter)

Appendix C

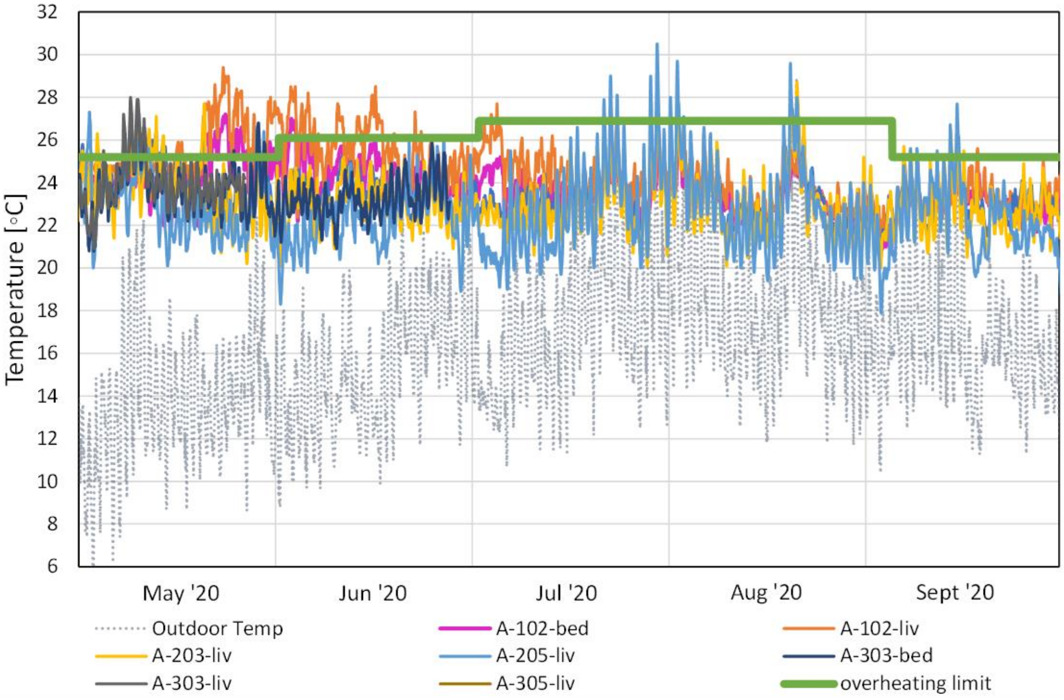
Suite Overheating Analysis



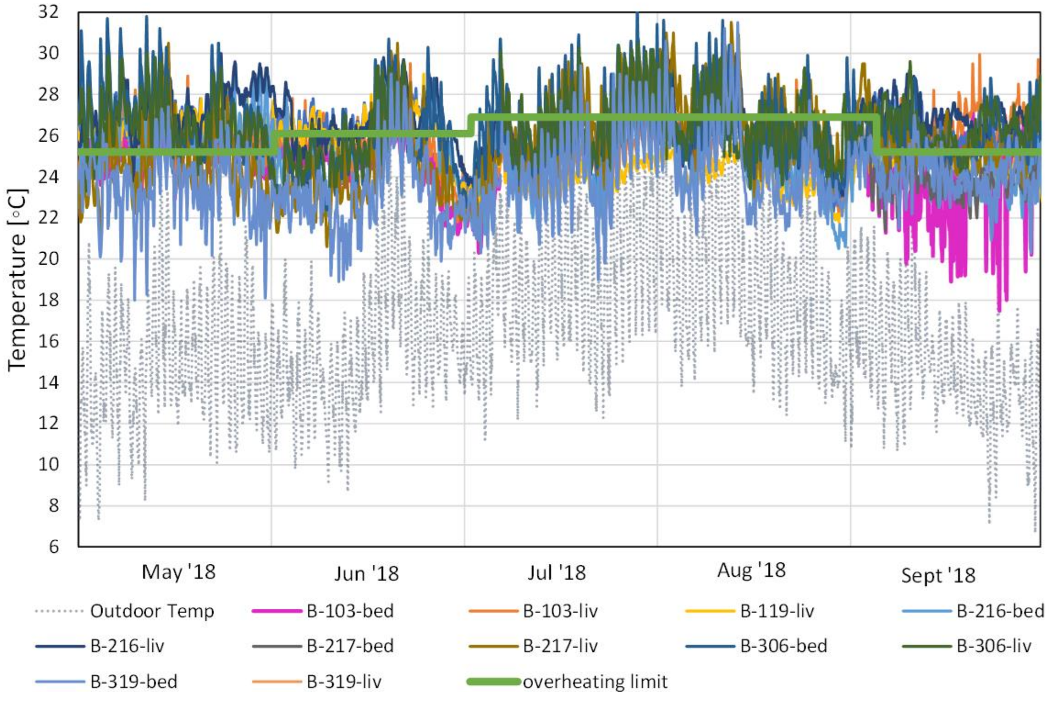
Appendix C.1 – Suite interior air temperature for Building E (2018, post-retrofit) against the summer overheating limit defined by BC Housing Design Guideline and City of Vancouver Energy Modelling Guidelines.



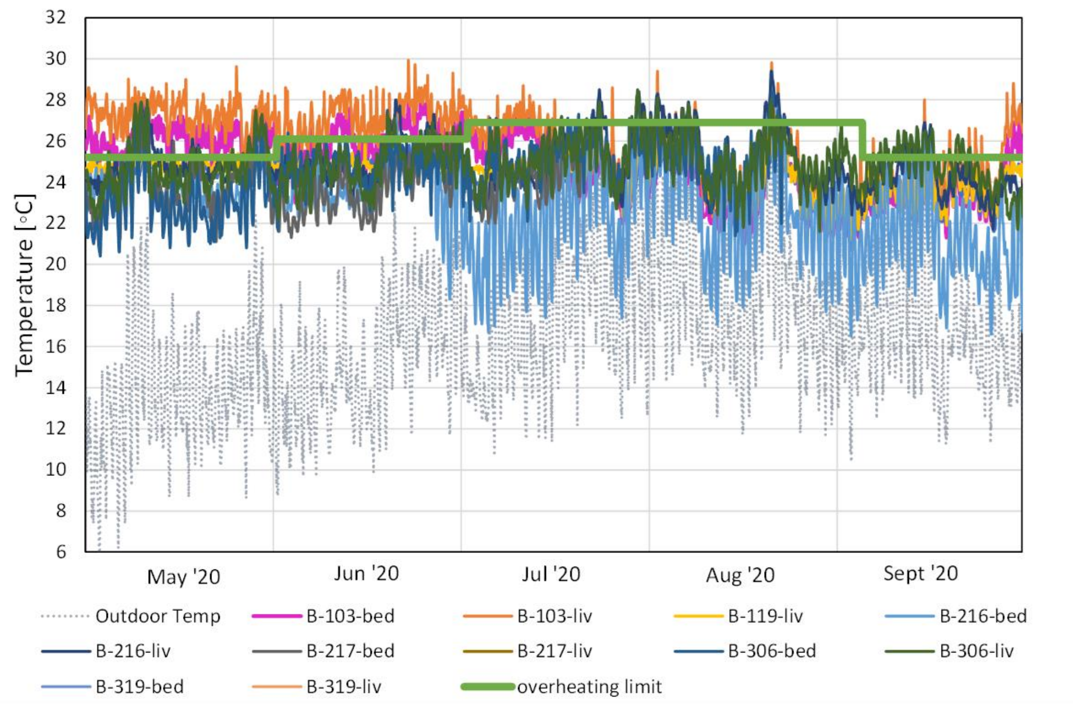
Appendix C.2 – Suite interior air temperature for Building E (2020, post-retrofit) against the summer overheating limit defined by BC Housing Design Guideline and City of Vancouver Energy Modelling Guidelines.



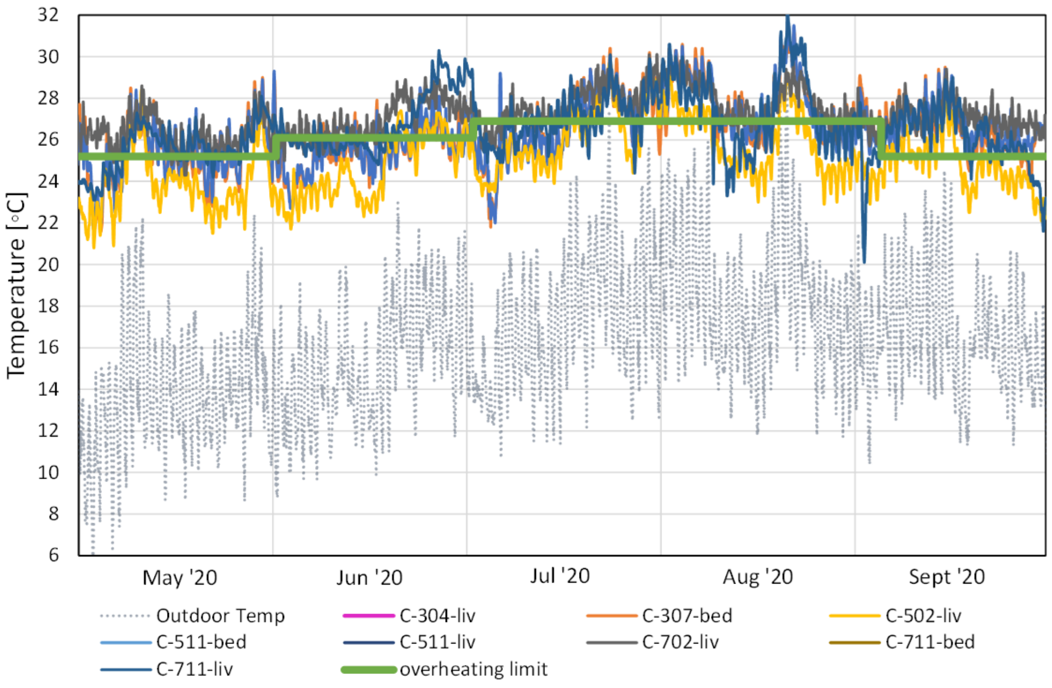
Appendix C.3 – Suite interior air temperature for Building A (2020, post-retrofit) against the summer overheating limit defined by BC Housing Design Guideline and City of Vancouver Energy Modelling Guidelines.



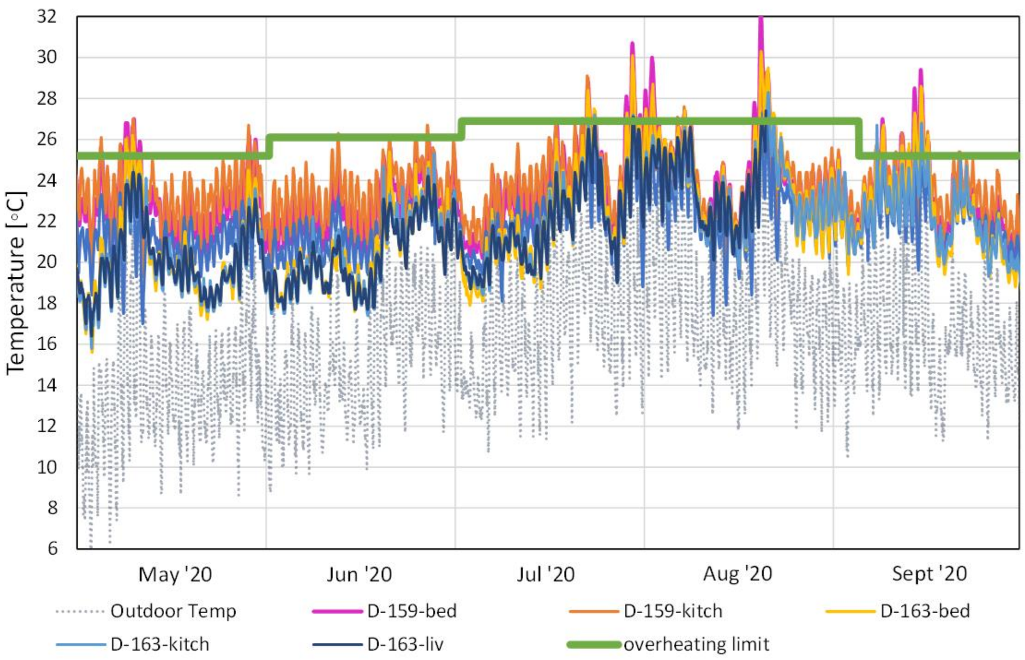
Appendix C.4 – Suite interior air temperature for Building B (2018, pre-retrofit) against the summer overheating limit defined by BC Housing Design Guideline and City of Vancouver Energy Modelling Guidelines.



Appendix C.5 – Suite interior air temperature for Building B (2020, post-retrofit) against the summer overheating limit defined by BC Housing Design Guideline and City of Vancouver Energy Modelling Guidelines.



Appendix C.6 – Suite interior air temperature for Building C (2020, post-retrofit) against the summer overheating limit defined by BC Housing Design Guideline and City of Vancouver Energy Modelling Guidelines.



Appendix C.7 – Suite interior air temperature for Building D (2020, post-retrofit) against the summer overheating limit defined by BC Housing Design Guideline and City of Vancouver Energy Modelling Guidelines.

Appendix D

Summary Tables with Values

LOCATION	avg (pre)	avg (post)	pre vs. post	2016	2017												2018												2019												2020												2021		
				DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
Outdoor	-	-	-	2	2	5	7	9	13	16	18	19	16	10	7	3	5	4	6	9	15	16	19	18	14	10	8	5	5	1	6	10	14	17	18	19	15	9	6	6	5	5	6	10	14	15	18	18	16	12	7	5	5	4	7
A-102-bed	22	23	1			21	22	23	22	23	Retrofit												23	24	23	22	23	23	23	21	23	23	24	-	-	-	-	-	-	-	-	24	23	25	24	24	24	23	23	23	-	-	-	-	-
A-102-liv	23	24	1			22	23	24	24	24													24	24	24	23	24	25	24	22	23	24	24	-	-	-	25	26	25	24	25	25	25	26	25	26	25	23	24	25	25	25	25	25	24
A-203-bed	23	24	1			22	22	22	25														26	26	25	25	24	24	24	22	24	24	24	-	-	-	-	-	-	-	-	22	23	24	24	24	24	23	23	24	24	24	26	26	25
A-203-liv	23	24	1			23	23	22	24	25													25	25	26	25	23	24	25	23	24	23	24	-	-	-	26	25	23	23	23	23	23	24	24	23	23	23	23	24	24	24	28	28	26
A-205-liv	22	22	1			21	22	22	22	23													26	24	23	22	22	20	20	19	21	22	24	-	-	-	23	23	23	23	24	23	23	23	23	22	23	22	22	-	-	-	-	-	-
A-303-bed	23	23	0			20	21	22	25	26													26	25	25	24	23	22	22	20	23	23	24	-	-	-	24	24	22	22	-	22	22	23	24	23	-	-	24	22	23	23	23	22	21
A-303-liv	23	23	0			20	21	22	25	26													27	26	25	24	23	22	23	21	23	24	25	-	-	-	25	24	22	22	22	22	22	23	24	-	-	-	25	22	23	23	23	22	21
A-305-liv	23	25	2			22	23	23	23	24													26	25	24	25	25	25	24	23	25	25	26	-	-	-	26	25	26	25	25	24	25	-	-	-	-	-	-	-	-	-	-	-	-
B-103-bed	24	24	0						23	25	25	26	25	24	24	22	23	22	23	24	25	25	22	24	24	Retrofit												26	25	24	24	23	24	25	26	26	25	23	24	24	23	23	24	23	23
B-103-liv	25	26	0						24	25	26	27	26	26	25	24	25	24	24	25	26	25	24	25	26													28	27	26	26	24	25	26	27	27	26	24	25	25	24	25	26	25	24
B-119-bed	26	23	-2						24	26	27	27	26	26	26	24	23	25	25	25	27	26	25	26	26													25	25	25	25	25	25	24	25	25	24	24	24	19	15	21	18	25	25
B-119-liv	25	24	-1						24	26	26	27	26	26	26	25	23	25	25	25	27	26	24	24	24													24	24	24	24	24	24	24	25	25	25	24	24	-	-	-	-	-	-
B-216-bed	23	19	-5						24	25	27	28	26	23	20	18	20	19	20	23	26	25	26	25	24													19	16	15	15	22	23	23	24	24	23	23	21	18	15	13	13	12	16
B-216-liv	26	23	-3						25	27	28	29	28	26	25	23	23	24	24	26	28	27	27	27	27													25	23	22	22	24	23	24	25	25	25	25	24	22	20	20	21	20	20
B-217-bed	26	23	-3						25	26	27	27	27	-	-	-	-	-	-	-	-	-	-	25	24													23	22	23	23	22	23	23	24	24	24	-	24	24	-	-	-	-	-
B-217-liv	24	24	0						25	25	26	26	25	23	24	21	22	23	24	23	25	24	26	27	26													25	-	-	-	23	23	-	-	-	-	-	25	24	25	25	25	25	22
B-306-bed	26	24	-2						26	26	27	27	27	26	26	23	23	26	26	27	27	25	27	26	26													24	24	23	24	23	23	23	23	25	25	25	27	26	26	25	25	25	23
B-306-liv	26	24	-2						26	26	27	27	27	26	26	23	21	26	26	26	27	26	27	26	27													-	-	-	-	24	24	24	25	25	25	25	25	24	23	23	23	23	22
B-319-bed	24	22	-1						23	24	25	25	24	23	23	22	22	24	23	23	24	23	24	24	24													-	-	-	-	-	-	-	-	-	-	-	24	23	22	22	22	22	22
B-319-liv	25	23	-2						20	24	26	26	26	25	25	24	26	-	-	-	-	-	-	-	-													-	-	-	-	-	-	-	-	-	-	-	-	24	24	23	23	23	22
C-304-liv	25	25	0					24	25	27	Retrofit																25	25	25	25	25	-	-	-	-	-	-	-	-	-	-	25	25	-	-	-	-	-	28	26	25	25	25	25	23
C-307-bed	25	26	1					24	25	26																	25	24	25	25	26	-	-	-	-	-	26	26	26	26	26	26	26	26	25	26	27	28	26	25	27	27	26	25	24
C-307-liv	24	25	1					24	25	24																	24	24	24	24	25	-	-	-	-	-	26	26	25	26	25	26	26	25	25	26	27	28	27	-	-	-	-	-	-
C-502-liv	21	22	1					20	22	23																	21	21	21	20	21	22	24	-	-	-	24	22	20	20	21	21	21	23	24	25	26	26	25	-	-	-	-	-	-
C-511-bed	24	-	-					24	25	25																	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C-511-liv	25	-	-					24	25	26																	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C-702-liv	25	26	0					24	26	26																	24	24	24	24	25	-	-	-	-	-	25	24	24	25	25	26	26	26	26	27	28	28	27	26	25	25	24	24	23
C-711-bed	23	-	-					21	23	24																	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C-711-liv	23	23	0					21	23	25																	20	20	20	20	22	23	25	-	-	-	24	21	20	22	22	22	23	24	26	27	27	27	26	24	23	23	23	23	22
D-159-bed	23	21	-2			21	21	22	23	23	24	25	23	Retrofit											21	21	21	20	20	20	21	21	22	-	-	-	22	21	20	20	20	20	21	22	23	23	24	24	23	21	22	21	21	21	21
D-159-kitch	23	22	-1			22	22	23	23	23	24	24	23												22	22	21	21	21	20	21	22	22	-	-	-	22	22	21	20	20	20	21	23	23	23	24	24	23	21	22	22	21	21	20
D-159-liv	21	20	-1			19	19	20	21	21	22	23	21												20	20	19	18	18	18	19	20	21	-	-	-	21	20	19	18	18	18	19	21	21	22	22	22	22	20	19	19	19	18	19
D-163-bed	22	19	-2			19	19	19	21	22	25	25	23												21	19	17	18	18	18	19	19	20	-	-	-	20	19	18	19	19	18	18	19	20	21	23	24	22	18	18	19	18	19	19
D-163-kitch	21	19	-2			18	18	18	20	22	24	25	23												21	18	17	16	17	17	18	18	20	-	-	-	20	18	18	18	17	17	17	18	20	20	22	23	22	18	17	17	17	18	18
D-163-liv	21	20	-2			19	20	19	20	22	24	25	23												21	19	18	18	19	19	20	19	20	-	-	-	21	19	19	19	19	19	18	18	20	20	22	23	23	19	20	19	19	19	19
E-225-liv	24	25	1	24	24	24	Retrofit				25	25	24	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E-226-liv	23	24	0	22	23	25					25	25	24	23	24	23	24	24	24	-	-	-	-	23	23	24	24	24	24	24	24	23	24	-	-	-	24	23	23	22	22	22	22	22	23	24	25	24	24	23	23	23	23	23	22
E-319-liv	25	26	0	24	24	28					28	28	26	25	-	24	26	25	26	25	24	25	27	27	24	25	26	27	27	26	27	25	26	-	-	-	25	27	28	28	27	27	26	24	25	25	26	26	25	25	-	-	-	-	-
E-337-liv	25	26	1	24	26	26					27	27	26	25	-	24	25	25	26	26	26	26	28	27	25	26	26	26	26	26	27	26	27	-	-	-	25	24	26	26	25	25	-	-	-	-	-	-	24	25	27	27	26	25	24
E-421-liv	25	26	1	24	25	26					26	27	27	26	-	26	26	25	26	26	25	26	27	27	26	26	26	26	26	25	26	25	26	-	-	-	25	27	26	26	26	26	25	25	25	25	26	26	26	26	27	27	27	27	25
E-435-liv	28	27	-1	28	29	29					29	29	29	27	-	-	-	-	-	-	-	-	-	25	27	28	25	28	28	28	28	28	28	-	-	-	28	28	28	29	22	22	26	26	27	26	28	28	27	26	26	26	26	25	24

Appendix D.1 – Summary table: average monthly temperature in degrees Celsius

LOCATION	avg (pre)	avg (post)	pre vs. post	2016	2017												2018												2019												2020												2021			
				DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR
A-102-bed	47	49	2			42	47	47	49	52	Retrofit												58	61	59	53	49	41	45	38	40	44	46	.	.	.	.	.	.	.	.	40	38	38	45	54	58	62	63	59	.	.	.	.	.	.
A-102-liv	44	44	-1			40	44	43	46	48													56	60	55	49	46	37	41	34	38	42	44	.	.	.	53	39	38	38	37	36	33	35	42	50	54	60	61	48	41	39	37	31	33	38
A-203-bed	43	39	-4			45	43	40	42	46													50	53	46	39	41	36	37	33	33	36	27	.	.	.	.	.	.	.	.	33	30	32	41	51	55	58	57	44	37	35	29	23	26	36
A-203-liv	39	38	-1			37	38	37	40	44													50	54	46	39	39	33	34	28	30	35	40	.	.	.	48	35	34	34	33	31	28	31	41	51	55	58	57	43	36	34	28	21	24	34
A-205-liv	45	49	4			40	43	42	48	50													52	55	55	54	52	44	50	42	47	45	46	.	.	.	60	45	42	41	38	39	38	40	50	58	60	62	63	.	.	.	.	.	.	.
A-303-bed	44	43	-2			43	44	45	43	46													51	54	50	44	43	39	40	32	33	39	39	.	.	.	56	39	40	42	.	39	36	35	42	51	.	.	59	52	45	42	40	36	37	39
A-303-liv	45	43	-2			43	45	46	43	46													49	52	49	44	43	38	40	34	35	40	42	.	.	.	55	40	42	43	39	40	37	37	43	.	.	.	57	52	47	44	43	39	39	40
A-305-liv	43	43	0			42	43	42	44	46													50	55	52	47	46	40	42	39	38	39	41	.	.	.	53	41	38	41	40	38	38	.	.	.	.	.	.	.	.	.	.	.	.	.
B-103-bed	45	40	-5						48	48	51	53	49	43	38	35	39	35	37	40	45	48	56	53	53	Retrofit												35	34	36	34	33	31	33	40	47	54	61	59	46	41	40	36	32	34	40
B-103-liv	44	38	-6						46	46	49	51	47	40	36	34	37	34	35	38	44	46	56	56	49													33	32	34	32	31	29	31	38	45	52	58	57	44	38	38	34	30	32	38
B-119-bed	42	44	1						46	47	48	51	47	39	35	32	38	30	31	34	41	44	55	56	48													41	37	36	35	32	30	34	44	50	56	60	61	57	57	44	47	33	34	39
B-119-liv	43	42	-1						46	47	48	51	47	39	34	32	38	30	30	34	41	43	60	61	50													40	38	37	35	33	30	34	42	49	54	58	59	.	.	.	.	.	.	.
B-216-bed	44	51	7						44	46	44	47	47	43	41	40	44	36	38	39	40	43	51	54	51													49	50	55	52	37	30	34	43	51	58	60	64	57	56	60	59	52	49	44
B-216-liv	39	40	1						40	41	42	45	42	37	34	33	38	28	31	33	37	40	47	49	45													34	34	36	35	33	29	32	39	46	49	52	54	47	43	42	36	34	37	39
B-217-bed	48	48	-1						42	44	45	50	52	.	.	.	.	.	.	.	.	.	.	51	55													46	46	44	42	42	37	38	47	54	55	.	59	61	.	.	.	.	.	.
B-217-liv	47	45	-2						44	47	48	53	52	51	46	43	45	43	41	44	46	50	51	51	49													46	.	.	.	41	36	.	.	.	.	.	58	48	42	40	38	35	66	.
B-306-bed	39	37	-1						39	42	43	47	45	37	33	34	37	26	27	30	37	42	45	49	45													38	36	37	34	33	32	35	42	47	49	52	49	39	32	32	30	27	31	38
B-306-liv	40	40	0						39	43	44	48	45	37	32	33	43	28	30	33	39	42	47	51	47													.	.	.	.	33	30	33	41	48	50	53	53	45	38	37	35	31	34	38
B-319-bed	46	45	-1						44	47	50	54	52	45	40	38	42	38	38	40	47	50	54	56	53													.	.	.	.	.	.	.	.	.	.	.	58	51	43	44	41	38	39	41
B-319-liv	43	42	-1						51	46	47	50	46	41	36	34	32	.	.	.	.	.	.	.	.													.	.	.	.	.	.	.	.	.	.	.	.	52	41	43	39	38	38	40
C-304-liv	43	35	-8					43	48	39	Retrofit																42	38	37	26	30	.	.	.	.	.	.	.	.	.	.	30	32	.	.	.	.	.	46	40	34	34	33	29	34	39
C-307-bed	46	37	-9					43	47	48																	39	34	33	23	26	.	.	.	.	.	51	40	34	35	33	31	29	31	40	47	48	47	49	42	33	32	33	29	35	40
C-307-liv	46	38	-8					44	47	47																	41	35	35	24	28	.	.	.	.	.	50	39	35	37	34	31	29	31	40	47	48	47	48	.	.	.	.	.	.	.
C-502-liv	48	45	-4					46	48	50																	50	42	42	33	38	44	43	.	.	.	56	46	46	45	41	39	35	37	45	50	50	53	55	.	.	.	.	.	.	.
C-511-bed	40	-	-					37	40	44																	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
C-511-liv	40	-	-					37	39	43																	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
C-702-liv	49	45	-3					45	49	51																	52	48	49	41	43	.	.	.	.	.	56	47	46	43	40	36	34	36	44	48	49	52	53	49	44	43	42	37	39	41
C-711-bed	56	-	-					51	58	60																	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
C-711-liv	54	46	-8					50	56	57																	63	52	55	47	44	43	43	.	.	.	57	50	50	45	40	39	36	37	40	43	47	48	50	45	40	41	38	34	35	41
D-159-bed	47	48	1			40	42	44	46	50	49	53	54	Retrofit											58	52	50	45	45	36	38	44	47	.	.	.	61	49	47	47	44	44	41	41	48	55	55	56	59	56	44	43	44	39	41	41
D-159-kitch	48	48	0			39	40	42	46	51	52	57	56												59	52	49	43	44	36	38	44	48	.	.	.	61	47	45	46	44	44	41	41	48	54	56	58	60	55	45	43	45	40	42	42
D-159-liv	54	52	-2			48	49	50	52	56	57	61	60												61	55	54	49	50	41	41	48	51	.	.	.	65	52	51	52	50	49	45	44	52	58	60	61	63	59	50	48	49	44	46	43
D-163-bed	51	51	1			43	48	52	52	53	51	53	53												59	56	55	48	48	40	40	48	50	.	.	.	65	53	49	46	44	46	45	46	53	60	59	57	61	61	51	48	49	44	45	43
D-163-kitch	52	54	2			46	49	54	53	54	51	54	54												60	59	59	54	52	44	43	53	53	.	.	.	65	56	51	49	50	49	47	49	55	62	61	58	62	63	54	53	52	47	49	45
D-163-liv	51	51	0			42	45	52	53	54	52	55	55												57	54	54	48	45	37	38	49	51	.	.	.	64	51	47	45	45	43	43	46	53	61	61	57	65	59	47	46	46	42	45	43
E-225-liv	27	46	19	26	25	31	Retrofit				46	52	48	39	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
E-226-liv	32	42	10	34	33	29					48	52	51	45	35	31	35	31	30	.	.	.	.	54	54	44	39	36	34	26	29	41	42	.	.	.	55	43	39	40	38	36	37	38	45	52	53	54	56	50	41	38	37	32	34	39
E-319-liv	27	48	21	25	23	32					47	50	48	39	.	25	31	26	28	29	46	51	54	55	61	53	48	38	38	33	38	44	55	.	.	.	69	52	49	48	47	47	46	53	61	67	70	69	72	65	.	.	.	.	.	.
E-337-liv	38	43	5	41	33	40					44	48	47	43	.	35	39	36	35	37	45	47	47	49	54	48	46	42	42	32	34	43	48	.	.	.	57	46	42	37	37	37	.	.	.	.	.	.	56	42	31	30	29	25	28	38
E-421-liv	27	36	9	29	25	28					45	48	43	34	.	24	30	26	28	30	40	40	44	48	46	39	35	28	29	20	25	33	38	.	.	.	52	33	30	31	30	28	28	33	41	49	49	49	53	41	31	32	31	26	31	39
E-435-liv	25	34	9	25	23	25					37	42	37	32	.	.	.	.	.	.	.	.	.	48	41	33	34	24	24	15	21	27	32	.	.	.	42	30	26	25	34	32	29	33	37	44	44	44	46	40	32	33	32	29	31	38

Appendix D.2 – Summary table: average monthly relative humidity in percent

LOCATION	2016	2017												2018												2019												2020												2021			
	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR
A-102-bed			8	10	11	11	12	Retrofit												15	16	15	12	12	9	11	6	8	10	12	-	-	-	-	-	-	-	-	9	8	9	12	14	15	15	16	14	-	-	-	-	-	-
A-102-liv			8	10	11	11	12													15	16	14	12	12	9	10	5	8	10	11	-	-	-	14	11	10	9	9	9	7	9	12	14	15	15	15	13	10	10	10	7	7	5
A-203-bed			9	9	8	11	12													15	15	13	10	9	8	9	5	6	8	3	-	-	-	-	-	-	-	-	5	4	6	10	13	14	14	14	11	8	8	7	3	4	4
A-203-liv			7	7	7	10	12													14	15	13	10	8	7	8	4	5	7	10	-	-	-	14	8	6	7	6	5	3	6	10	12	14	14	14	11	8	7	7	3	4	3
A-205-liv			7	9	8	10	12													15	14	13	12	11	7	10	5	9	10	12	-	-	-	15	10	9	9	8	8	7	8	12	14	15	15	15	-	-	-	-	-	-	-
A-303-bed			7	8	10	11	13													15	15	13	11	10	7	8	3	6	9	9	-	-	-	15	9	7	8	-	7	6	7	10	13	-	-	16	11	10	9	8	6	6	6
A-303-liv			7	9	10	11	13													15	15	14	11	10	7	8	4	7	9	11	-	-	-	15	9	8	9	7	7	7	8	11	-	-	-	16	12	11	10	9	7	6	6
A-305-liv			9	9	9	10	11													15	15	14	13	12	10	10	8	9	10	11	-	-	-	15	11	10	11	10	9	9	-	-	-	-	-	-	-	-	-	-	-	-	-
B-103-bed						11	13	14	16	14	10	8	6	8	5	7	9	12	13	13	14	14	Retrofit												9	8	8	8	6	5	7	11	14	15	15	15	12	9	9	8	5	6	6
B-103-liv						12	13	15	16	14	11	9	7	9	6	8	9	13	13	15	16	15													10	8	9	8	6	6	8	12	14	15	15	16	12	9	9	9	6	7	5
B-119-bed						12	14	15	16	14	11	9	6	8	6	7	9	13	13	16	16	14													10	9	9	8	7	6	8	12	14	15	15	15	10	7	8	6	7	8	5
B-119-liv						11	13	14	16	14	11	9	7	8	6	6	8	12	13	16	16	13													10	9	8	8	7	6	7	11	13	15	15	15	-	-	-	-	-	-	-
B-216-bed						10	12	13	15	13	10	6	4	7	3	5	8	12	12	15	15	14													7	6	6	5	7	5	6	10	13	14	14	14	9	6	5	5	2	5	7
B-216-liv						11	12	14	15	14	10	7	5	8	4	6	8	12	12	15	15	14													8	6	6	6	7	4	6	10	13	14	14	14	10	7	6	6	3	5	5
B-217-bed						11	13	14	16	16	-	-	-	-	-	-	-	-	-	-	14	14													11	10	10	9	9	7	8	12	14	15	-	16	16	-	-	-	-	-	-
B-217-liv						12	13	14	16	14	13	11	8	9	10	10	10	12	13	15	16	14													12	-	-	-	9	7	-	-	-	-	-	16	13	11	10	9	9	13	-
B-306-bed						11	12	13	15	13	10	8	6	7	5	6	7	11	12	14	15	13													9	8	7	7	6	5	6	10	13	14	14	15	11	7	7	6	4	5	5
B-306-liv						11	12	14	15	14	10	8	6	8	5	7	8	12	12	15	15	14													-	-	-	-	7	6	7	11	13	14	15	15	11	8	8	7	5	6	5
B-319-bed						10	12	13	15	13	11	8	7	9	8	8	9	11	12	14	15	14													-	-	-	-	-	-	-	-	-	-	-	15	12	9	9	8	7	7	6
B-319-liv						9	12	13	15	13	11	8	7	8	-	-	-	-	-	-	-	-													-	-	-	-	-	-	-	-	-	-	-	-	13	9	9	8	8	7	6
C-304-liv					11	13	11	Retrofit																11	9	9	4	6	-	-	-	-	-	-	-	-	-	-	6	7	-	-	-	-	-	15	12	8	8	8	5	6	6
C-307-bed					11	13	14																	10	7	7	1	5	-	-	-	-	-	14	11	9	10	8	8	6	7	11	13	15	15	15	11	9	9	8	6	7	6
C-307-liv					11	13	12																	10	7	7	1	5	-	-	-	-	-	14	11	8	9	8	7	6	7	11	13	15	15	15	-	-	-	-	-	-	-
C-502-liv					8	10	12																	10	7	8	3	6	9	11	-	-	-	15	10	8	8	7	6	5	7	11	13	15	15	15	-	-	-	-	-	-	-
C-511-bed					8	10	12																	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C-511-liv					8	10	12																	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C-702-liv					12	14	15																	14	13	13	10	12	-	-	-	-	-	16	12	11	12	11	9	8	10	13	15	16	17	17	14	12	11	11	9	8	6
C-711-bed					10	14	16																	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C-711-liv					10	14	16																	13	10	10	8	9	10	11	-	-	-	15	10	10	10	8	8	7	8	11	13	15	15	15	11	9	9	8	6	6	6
D-159-bed			7	8	10	11	12	13	15	13	Retrofit											13	11	10	7	8	5	6	9	10	-	-	-	14	10	8	8	7	7	7	8	11	13	14	15	14	12	9	8	8	6	7	6
D-159-kitch			7	8	9	11	12	13	15	13												13	11	10	8	8	5	6	9	11	-	-	-	14	10	9	8	8	8	7	9	12	14	15	15	15	12	9	9	8	7	7	6
D-159-liv			7	8	9	11	12	13	15	13												13	11	9	7	8	4	6	8	10	-	-	-	14	10	8	8	7	7	6	8	11	13	14	14	14	12	9	8	8	6	7	6
D-163-bed			6	8	9	11	12	14	15	13												12	10	8	7	7	5	5	7	10	-	-	-	13	9	8	7	6	6	6	7	10	13	14	14	14	11	8	7	7	6	6	7
D-163-kitch			6	8	9	11	12	14	15	13												13	10	9	7	7	4	6	8	10	-	-	-	13	9	8	7	6	7	6	7	10	13	14	15	14	11	8	8	7	6	7	7
D-163-liv			6	7	8	10	12	14	15	13												12	10	9	7	7	4	5	8	10	-	-	-	13	9	7	7	6	6	5	7	10	13	14	14	16	11	8	7	7	6	6	7
E-225-liv	4	2	5	Retrofit				13	15	13	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E-226-liv	5	6	6					13	15	13	10	8	5	8	5	5	-	-	-	-	14	14	11	9	8	7	4	5	9	10	-	-	-	14	10	8	8	7	6	6	7	11	13	14	14	14	11	9	8	7	5	6	5
E-319-liv	3	1	9					15	17	14	10	-	3	7	3	6	6	12	14	17	17	16	14	14	11	12	8	11	12	16	-	-	-	19	17	16	16	15	15	13	14	17	18	20	20	19	18	-	-	-	-	-	-
E-337-liv	10	8	11					14	15	14	12	-	8	10	9	9	10	13	13	15	15	15	14	14	11	12	8	9	12	15	-	-	-	16	12	11	10	9	9	-	-	-	-	-	-	15	11	8	8	6	4	4	5
E-421-liv	5	4	6					13	14	13	9	-	4	7	4	6	7	11	11	14	15	13	10	9	6	7	1	4	7	10	-	-	-	14	9	7	8	7	6	5	7	10	13	15	15	15	11	8	9	8	6	7	5
E-435-liv	6	6	7					13	15	13	9	-	-	-	-	-	-	-	-	-	14	13	10	8	5	6	-2	3	7	10	-	-	-	13	8	6	7	5	4	7	9	11	13	15	15	15	11	8	8	8	6	6	5

Appendix D.3 – Summary table: average monthly dew point temperature in degrees Celsius

LOCATION	avg	avg	pre vs.	2016	2017												2018												2019												2020												2021			
	(pre)	(post)	post	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR
A-102-bed	4.0	4.2	0.2			5.6	6.0	4.7	2.2	1.3	Retrofit												0.4	1.2	3.0	3.9	5.9	6.4	7.2	9.3	6.2	4.6	2.5	.	.	.	.	.	.	.	.	6.4	6.9	4.7	2.5	2.8	1.6	1.7	2.3	3.9	.	.	.	.	.	.
A-102-liv	4.0	4.4	0.5			5.6	5.9	4.7	2.3	1.3													0.7	1.7	2.7	3.7	5.7	6.0	6.7	8.9	5.9	4.4	2.3	.	.	.	3.0	5.0	5.9	5.2	6.5	6.5	6.4	4.4	2.3	2.6	1.5	1.5	2.2	4.6	6.0	5.9	6.0	6.6	4.1	2.8
A-203-bed	3.5	2.6	-1.0			7.3	4.8	2.3	1.8	1.5													0.5	0.8	1.5	1.9	3.2	4.8	5.2	8.7	4.2	2.1	2.1	.	.	.	.	.	.	.	.	2.8	3.2	1.9	0.6	1.1	0.6	0.8	1.1	3.0	4.1	3.5	3.3	2.9	1.2	1.6
A-203-liv	2.3	2.2	-0.1			5.3	3.5	1.2	0.7	0.7													0.3	0.5	1.6	2.0	2.0	3.6	4.2	7.4	3.0	1.2	0.7	.	.	.	2.9	2.3	2.6	2.5	3.6	2.4	2.3	1.2	0.3	0.8	0.4	0.6	0.9	2.7	3.4	3.2	3.5	3.2	1.3	0.9
A-205-liv	2.7	3.8	1.1			4.5	4.6	2.5	1.2	0.7													0.8	0.3	1.8	3.6	5.1	4.4	6.1	9.2	6.8	3.9	2.5	.	.	.	3.1	4.1	5.2	5.2	5.8	5.7	6.4	3.5	2.5	2.1	1.3	1.2	1.5	.	.	.	.	.	.	.
A-303-bed	3.6	3.3	-0.3			5.3	4.5	3.7	2.3	2.2													1.0	1.2	1.8	2.3	3.3	4.1	4.5	6.4	3.7	3.0	1.4	.	.	.	3.2	3.5	3.6	3.8	.	4.6	4.9	2.2	0.8	1.2	.	.	1.6	3.5	6.2	5.2	4.8	5.6	3.0	3.0
A-303-liv	3.7	4.0	0.3			5.4	4.6	3.9	2.3	2.2													1.0	1.2	2.0	2.9	3.7	4.6	5.0	7.8	4.8	3.3	1.7	.	.	.	3.3	3.6	4.6	4.5	4.2	5.0	5.8	3.1	1.5	.	.	.	1.8	4.0	6.9	6.0	5.8	6.6	3.7	3.1
A-305-liv	3.4	5.5	2.1			6.7	5.4	3.4	1.0	0.7													1.1	1.1	1.9	4.6	6.0	7.3	7.1	11.8	7.4	4.6	2.2	.	.	.	3.8	5.4	6.1	6.6	7.5	6.8	8.3	.	.	.	.	.	.	.	.	.	.	.	.	.
B-103-bed	2.7	3.5	0.8						1.3	2.0	2.0	1.6	1.6	3.1	4.1	4.6	4.4	5.0	4.2	3.1	2.1	1.9	1.0	1.6	2.3	Retrofit												3.4	3.8	3.9	5.0	3.7	4.2	2.8	2.1	2.2	1.7	1.7	2.2	3.6	4.3	4.6	4.5	5.1	3.7	3.1
B-103-liv	3.1	3.8	0.7						1.5	2.1	2.2	1.9	2.0	3.8	4.8	5.6	5.2	5.9	4.5	3.5	2.3	2.2	1.1	1.6	3.0													4.2	4.4	4.4	5.2	4.1	4.7	3.2	2.2	2.5	1.9	1.9	2.5	3.9	4.7	5.2	5.1	5.7	3.9	2.5
B-119-bed	2.9	3.6	0.7						1.6	2.6	2.2	1.7	1.8	3.6	4.5	5.2	4.2	5.4	3.5	2.5	2.2	2.3	1.5	2.0	2.4													4.6	5.3	4.6	5.7	4.9	4.7	3.1	2.2	2.3	1.7	1.9	2.2	2.2	2.2	4.1	2.7	6.9	4.9	2.9
B-119-liv	2.7	3.3	0.6						1.4	2.3	2.0	1.6	1.7	3.4	4.5	5.2	4.0	5.2	2.9	2.2	1.8	1.9	1.6	1.7	1.9													4.1	5	4.3	5.2	4.6	4.4	2.6	1.7	2.0	1.5	1.7	1.9	.	.	.	.	.	.	.
B-216-bed	1.6	1.9	0.2						0.4	1.0	1.0	1.1	1.1	2.2	2.2	2.8	3.3	2.7	2.2	1.7	1.3	1.2	0.7	0.9	2.0													1.6	1.8	1.8	2.5	4.5	3.5	1.8	1.0	1.3	0.6	0.8	0.8	1.4	1.6	1.3	1.3	1.5	2.2	4.5
B-216-liv	2.0	2.1	0.1						0.8	1.4	1.1	1.2	1.5	2.9	3.3	4.0	3.6	3.4	2.5	2.1	1.3	1.1	0.6	0.9	2.5													2	2.1	2.3	3.4	4.4	3.2	1.5	0.7	1.0	0.7	0.8	0.9	1.9	2.3	2.2	2.2	2.7	2.4	3.0
B-217-bed	1.6	4.3	2.7						1.2	1.7	1.7	1.3	1.0	.	.	.	.	.	.	.	.	.	.	1.7	2.8													5.1	6.2	6	6.7	6.3	6.1	3.4	2.6	2.2	2.3	.	1.7	3.1	.	.	.	.	.	.
B-217-liv	3.7	6.1	2.5						1.5	1.7	1.8	1.4	2.0	5.3	7.1	6.8	5.5	9.3	6.4	4.2	1.9	2.2	1.2	1.5	2.3													5.6	.	.	.	5.2	6.4	.	.	.	.	.	1.8	4.7	6.5	6.1	5.7	8.6	10.6	.
B-306-bed	1.8	2.6	0.8						0.5	0.9	1.0	0.8	1.1	2.7	3.9	4.6	3.6	4.3	2.5	1.4	0.5	0.8	-0.2	0.5	1.7													3.1	4.1	3.3	4.0	4.0	4.0	1.8	0.3	1.1	0.5	0.5	1.7	2.6	3.2	3.1	2.9	4.0	2.5	2.7
B-306-liv	2.3	2.8	0.5						0.7	1.3	1.4	1.2	1.4	2.9	4.1	4.6	4.0	4.8	3.6	2.2	1.3	1.4	0.3	1.4	2.6													.	.	.	.	3.4	4.5	2.6	1.3	1.6	1.1	1.2	1.3	3.1	3.7	3.8	3.6	4.6	3.0	2.9
B-319-bed	2.5	4.3	1.8						0.3	0.9	0.9	0.7	1.1	3.3	4.1	5.6	5.0	7.6	4.9	2.8	1.2	1.3	0.3	0.9	2.1													.	.	.	.	.	.	.	.	.	.	.	0.9	3.8	4.8	5.3	4.6	7.2	4.4	3.6
B-319-liv	2.2	5.0	2.8						-0.8	0.8	1.0	0.7	1.0	3.1	4.1	5.4	4.5	.	.	.	.	.	.	.	.													.	.	.	.	.	.	.	.	.	.	.	.	4.6	4.9	5.2	4.6	7.6	4.4	3.4
C-304-liv	2.8	4.4	1.7					4.1	3.7	0.5	Retrofit																4.8	6.4	5.6	7.8	4.5	.	.	.	.	.	.	.	.	.	.	4.1	4.6	.	.	.	.	.	1.0	3.5	4.0	4.1	4.4	5.2	3.6	3.1
C-307-bed	3.5	3.8	0.4					4.1	3.6	2.7																	3.4	3.9	3.8	4.9	3.5	.	.	.	.	.	2.7	5.5	4.9	5.5	5.6	5.7	5.4	2.6	1.5	1.7	1.5	1.7	1.6	3.0	4.8	5.1	4.4	5.5	4.4	3.2
C-307-liv	3.3	3.5	0.2					4.1	3.5	2.3																	3.6	4.0	3.7	5.0	3.7	.	.	.	.	.	2.7	4.9	4.5	5.4	5.1	4.9	5.0	2.1	1.5	1.9	1.5	1.7	1.5	.	.	.	.	.	.	.
C-502-liv	1.2	3.4	2.2					1.4	1.2	1.0																	3.8	4.5	4.1	7.0	4.2	3.0	2.0	.	.	.	3.5	4.2	4.0	3.7	4.4	4.0	3.9	2.7	1.7	1.9	1.7	1.8	1.7	.	.	.	.	.	.	.
C-511-bed	1.1	-	-					1.7	0.8	0.9																	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
C-511-liv	1.4	-	-					2.0	1.1	1.1																	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
C-702-liv	4.9	6.7	1.7					5.4	5.0	4.4																	7.4	9.7	9.3	13.5	9.8	.	.	.	.	.	4.4	6.6	7.7	7.5	8.3	7.0	7.4	5.5	3.6	3.6	2.9	3.3	3.3	6.1	7.6	7.4	7.1	8.5	5.3	3.8
C-711-bed	4.8	-	-					3.6	5.2	5.5																	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
C-711-liv	4.4	4.6	0.1					3.3	4.8	5.2																	6.9	7.3	6.8	11.8	7.1	4.0	2.2	.	.	.	2.9	4.8	5.9	5.5	5.5	5.3	6.1	3.7	1.5	1.8	1.6	1.6	1.3	3.3	4.3	5.1	4.5	5.8	3.2	3.4
D-159-bed	2.2	3.7	1.5			5.8	3.7	3.6	1.6	0.9	0.6	0.5	0.8	Retrofit											1.2	2.9	3.6	4.4	4.3	8.3	4.3	3.1	1.0	.	.	.	2.5	4.2	4.7	4.1	4.8	5.2	5.8	3.7	1.8	1.7	1.2	1.0	1.3	3.8	4.6	4.2	4.5	6.0	4.2	3.7
D-159-kitch	2.3	3.9	1.7			5.7	3.7	3.5	1.6	1.2	0.7	0.6	1.2												1.7	2.9	3.7	4.7	4.6	8.6	4.4	3.2	1.3	.	.	.	2.8	4.5	4.9	4.3	5.0	5.3	6.1	4.2	2.3	2.1	1.6	1.4	1.9	4.0	4.8	4.5	4.8	6.3	4.5	3.9
D-159-liv	2.1	3.4	1.3			5.6	3.7	3.4	1.4	0.9	0.7	0.5	0.9												1.0	2.3	3.3	4.3	4.2	8.0	3.8	2.6	0.8	.	.	.	2.3	3.9	4.5	3.9	4.5	4.9	5.4	3.4	1.5	1.4	1.0	0.8	1.2	3.5	4.2	3.9	4.3	5.7	4.1	4.0
D-163-bed	2.1	2.9	0.8			4.7	3.6	2.6	1.6	1.2	1.2	0.8	1.1												0.7	1.4	2.2	4.2	3.6	8.3	3.4	1.8	0.3	.	.	.	1.8	3.1	3.8	2.7	3.7	4.1	4.5	2.2	0.8	1.1	0.8	0.9	0.9	2.6	3.6	3.3	3.8	5.9	3.8	4.2
D-163-kitch	2.1	3.1	1.0			4.5	3.5	2.6	1.5	1.2	1.2	0.8	1.1												0.9	1.7	2.6	4.2	3.8	7.9	3.6	2.3	0.8	.	.	.	1.9	3.3	3.8	2.7	3.9	4.3	4.6	2.5	1.2	1.3	1.0	1.1	1.1	2.7	3.8	3.5	3.8	5.9	4.1	4.7
D-163-liv	2.0	2.9	0.9			4.5	3.4	2.5	1.4	1.2	1.2	0.8	1.1												0.7	1.5	2.3	3.9	3.5	7.6	3.1	2.0	0.5	.	.	.	1.9	3.2	3.7	2.6	3.7	4.1	4.3	2.2	0.8	1.0	0.9	0.9	1.9	2.6	3.7	3.3	3.7	5.7	3.7	4.2
E-225-liv	3.8	0.8	-3.1	2.9	3.4	5.1	Retrofit				0.5	0.6	0.4	1.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
E-226-liv	5.8	3.0	-2.7	4.5	7.4	5.4					0.7	0.7	0.8	2.7	3.5	3.7	3.7	4.6	2.4	.	.	.	.	0.9	1.9	2.4	3.1	5.0	3.5	7.3	3.2	3.7	1.4	.	.	.	2.4	4.4	3.9	4.0	4.3	4.1	5.3	2.3	1.2	1.5	1.1	0.8	1.1	3.4	4.9	3.6	3.9	4.8	3.1	2.9
E-319-liv	4.4	6.3	1.9	1.9	2.4	8.8					2.6	2.4	1.9	2.7	.	2.3	3.0	3.0	2.3	-0.4	1.2	3.5	2.8	2.5	4.8	6.0	7.4	8.3	8.2	11.7	8.8	6.4	6.6	.	.	.	7.3	11.0	12.0	11.4	12.4	12.7	12.3	9.7	7.2	6.5	6.7	6.4	6.3	7.2	.	.	.	.	.	.
E-337-liv	9.9	4.8	-5.1	9.3	9.6	10.7					1.3	1.1	1.9	4.4	.	7.5	6.3	8.1	5.8	4.4	3.0	2.7	1.4	1.3	3.7	5.7	7.3	8.6	8.5	11.9	7.1	6.7	5.7	.	.	.	4.3	6.3	7.7	5.9	6.5	7.1	.	.	.	.	.	.	0.4	3.0	3.4	3.8	2.8	3.3	1.7	2.3
E-421-liv	4.8	2.5	-2.4	4.1	4.9	5.5					0.5	0.2	0.8	1.7	.	3.2	2.7	3.3	2.3	1.1	0.3	0.5	-0.1	0.8	1.6	2.1	2.9	3.4	3.2	4.4	2.4	1.8	1.3	.	.	.	2.8	3.3	3.4	3.5	4.6	3.9	4.0	2.7	1.1	1.9	1.4	1.4	1.9	3.2	3.8	4.5	4.2	5.3	3.9	2.8
E-435-liv	6.3	2.2	-4.1	5.2	7.1	6.5					0.5	0.5	0.4	1.2	.	.	.	.	.	.	.	.	.	0.9	1.4	1.7	1.7	2.5	2.3	2.2	1.1	1.2	0.4	.	.	.	1.8	2.6	2.4	2.5	2.3	2.3	5.5	4.2	1.6	1.4	1.2	1.5	1.2	3.0	3.9	4.1	4.4	5.6	3.2	2.6

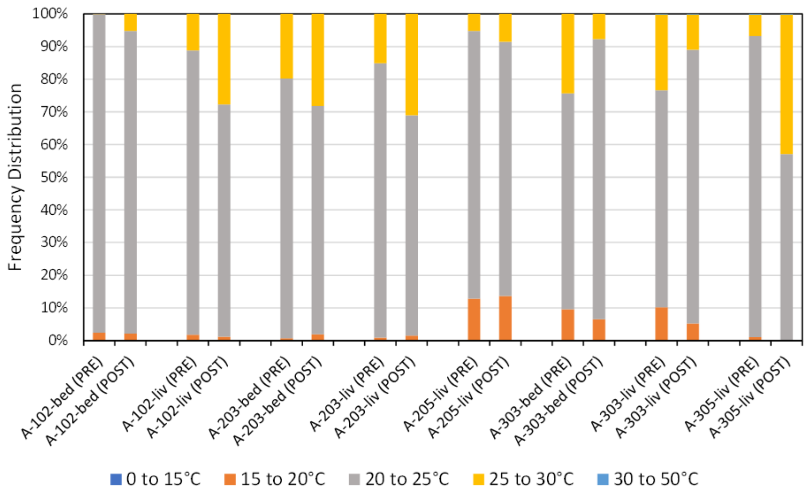
Appendix D.4 – Summary table: average monthly delta dew point temperature in degrees Celsius

LOCATION	avg (pre)	avg (post)	pre vs. post	2016	2017												2018												2019												2020												2021		
				DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
A-102-bed	982	1107	125			840	1310	1108	899	751	Retrofit												800	925	1202	1097	1208	1077	1236	1145	1147	1178	971	-	-	-	-	-	-	-	-	1176	1220	1117	1056	1239	982	1000	1324	1037	-	-	-	-	-
A-102-liv	941	788	-153			679	1255	1110	923	737													681	856	840	831	885	807	881	846	887	859	736	-	-	-	641	772	842	792	803	780	801	801	781	873	689	714	908	731	765	747	754	690	644
A-203-bed	1099	788	-311			1535	1301	881	870	905													788	781	673	622	908	1041	1173	1245	1050	781	721	-	-	-	-	-	-	-	-	817	762	711	668	737	706	686	725	819	811	823	584	494	568
A-203-liv	814	616	-198			868	1072	758	686	686													600	598	627	514	573	705	851	950	733	562	559	-	-	-	488	530	597	625	674	602	598	571	553	607	560	591	617	654	652	676	555	509	558
A-205-liv	710	778	68			789	866	701	638	559													635	570	691	865	590	610	1059	828	928	750	825	-	-	-	792	705	935	895	831	901	853	723	823	727	712	681	755	-	-	-	-	-	-
A-303-bed	739	839	100			672	783	791	720	730													634	723	691	675	722	810	858	871	737	746	632	-	-	-	709	619	839	845	-	1169	1106	912	735	783	-	-	407	1032	1303	1095	1052	1038	919
A-303-liv	766	726	-40			653	791	856	758	772													631	658	677	685	694	749	783	777	702	706	622	-	-	-	624	566	739	759	653	838	954	799	670	-	-	-	356	794	1002	864	824	801	686
A-305-liv	982	1178	196			1124	1288	1131	723	645													759	721	756	1096	1156	1206	1466	1516	1513	1201	908	-	-	-	1057	1194	1266	1388	1437	1392	-	-	-	-	-	-	-	-	-	-	-	-	-
B-103-bed	916	660	-256						619	831	1185	933	1056	988	1163	1114	846	896	919	904	971	871	870	639	760	Retrofit												625	630	618	745	583	621	631	663	636	689	707	731	638	704	692	639	673	649
B-103-liv	738	937	199						552	666	655	654	657	699	759	777	812	826	836	820	781	751	679	765	859													827	831	827	984	845	899	853	862	847	900	922	1028	937	1001	1079	1063	1082	1077
B-119-bed	693	739	46						634	728	670	656	681	737	791	759	768	684	638	626	621	673	703	780	630													768	825	802	791	744	734	720	772	734	740	819	891	702	592	537	613	735	776
B-119-liv	730	826	96						492	818	768	762	822	794	826	821	788	713	647	638	651	705	769	789	602													809	925	886	936	821	781	772	798	724	740	831	886						
B-216-bed	540	535	-5						536	542	522	534	604	607	560	563	690	603	489	434	450	468	504	539	534													464	504	510	502	533	550	547	559	575	507	522	572	558	554	522	538	564	549
B-216-liv	567	558	-9						503	559	546	549	598	625	628	638	728	552	547	520	510	536	525	543	536													501	517	553	557	610	607	573	553	561	537	548	571	539	552	555	505	571	629
B-217-bed	594	984	390						488	532	564	564	592	-	-	-	-	-	-	-	-	-	-	616	800													985	1050	1133	1414	1549	1031	692	877	562	544	-	-	-	-	-	-	-	-
B-217-liv	767	3003	2236						553	571	590	601	636	1023	1151	961	929	942	1032	1003	629	718	523	568	605													4384	-	-	-	2002	4721	-	-	-	-	-	425	1253	3338	4004	4240	3163	2499
B-306-bed	695	772	77						532	627	615	619	730	856	965	934	921	729	672	607	596	627	544	610	635													784	855	854	838	908	984	863	699	813	687	661	101	776	769	741	766	908	897
B-306-liv	755	791	36						348	596	569	584	616	650	668	665	805	575	626	570	698	2076	400	400	1992													-	-	-	-	1840	785	708	670	756	699	944	685	634	654	622	592	677	805
B-319-bed	751	1016	265						640	680	587	589	641	844	805	967	1042	1178	993	800	669	605	506	579	641													-	-	-	-	-	-	-	-	-	-	-	613	960	911	1220	1040	1320	1050
B-319-liv	649	1161	512						621	530	549	539	552	720	742	810	780	-	-	-	-	-	-	-	-													-	-	-	-	-	-	-	-	-	-	-	-	877	1143	1310	1076	1484	1076
C-304-liv	694	644	-49					695	893	492	Retrofit																677	647	679	640	676	-	-	-	-	-	-	-	-	-	-	523	626	-	-	-	-	-	686	633	669	681	662	637	766
C-307-bed	865	764	-100					877	954	763																	682	687	725	647	689	-	-	-	-	-	696	954	830	952	835	934	877	760	682	652	680	718	758	722	769	779	713	737	812
C-307-liv	838	828	-10					894	995	624																	793	874	996	737	826	-	-	-	-	-	711	944	825	971	848	923	933	764	715	742	750	771	788	-	-	-	-	-	-
C-502-liv	558	753	195					539	556	580																	679	679	717	755	676	655	689	-	-	-	764	736	872	759	771	760	797	766	743	765	796	820	863	-	-	-	-	-	-
C-511-bed	642	-	-					644	640	643																	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C-511-liv	618	-	-					625	641	588																	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C-702-liv	813	934	121					683	840	916																	982	1096	1234	1071	1154	-	-	-	-	-	829	953	1098	995	978	865	858	845	784	742	727	752	844	899	926	964	950	959	939
C-711-bed	1544	-	-					773	1832	2026																	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C-711-liv	1353	937	-416					684	1606	1769																	1602	1167	1426	1443	1221	894	898	-	-	-	696	997	1024	942	881	861	816	749	604	598	614	677	627	609	632	808	663	735	695
D-159-bed	739	655	-84			781	869	942	805	700	571	583	657	Retrofit											665	740	637	598	574	583	675	690	711	-	-	-	673	600	592	616	615	576	665	709	687	628	643	769	758	622	597	576	546	586	625
D-159-kitch	718	604	-114			732	852	917	748	671	589	569	667												607	611	632	637	601	587	624	633	596	-	-	-	592	625	615	614	581	559	634	648	598	575	565	570	584	553	571	550	550	602	649
D-159-liv	842	628	-214			920	1051	1042	876	765	650	660	771												631	629	643	639	636	621	656	638	620	-	-	-	624	649	607	614	595	568	672	699	644	592	598	602	638	595	599	602	575	573	595
D-163-bed	855	653	-201			785	1038	1027	938	851	693	676	831												591	666	663	625	635	711	752	681	717	-	-	-	596	579	621	633	602	580	653	768	739	627	603	650	685	597	625	609	612	647	657
D-163-kitch	792	599	-193			765	888	934	860	789	693	669	739												543	625	598	604	592	624	659	670	651	-	-	-	527	600	585	582	593	564	609	699	627	571	549	534	573	531	556	574	572	615	665
D-163-liv	765	617	-148			725	866	913	811	735	659	637	772												549	620	592	600	584	605	669	688	681	-	-	-	571	575	576	573	609	534	636	718	632	607	578	598	776	560	580	572	559	608	644
E-225-liv	695	631	-64	429	655	1001	Retrofit				615	660	654	596	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E-226-liv	755	691	-64	521	959	786					641	655	688	714	603	646	677	751	641	-	-	-	-	-	743	670	638	760	663	716	719	902	674	-	-	-	648	780	714	792	667	682	829	697	628	644	596	581	654	658	781	654	699	739	641
E-319-liv	856	1463	607	610	644	1313					985	1038	999	910	-	613	671	668	705	468	988	1725	1834	1666	1567	1418	1323	1292	1398	1254	1353	1189	2054	-	-	-	826	1583	1681	1660	1635	1664	1799	2231	2275	2408	2379	2391	2563	1846	-	-	-	-	-
E-337-liv	1442	1093	-349	1230	1080	2018					739	715	1001	1259	-	1018	988	1217	1119	1156	1261	1232	945	839	975	1084	1183	1168	1217	1121	961	1211	1536	-	-	-	1348	1375	1383	1008	1021	1136	-	-	-	-	-	-	489	670	686	732	650	669	642
E-421-liv	686	675	-11	597	718	744					564	544	682	632	-	579	630	646	675	666	726	642	670	804	622	626	601	622	631	599	621	639	730	-	-	-	817	652	683	664	726	727	724	770	693	796	720	656	852	705	642	711	672	678	654
E-435-liv	751	661	-90	531	829	892					662	752	709	672	-	-	-	-	-	-	-	-	-	596	634	642	518	589	624	581	597	570	608	-	-	-	637	638	635	620	572	630	871	1052	852	694	617	624	662	616	720	695	738	764	630

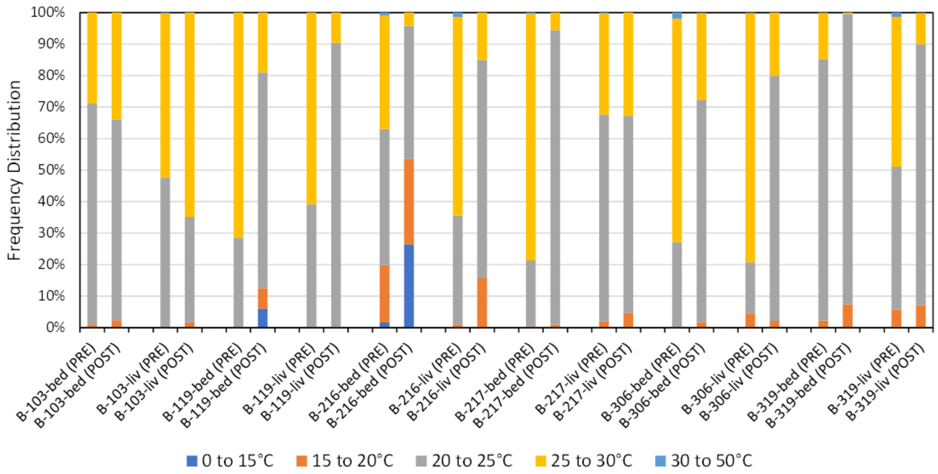
Appendix D.5 – Summary table: average monthly carbon dioxide concentrations in parts per million

Appendix E

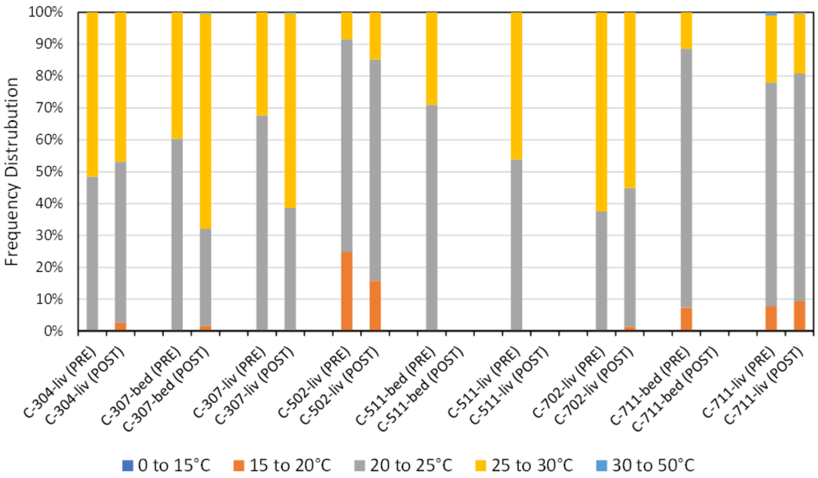
Frequency Distribution Bar Charts



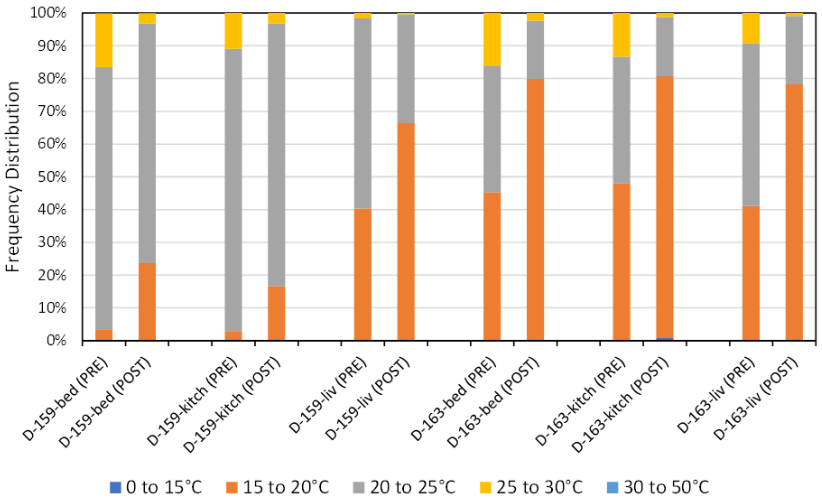
Appendix E.1 – Pre/post-retrofit air temperature frequency distribution for Building A



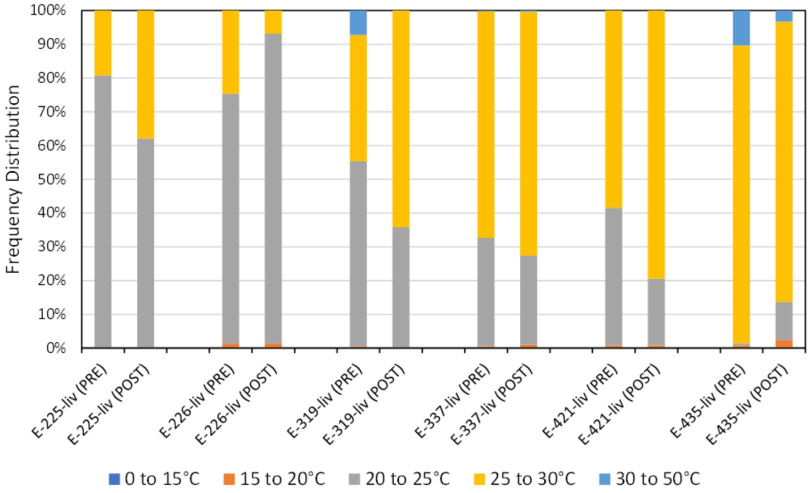
Appendix E.2 – Pre/post-retrofit air temperature frequency distribution for Building B



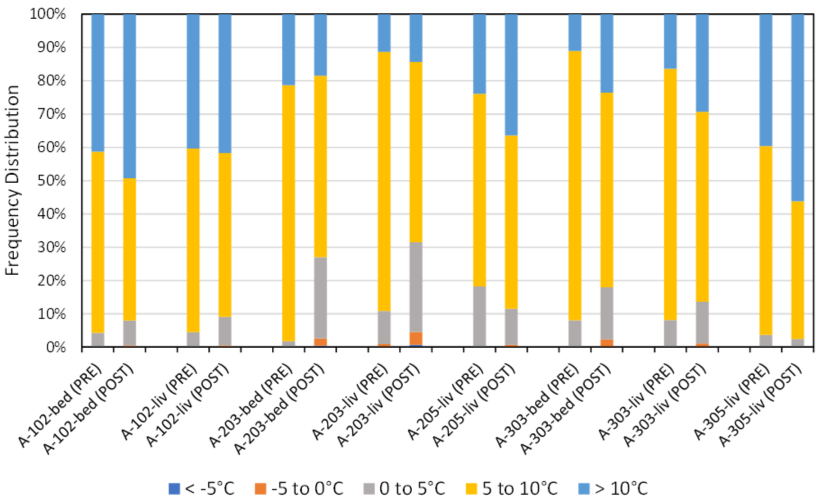
Appendix E.3 – Pre/post-retrofit air temperature frequency distribution for Building C



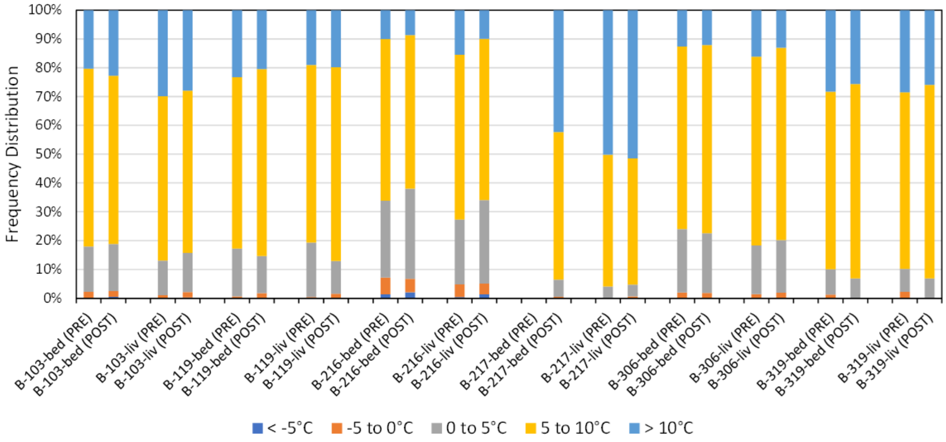
Appendix E.4 – Pre/post-retrofit air temperature frequency distribution for Building D



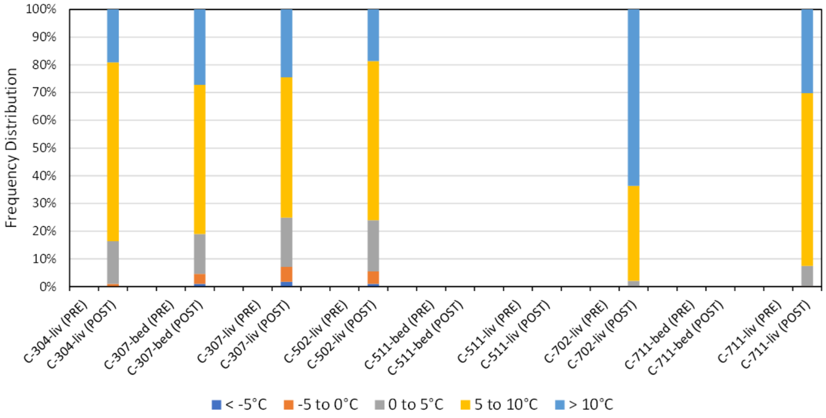
Appendix E.5 – Pre/post-retrofit air temperature frequency distribution for Building E



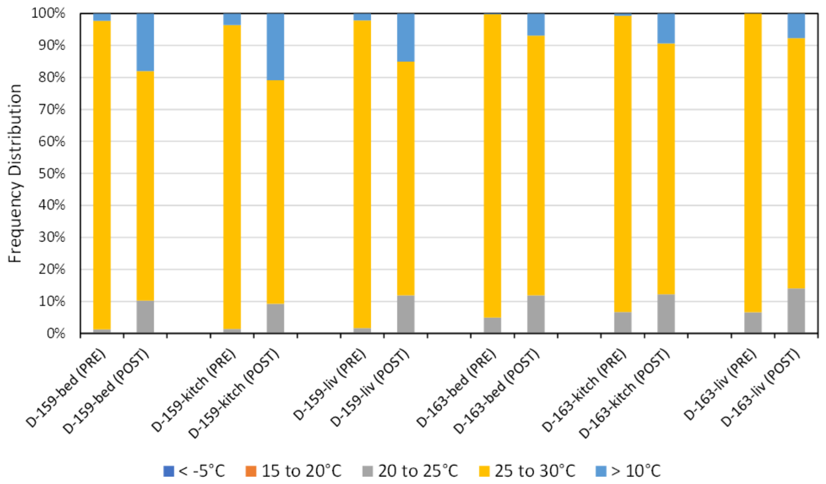
Appendix E.6 – Pre/post-retrofit dewpoint temperature frequency distribution for Building A between Oct-Mar



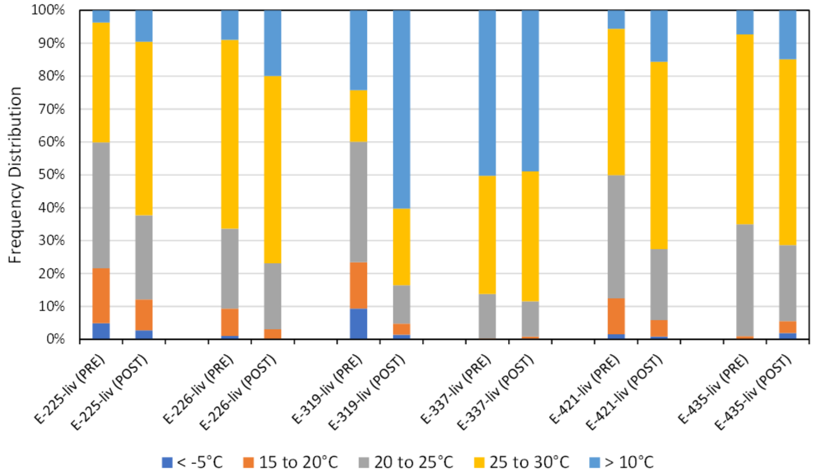
Appendix E.7 – Pre/post-retrofit dewpoint temperature frequency distribution for Building B between Oct-Mar



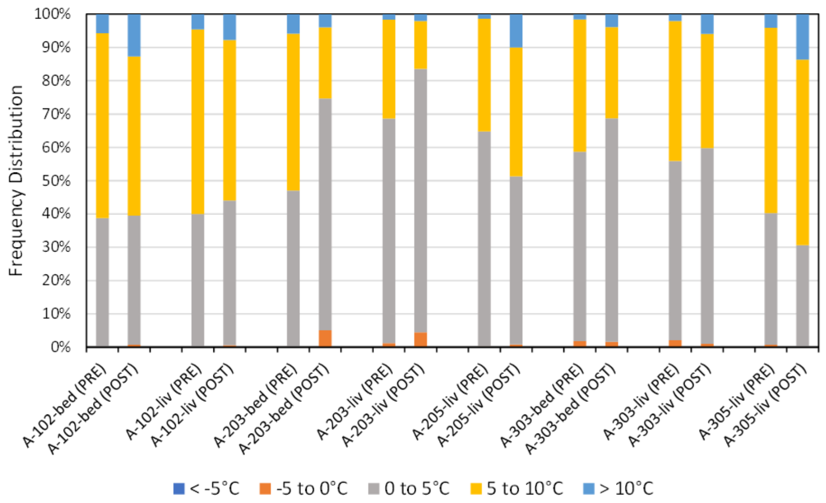
Appendix E.8 – Pre/post-retrofit dewpoint temperature frequency distribution for Building C between Oct-Mar



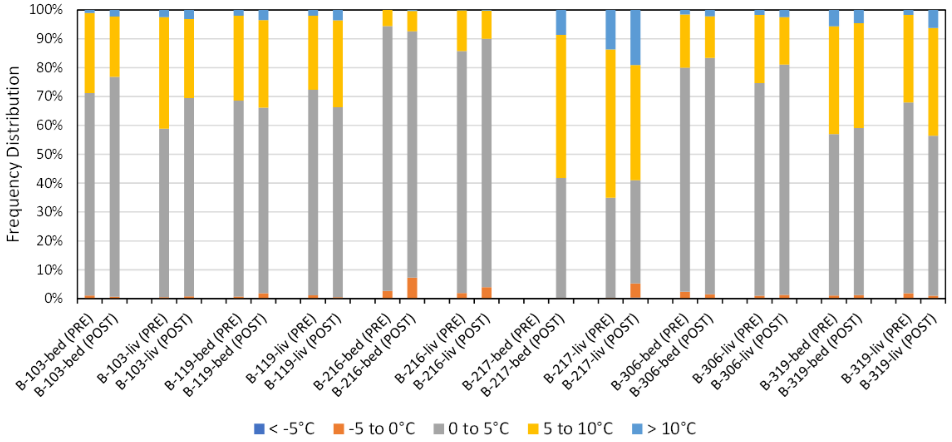
Appendix E.9 – Pre/post-retrofit dewpoint temperature frequency distribution for Building D between Oct-Mar



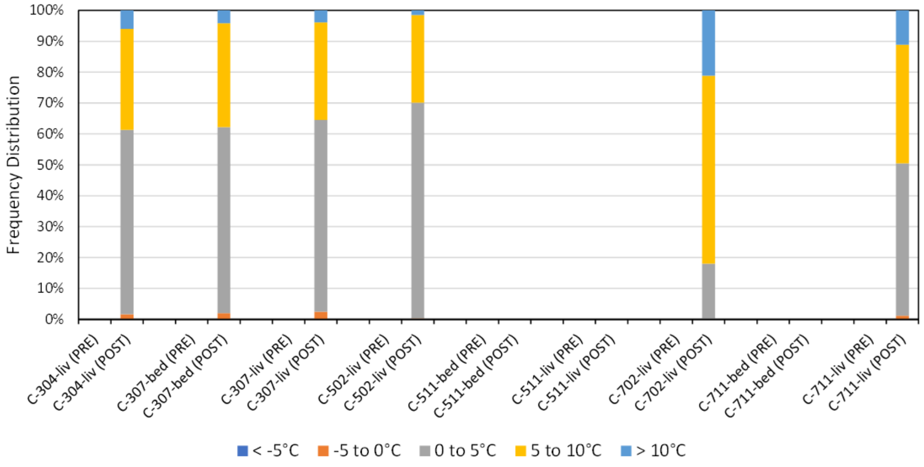
Appendix E.10 – Pre/post-retrofit dewpoint temperature frequency distribution for Building E between Oct-Mar



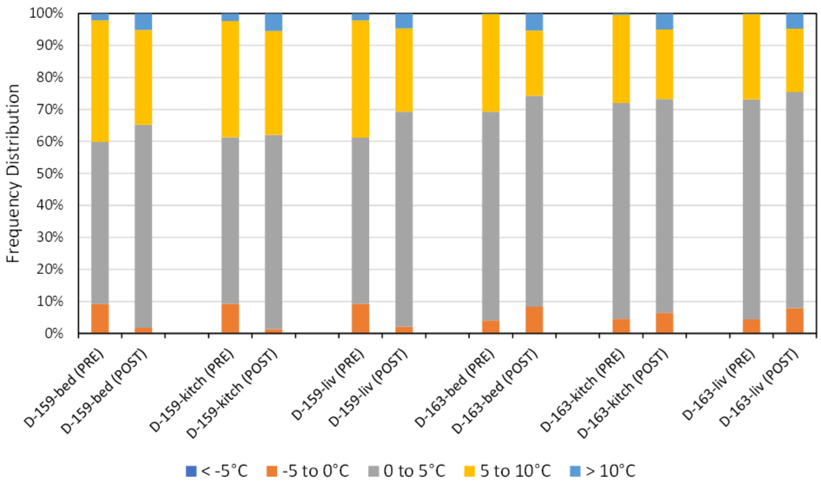
Appendix E.11 – Pre/post-retrofit delta dewpoint temperature frequency distribution for Building A between Oct-Mar



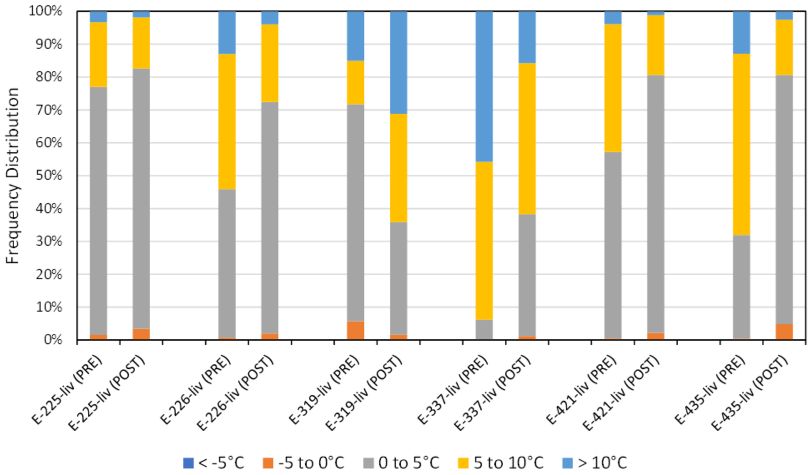
Appendix E.12 – Pre/post-retrofit delta dewpoint temperature frequency distribution for Building B between Oct-Mar



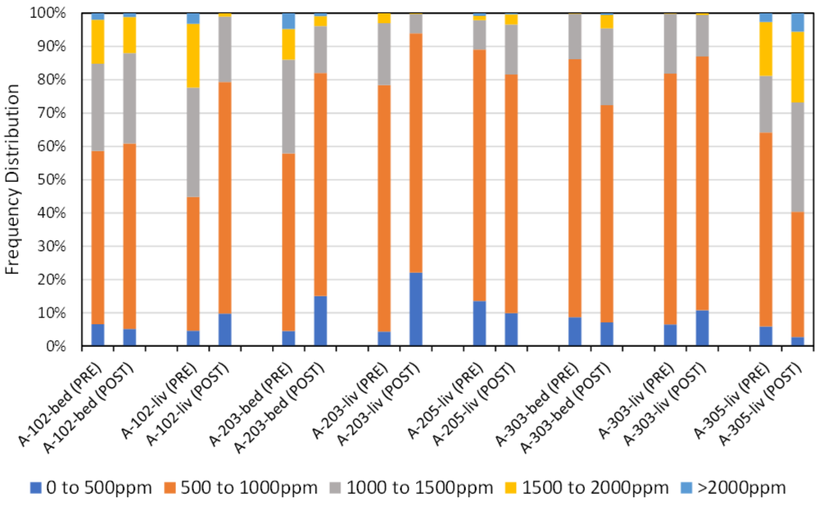
Appendix E.13 – Pre/post-retrofit delta dewpoint temperature frequency distribution for Building C between Oct-Mar



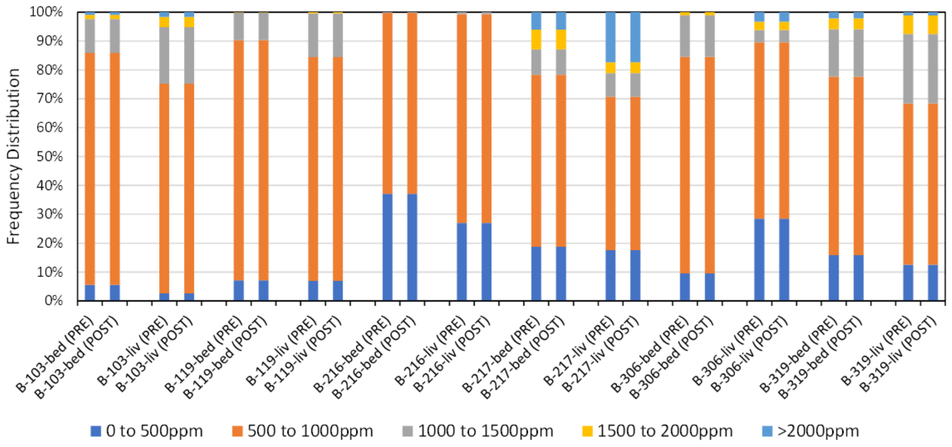
Appendix E.14 – Pre/post-retrofit delta dewpoint temperature frequency distribution for Building D between Oct-Mar



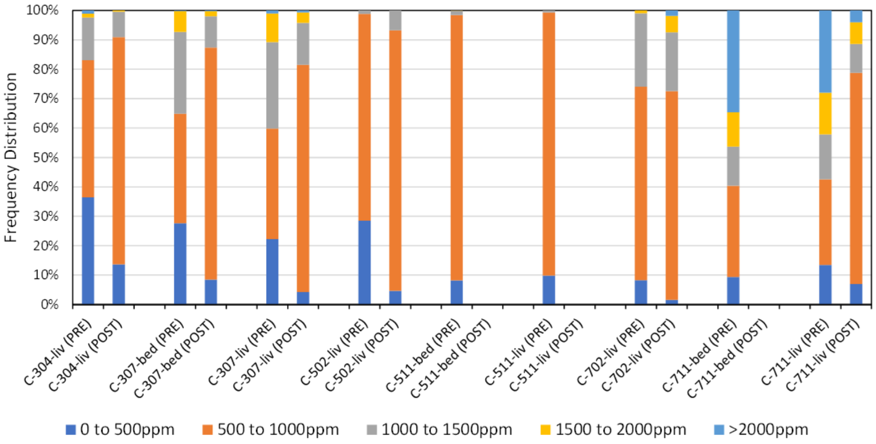
Appendix E.15 – Pre/post-retrofit delta dewpoint temperature frequency distribution for Building E between Oct-Mar



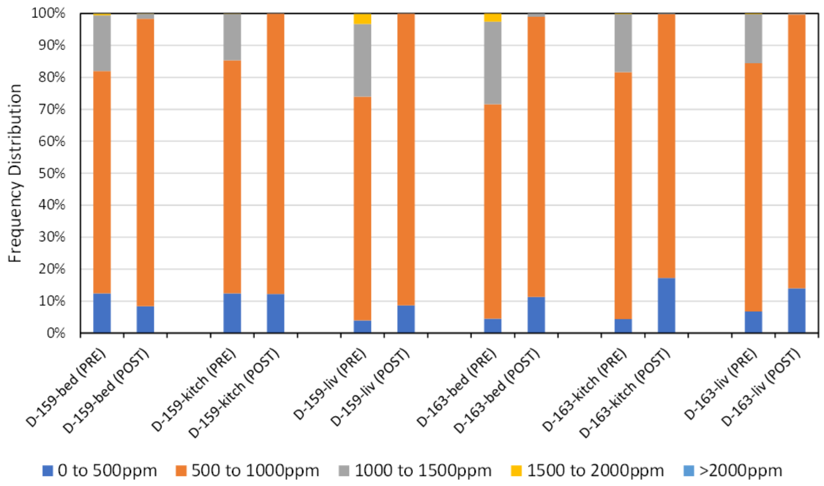
Appendix E.16 – Pre/post-retrofit carbon dioxide concentration frequency distribution for Building A



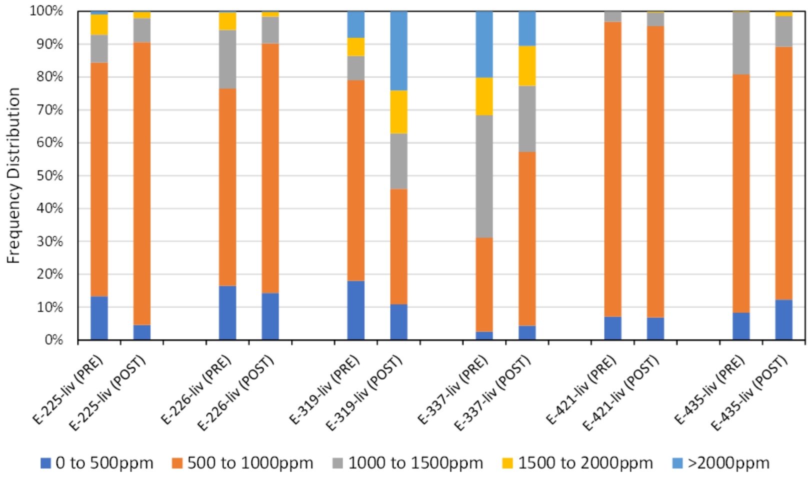
Appendix E.17 – Pre/post-retrofit carbon dioxide concentration frequency distribution for Building B



Appendix E.18 – Pre/post-retrofit carbon dioxide concentration frequency distribution for Building C



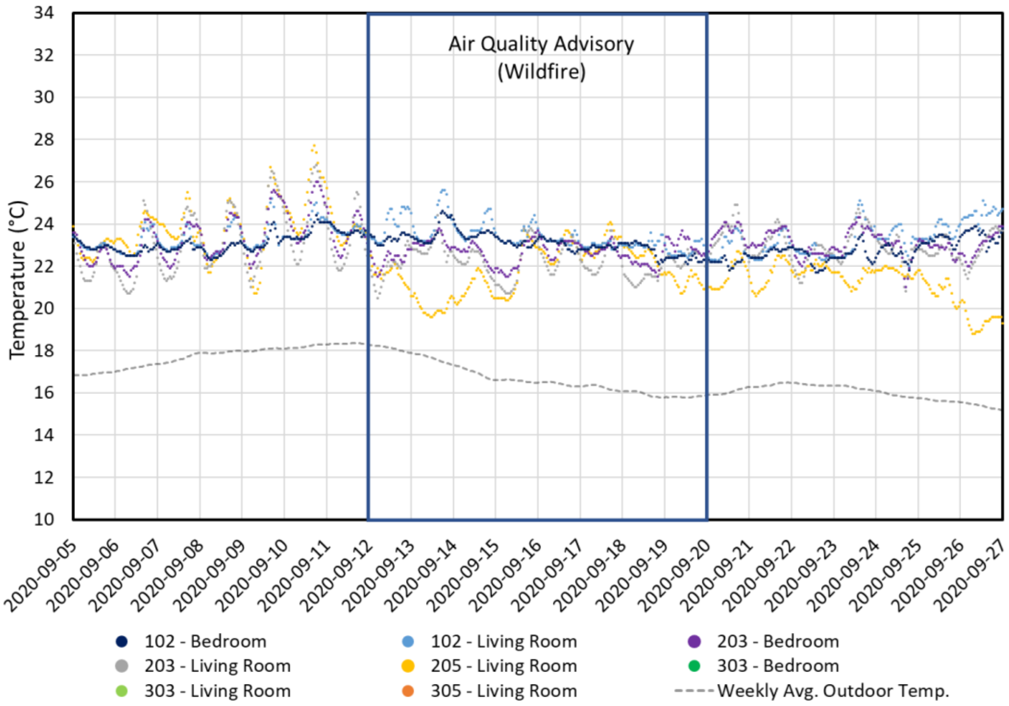
Appendix E.19 – Pre/post-retrofit carbon dioxide concentration frequency distribution for Building D



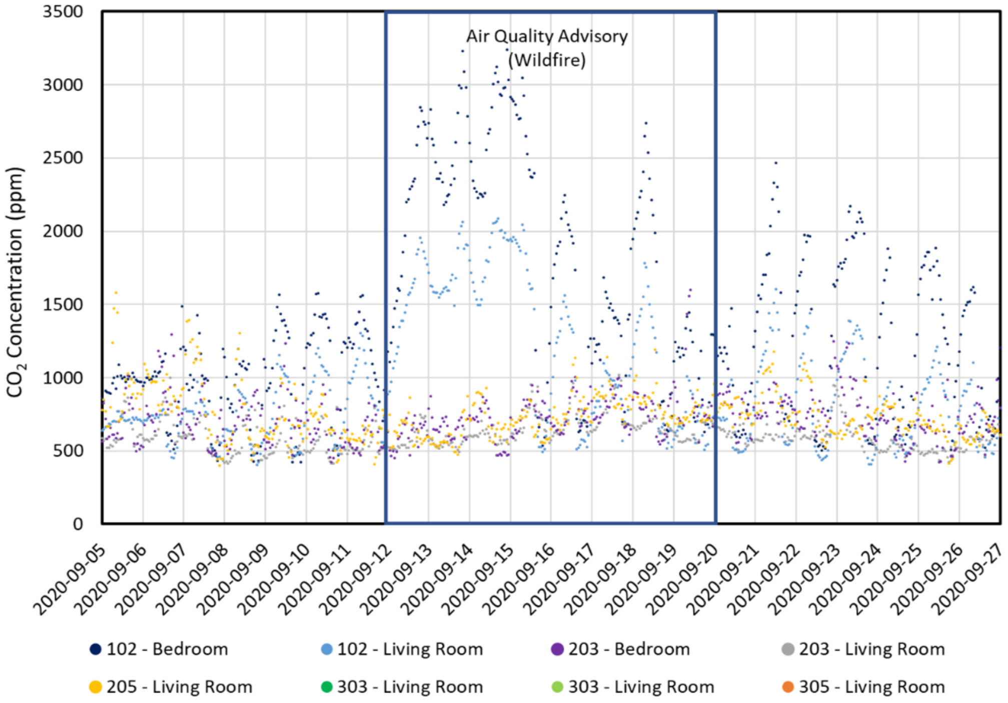
Appendix E.20 – Pre/post-retrofit carbon dioxide concentration frequency distribution for Building E

Appendix F

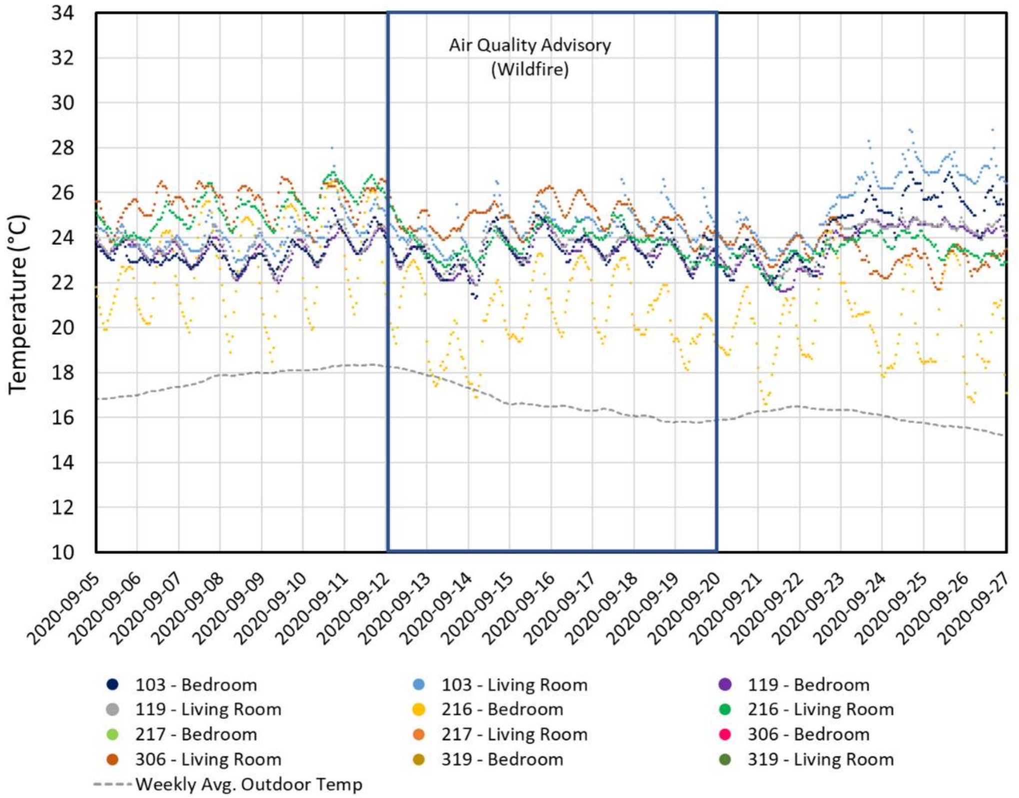
Air Quality Advisory (Wildfire) Analysis



Appendix F.1 – Air temperature for three-week period during Air Quality Advisory (Wildfire) for Building A

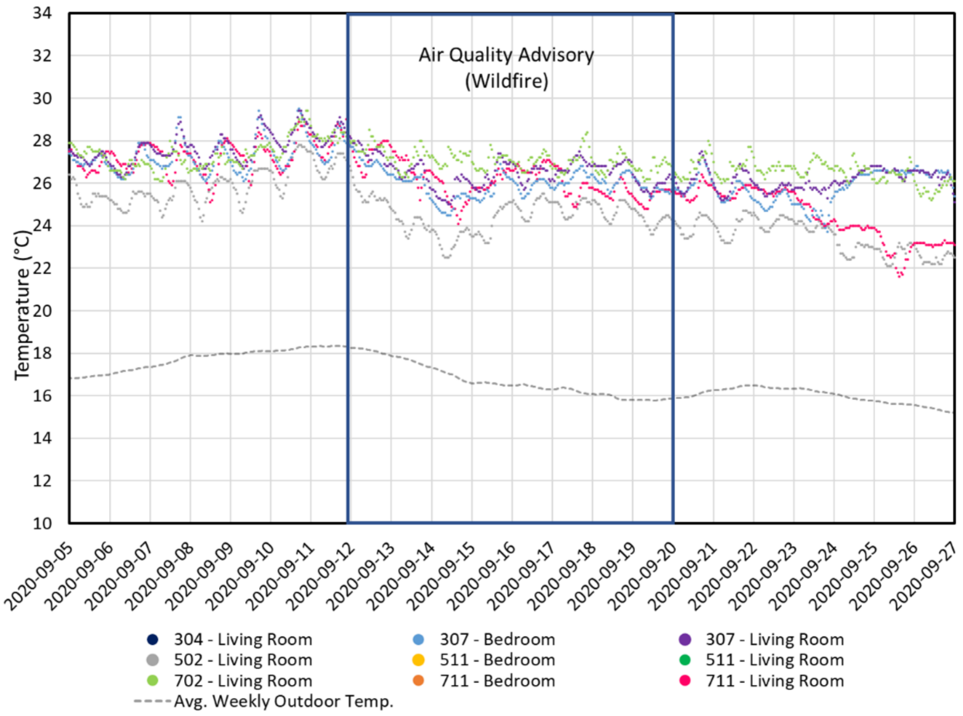


Appendix F.2 – Carbon Dioxide concentrations for three-week period during Air Quality Advisory (Wildfire) for Building A

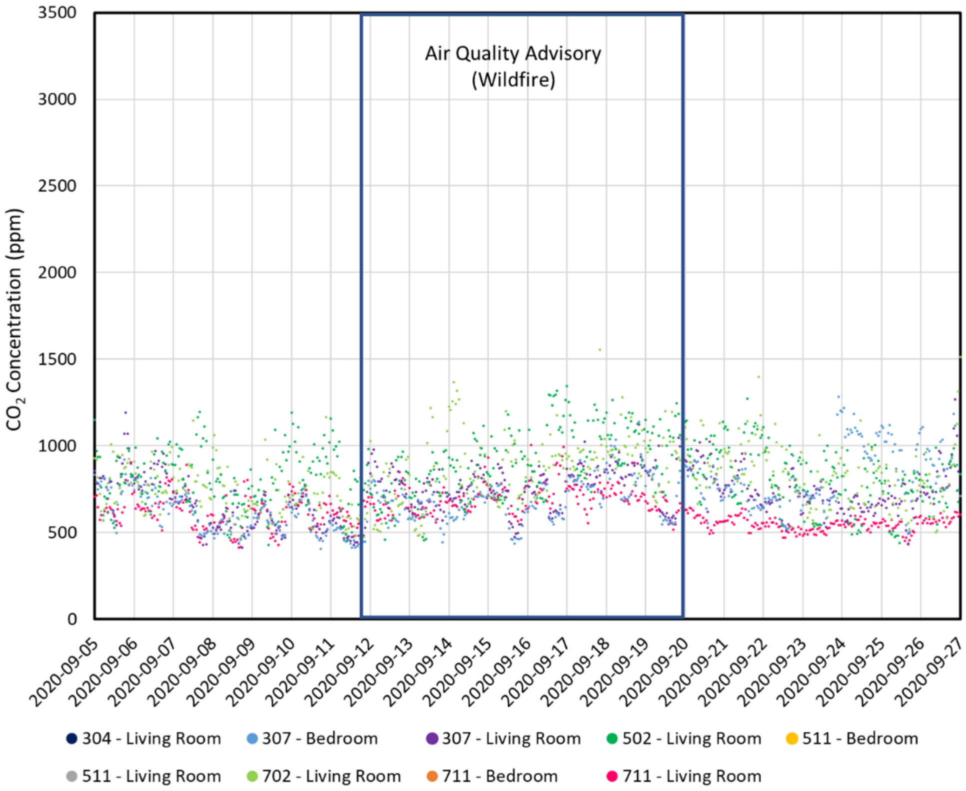


Appendix F.3 – Air temperature for three-week period during Air Quality Advisory (Wildfire) for Building B

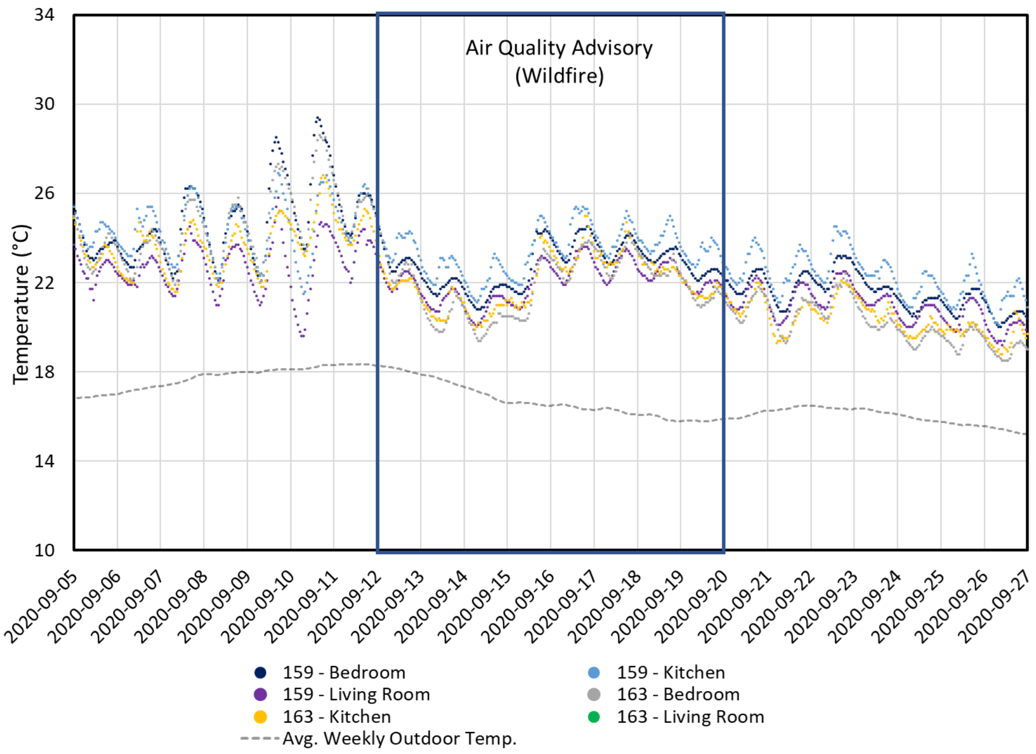
Appendix F.4 – Carbon Dioxide concentrations for three-week period during Air Quality Advisory (Wildfire) for Building B



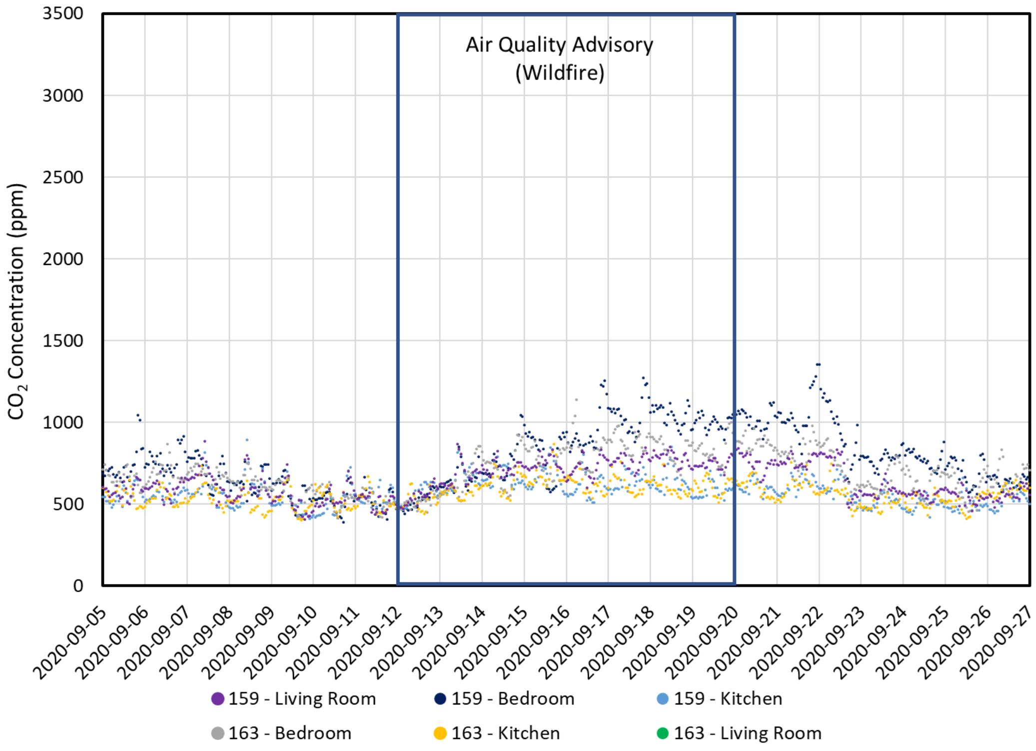
Appendix F.5 – Air temperature for three-week period during Air Quality Advisory (Wildfire) for Building C



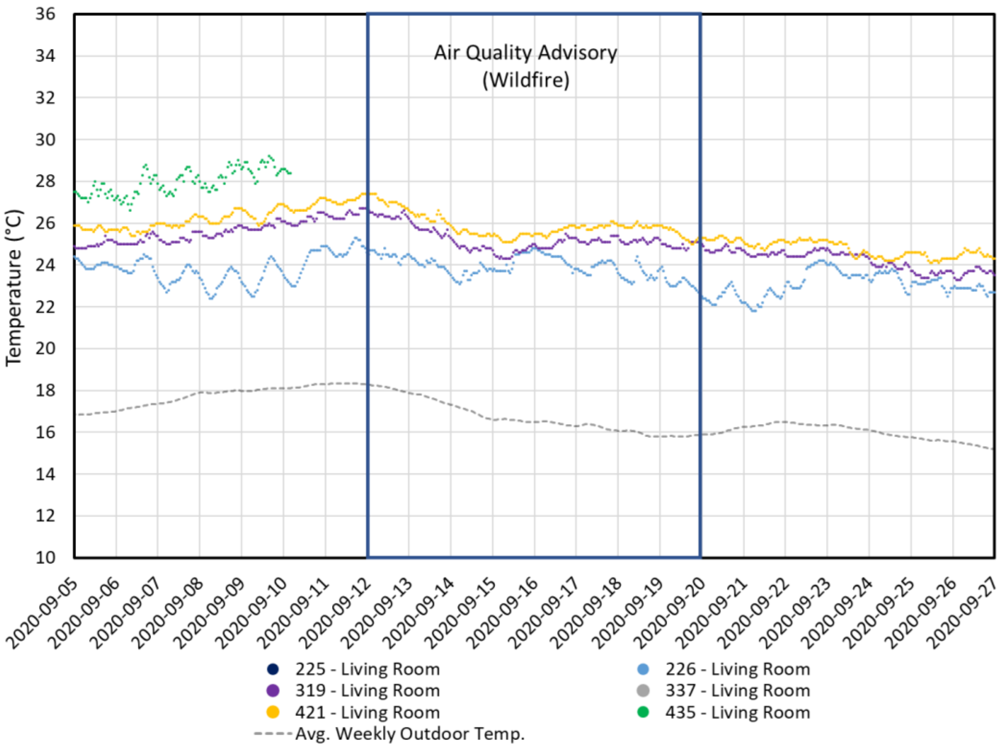
Appendix F.6 – Carbon Dioxide concentrations for three-week period during Air Quality Advisory (Wildfire) for Building C



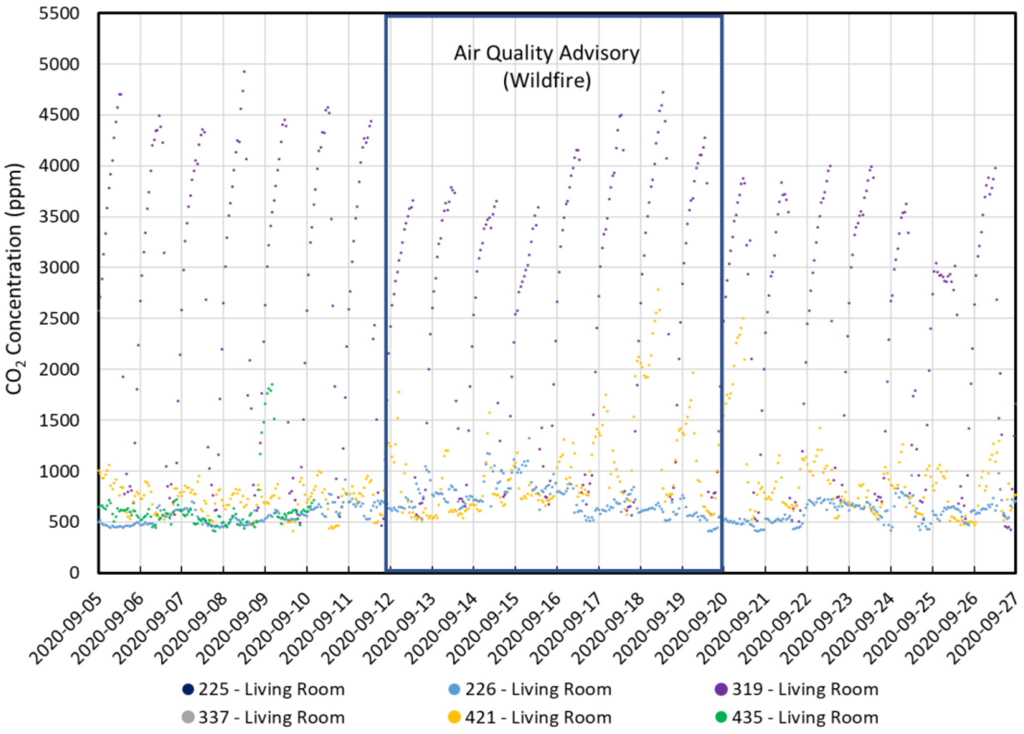
Appendix F.7 – Air temperature for three-week period during Air Quality Advisory (Wildfire) for Building D



Appendix F.8 – Carbon Dioxide concentrations for three-week period during Air Quality Advisory (Wildfire) for Building D



Appendix F.9 – Air temperature for three-week period during Air Quality Advisory (Wildfire) for Building E.



Appendix F.10 – Carbon Dioxide concentrations for three-week period during Air Quality Advisory (Wildfire) for Building E. Note the scale for this graph is significantly higher than the other buildings (3500 vs. 5000 ppm).

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