# Calibrating the Zero Emissions Building Plan and BC Energy Step Code


Prepared by:

**Sarah Crosby**

UBC Greenest City Scholar, 2019

Prepared for:

**Patrick Enright**

Green Building Engineer, City of Vancouver


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## Executive Summary

In 2011, the City of Vancouver developed the Greenest City Action Plan (GCAP) for the goal of becoming the greenest city in the world by 2020. The GCAP prepares the City of Vancouver to stay on the leading edge of urban sustainability while preparing the city for the future consequences of climate change. The Greenest City Action Plan is divided into 10 goal areas addressing three main areas: Zero Carbon, Zero Waste, and Healthy Ecosystems. The 3rd goal of the CoV GCAP is the 'Green buildings' goal, in which two targets are set to be achieved by 2020: First target aims to reduce the greenhouse gas (GHG) emissions in existing buildings by 20% over 2007 levels by 2020. The second target in the green buildings goals is to have all the new constructed buildings (from 2020 onwards) to be 'carbon neutral'. In order to achieve the greenest city green buildings goals, the City's Zero Emissions Building Plan (ZEBP) has been developed [3]. The CoV ZEBP and the provincial BC Energy Step Code set limits on energy use in new buildings in order to reduce the GHG emissions. To show that a proposed building design meets these limits, an energy model is created, and that model has a number of energy use assumptions laid out in the City of Vancouver Energy Modelling Guidelines (EMG) [1].

This study seeks to investigate the energy modelling assumptions laid-out in the CoV energy modelling guidelines (EMG) and the BC Energy Step Code by calibrating these baseline assumptions using actual building energy consumption data. This research study also aims to explore any discrepancies that exist between actual building energy consumptions and baseline assumptions in the current building codes. Possible causes of these discrepancies are discussed accordingly and potential improvements to the current version of the City of Vancouver's EMG are explored and proposed in this report.

Energy consumption data for residential buildings in the City of Vancouver are collected from different sources, such as sub-metering companies, energy providers and research centres. With a special focus on occupant-driven building's loads, energy consumption data for domestic hot water, space heating, cooking energy consumption, plug loads and lighting are gathered. Data collected has been cleaned, parsed and analyzed for the calibration process of each of the energy consumption dataset collected. A detailed study has been conducted on the domestic hot water building energy consumptions using data from 37 different building across Vancouver. Recommendations for improvements to the current methodology of domestic hot water modelling in the CoV energy modelling guidelines are proposed. The energy losses associated with the domestic hot water recirculation are studied using actual data from residential buildings

in Vancouver. A proposed mechanism which incentivizes the reduction of temperature maintenance heat losses is developed and discussed in this report.

Occupancy data from various sources are collected and used to calibrate the current occupancy assumptions made in the City's energy modelling guidelines. Proposed occupancy assumptions are developed and discussed accordingly. A detailed study of the effect of building's sub-metering on the energy savings has been conducted, using energy consumption data from the South East False Creek Neighbourhood. A factor that accounts for building sub-metering is proposed and added to the current domestic hot water modelling assumptions. A study on the plug load and lighting energy consumption is conducted and energy consumption calibration is performed on different residential buildings across Canada and the US. A proposed methodology for the plug loads estimation is proposed in this research study. The cooking energy consumption has been investigated and the current assumptions in the energy modelling guidelines are calibrated accordingly. A proposed correlation for the cooking energy consumption modelling is developed.

A detailed study is performed on the space heating energy consumption data from various residential building in Vancouver, the variation in the unit-level yearly heating demand has been investigated and compared with the current assumptions made in the provincial BC Energy Step Code. Recommendations have been developed in order to avoid common overheating problems, especially in passive house buildings.

The key findings developed in this research suggest improvements and recommendation on the current version of the City of Vancouver Energy Modelling Guidelines and the Zero Emissions Building Plan (ZEBP). These recommendations might be included in version 3.0 of the Energy Modelling Guidelines to be published by the City of Vancouver in 2019 or 2020, and might be included in a proposed new national standard for energy modelling guidelines to be developed by the Canadian Standards Association with the CoV Energy Modelling Guidelines as a foundational document.

# 1- Introduction

Climate change's effects are becoming more and more observable on the environment every day. Water availability has reduced, glaciers have shrunk, weather patterns have changed, plant and animal ranges have shifted, sea levels have risen, and icecaps have defrosted and melted. Scientists have high confidence that global temperatures will continue to rise for decades to come, largely due to greenhouse gases produced by human activities [4]. Thus, the need to mitigate climate change is becoming more urgent than ever. Governments around the world should put in place strategies to regulate greenhouse gas emissions and develop green industries and implement more renewables.

The City of Vancouver adopted the Greenest City Action Plan (GCAP) in 2011 aiming to become the greenest city in the world by 2020. This plan sets the course towards realizing a healthy, prosperous and resilient future for the city of Vancouver by helping Vancouver to stay on the leading edge of urban sustainability while preparing the city for the future consequences of climate change [2]. The GCAP is divided into 10 large goal areas addressing three main areas: Zero Carbon, Zero Waste, and Healthy Ecosystems.

Canadians spend 90% of the time indoors, which makes the buildings we live and work in a big part of our lives. Buildings are also a big part of Vancouver's carbon footprint—the amount of carbon we are responsible for releasing into the atmosphere. The electricity and natural gas that buildings use make up 55% of Vancouver's greenhouse gas emissions [2]. The green buildings goal is the 3$^{rd}$ goal in the Vancouver's Greenest City Action Plan. It sets two targets to be achieved by 2020: reducing the greenhouse gas (GHG) emissions in existing buildings by 20% over 2007 levels by 2020 and having all the new constructed buildings, from 2020 onwards, to be 'carbon neutral'.

The CoV Zero Emissions Building Plan (ZEBP) has been developed in order to achieve the greenest city's green buildings goals [3]. Along with the provincial BC Energy Step Code, the ZEBP sets limits on the energy used in new buildings to reduce the greenhouse gas emissions and in order to show that a proposed building design meets these limits, an energy model is created, and that model has a number of energy use assumptions laid out in the CoV Energy Modelling Guidelines (EMG) [1].

This research aims to calibrate the energy modelling assumptions laid-out in the CoV energy modelling guidelines (EMG), the zero-emissions building plan (ZEBP) and the BC Energy Step Code. Existing discrepancies between actual building energy consumptions and the baseline assumptions in the current building codes are explored in this report. Potential causes of these discrepancies are discussed and recommendations to the current building codes and policies are proposed to be implemented in version 3.0 of the Energy Modelling Guidelines to be published by the City of Vancouver in 2019 or 2020.

## 2- Research Objectives and Methodologies

This research seeks to investigate building energy consumption modelling criteria in the current building codes and policies by calibrating the building energy use assumptions laid-out in the City of Vancouver Zero Emissions Building Plan and the provincial BC Energy Step Code. Key findings and recommendations for future development on the current building codes and standards are proposed in this report.

In order to calibrate the assumptions made in the CoV energy modelling guidelines, actual building energy use data from residential buildings in Vancouver are collected from various sources, such as sub-metering companies, energy providers and research centres. Focusing on occupant-driven buildings energy consumption, energy use data for domestic hot water, space heating demand, cooking energy consumption, plug loads and lighting are collected for the purpose of this research.

Actual Energy consumption data of domestic hot water from 37 different residential buildings in the city of Vancouver are collected from various sources. The collected domestic hot water consumption data are either in-suite volumetric hot water consumption in litres for monthly or bimonthly consumption or thermal energy consumption for in-suite use. Occupancy information are also gathered and used to calibrate the DHW consumption with the assumptions made in the guidelines. Key findings and recommendations for improvements to the current methodology of domestic hot water modelling in the CoV energy modelling guidelines are discusses in detail in the next section.

A detailed study is conducted on calibrating the building's occupancy assumptions laid-out in the City's energy modelling guidelines in order to improve the energy consumptions predictions to accurately reflect the reality. Occupancy datasets are collected from different sources for the purpose of this research. A new modified occupancy assumptions methodology is proposed and discussed in the next sections. The energy losses from the service water heating recirculation are investigated using actual energy data from residential buildings in Vancouver. A proposed mechanism which drives incentives for reducing temperature maintenance heat losses is developed and discussed.

The potential energy savings from implementing building sub-metering are studied. Actual energy consumption data from residential buildings in the City of Vancouver are collected and used for comparing the energy consumption from both metered and non-metered buildings and calculate the energy savings accordingly. Energy use data from 30 multi-unit residential buildings (MURBs) in the City of Vancouver South East False Creek (SEFC) neighborhood are collected and analyzed. Data analysis results led to developing a proposed mechanism that should be used to incentivize building sub-metering in future versions of the City of Vancouver's energy modelling guidelines.

Cooking energy consumption data are collected in 2014, 2015, and 2016 by Redwood Energy Company. Cooking energy consumption data from 2 different buildings are used in this study. The cooking energy use data are used to calibrate the current assumptions in the CoV guidelines and a novel correlation for the cooking energy consumption modelling is developed and proposed in the coming section. Consumption data for plug loads and lighting are collected in order to calibrate the consumption with the assumptions made in the guidelines. Data from different residential buildings across Canada and the US are collected and analyzed. A proposed methodology for the plug loads estimation is proposed and discussed in the next sections.

A detailed study is performed on the space heating energy consumption data from various residential building in Vancouver, the variation in the unit-level yearly heating demand has been investigated and compared with the current assumptions made in the provincial BC Energy Step Code. Recommendations have been developed in order to avoid common overheating problems, especially in passive house buildings.

Key findings developed in this research are discussed in the coming section, recommendation for improvement on the current version of the City of Vancouver Energy Modelling Guidelines and the Zero Emissions Building Plan (ZEBP) are proposed. These recommendations might be included in coming version of the Energy Modelling and might be included in a proposed new national standard for energy modelling guidelines to be developed by the Canadian Standards Association with the CoV Energy Modelling Guidelines as a foundational document.

# 3- Research Findings and Discussion

## 3.1. Domestic Hot Water Consumption Analysis

### 3.1.1. Research Objectives

Domestic hot water (DHW) energy consumption accounts for a significant share of energy consumption in different types of buildings. In Canada, for example, between 2000 and 2008, the domestic hot water (DHW) demands accounted for 18% of all energy end-use in the housing sector and 3% of the country's total secondary energy consumption [5]. Prior studies found that domestic water heating accounts for 25% of the total energy use in multi-unit residential buildings in the US west coast [6].

Consequently, calibrating the domestic hot water modelling assumptions in the City of Vancouver's energy modelling guidelines is one of the most important goals of this study. The purpose of calibrating the current DHW modelling assumptions laid out in the guidelines is for the modelling assumptions to better reflect actual energy use, and hence identify additional ways to reduce consumption and energy use for DHW. Accordingly, actual DHW energy consumption data from buildings in the City of Vancouver are collected and compared with the assumptions made in the CoV energy modeling guidelines in order to research discrepancies between current assumptions and actual energy consumptions data and suggest recommendations to the current method of modeling the DHW energy consumption.

### 3.1.2. Research Methodologies

Actual Energy consumption data of domestic hot water from residential buildings in the city of Vancouver are collected. Data from 37 different buildings are collected from various sources; e.g. sub-metering companies, energy providers and research centres.

Since the DHW consumption data are collected from different sources, their format varies too: some of the data gathered are thermal energy consumption data for service water heating, and same data are for in-suite volumetric hot water consumption in litres for monthly or bimonthly consumption. The occupancy information for each building studied are also collected. In some cases when the building occupancy information are limited, the unit type breakdown for each building are used instead and the City's occupancy assumptions, laid-out in Table 7, are used to calculate the occupancy for each unit. The current modelling assumptions made in the City's energy modelling guidelines assumes a 0.0016 L/s/person modelled as the peak hourly flow and modified by the NECB operating schedule -Table A-8.4.3.2.1-G [7], as shown in Figure 1. The assumed DHW energy consumption is then calculated as follows:

$$Q = CoV\ Peak\ load * \#Persons/building * NECB\ operating\ schedule \quad (1)$$

Where:

Q is the DHW consumption in L/s,

The CoV peak load = 0.0016 L/s/person,

The NECB service water heating system schedule should be used to calculate the hourly fraction of load and multiply it by the CoV peak load,

The number of persons/buildings (if not directly known) should be calculated using the CoV occupancy assumptions along with the building's units' breakdown (the number of units for each type of unit, for e.g. the number of 1-bedroom unit, 2 bedrooms units...etc.)

As an example, Table 1 was used in the calculations process of the number of persons/ building in one of the buildings used in this study:

| Building Details | | CoV Occupancy | | |
|---|---|---|---|---|
| | **Count** | **Persons/unit** | **People Count** | |
| Studio | 22 | 1 | 22 | |
| 1 Bed | 26 | 2 | 52 | |
| 2 Bed | 15 | 3 | 45 | |
| 3 Bed | 7 | 4 | 28 | |
| Total | **70** | | **127** | person/bldg. |

Table 1: Occupancy Calculations using the CoV Occupancy Assumptions

| Service Water Heating System, fraction of load | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mon - Fri | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.2 | 0.8 | 0.7 | 0.5 | 0.4 | 0.2 | 0.2 | 0.2 | 0.3 | 0.5 | 0.5 | 0.7 | 0.7 | 0.4 | 0.4 | 0.2 | 0.2 | 0.1 | 0.1 |
| Sat | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.2 | 0.5 | 0.5 | 0.5 | 0.3 | 0.3 | 0.3 | 0.3 | 0.7 | 0.9 | 0.7 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 |
| Sun | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.2 | 0.3 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.4 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 |

Figure 1: Service Water Heating Faction of Load -NECB Operating Schedule G – Table A-8.4.3.2.1 [7]

The actual building DHW consumption data are calculated using in-suite consumption data and occupancy information for each building. If building occupancy information is limited, the CoV occupancy assumptions are used instead. If DHW thermal energy consumption data are collected, the building monthly volumetric consumption for the DHW is calculated as follows:

$$V = \frac{Q*10^6*3600}{\rho*\Delta T*C_p} \qquad (2)$$

Where:

Q= DHW Monthly Thermal Energy Use [MWh]

Cp = Specific Heat of Water [ KJ/Kg.K] = 4.18 KJ/KG.K

$\Delta$T = DHW Temperature Difference [C$^o$]

= DHW Output Temperature – DCW Supply Temperature = 60 – 10 = 50 [C$^o$]

V = DHW building monthly consumption [L/month]

$\rho$= Water Density = 1000 Kg/m$^3$

### 3.1.3. DHW Consumption Calibration Results

The actual domestic hot water energy use data are compared with calculated DHW energy assumptions for the 37 buildings studied. Results of all the calibrated DHW energy consumptions are shown in Figure 2Figure 3Figure 4Figure 5Figure 6Figure 7Figure 8.

Figure 2 shows the results of the DHW energy consumption for a 192 units MURB in Vancouver, the average unit area is 54 $m^2$. The units' breakdown for building 1 is laid out in Table 2.

| Building 1 | Count |
|---|---|
| **Studio** | 101 |
| **1 bedroom** | 56 |
| **2 bedrooms** | 35 |
| **Total** | 192 |

Table 2: Building 1 Units Breakdown

The actual monthly consumption is compared with the calculated monthly CoV assumptions in litres/month for the entire buildings. The results are showing an underestimation of the actual DHW consumption from the CoV energy modelling guidelines side. It is also obvious from the calibration results that there is an apparent seasonal variation in the domestic hot water consumption between winter, spring, summer and fall months. Figure 3 shows the DHW bimonthly energy consumption for 2 strata buildings in UBC neighbourhood. The number of units of both buildings is 172 units and the average unit size is 79 $m^2$. The units' breakdown for building 2 and 3 is laid out in Table 3.

| Building 2 and 3 | Count |
|---|---|
| **1 Bedroom** | 27 |
| **2 bedrooms** | 101 |
| **3 bedrooms** | 44 |
| **Total** | 172 |

Table 3: Building 2- and 3-Units Breakdown

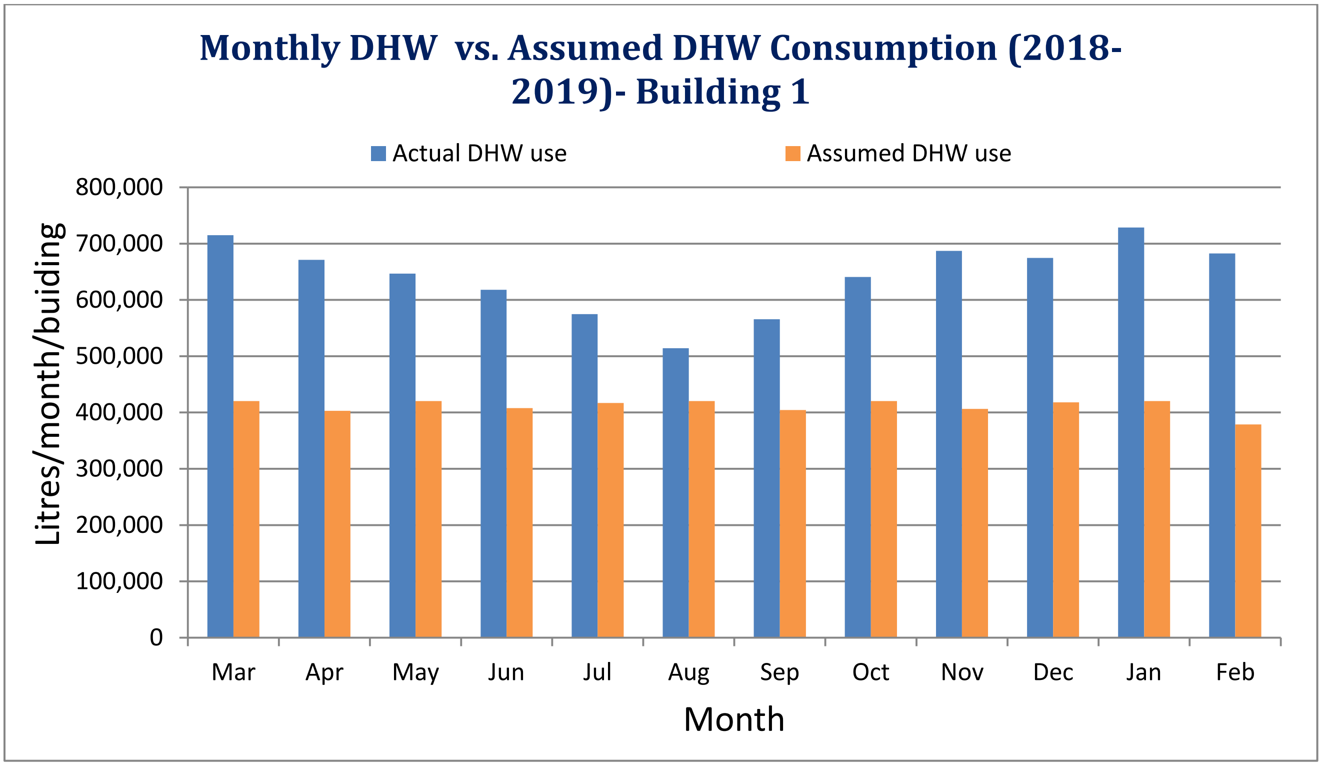


Figure 2: DHW Monthly Energy Consumption: actual vs CoV assumed consumption- Building 1

Figure 4 shows the calibration results for the DHW consumption of building 4. Building 4 is a wood frame low-rise in Kitsilano neighbourhood, which consists of 70 units. The units' breakdown for building 4 is laid out in Table 4.

| Building 4 | Count |
|---|---|
| **Studio** | 22 |
| **1 Bedroom** | 26 |
| **2 bedrooms** | 15 |
| **3 bedrooms** | 7 |
| **Total** | 70 |

Table 4: Building 4 Units Breakdown

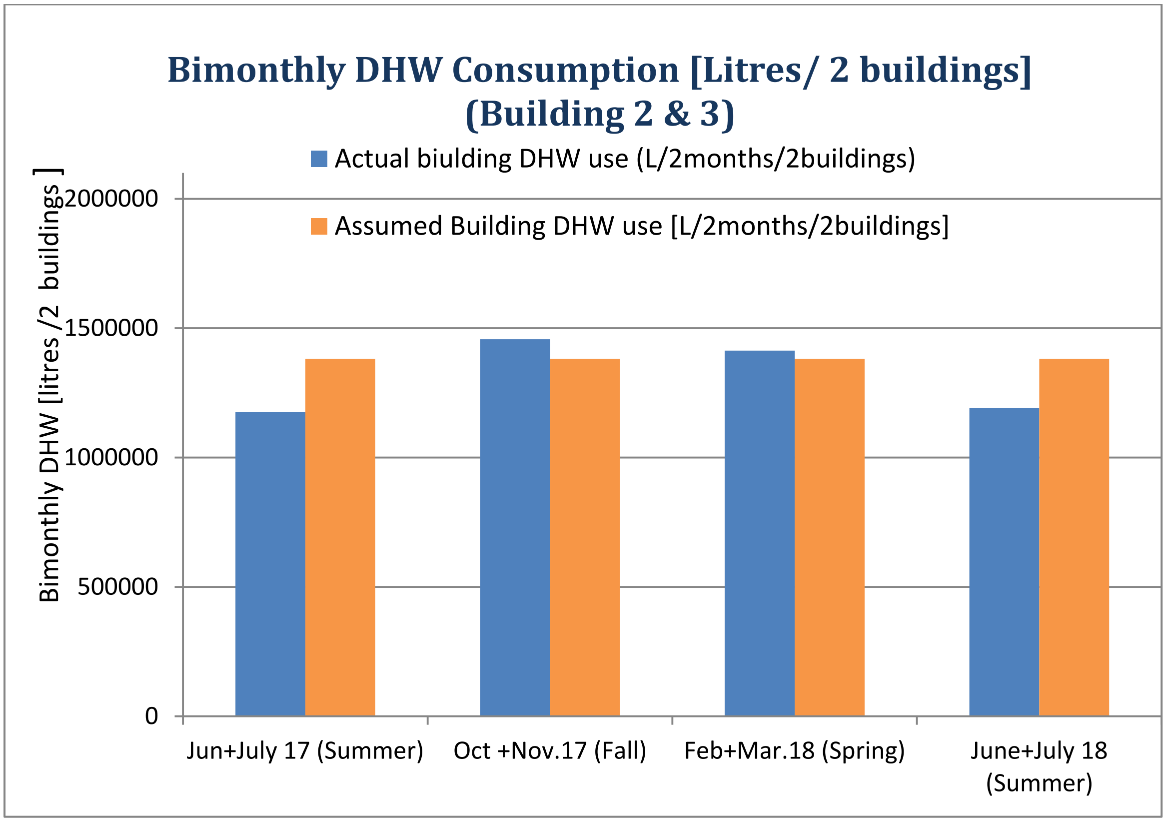


Figure 3: DHW Bimonthly Energy Consumption: actual vs CoV assumed consumption- Building 2 and 3.

Figure 5 shows the calibration results for the DHW consumption of building 5. The building is a 101 units MURB located in the Olympic Village are in Vancouver. The units' breakdown for building 5 is laid out in Table 5.

| Building 5 | Count |
|---|---|
| **1 Bedroom** | 59 |
| **2 Bedrooms** | 12 |
| **3 Bedrooms** | 16 |
| **4 Bedrooms** | 14 |
| **Total** | 101 |

Table 5: Building 5 Units Breakdown

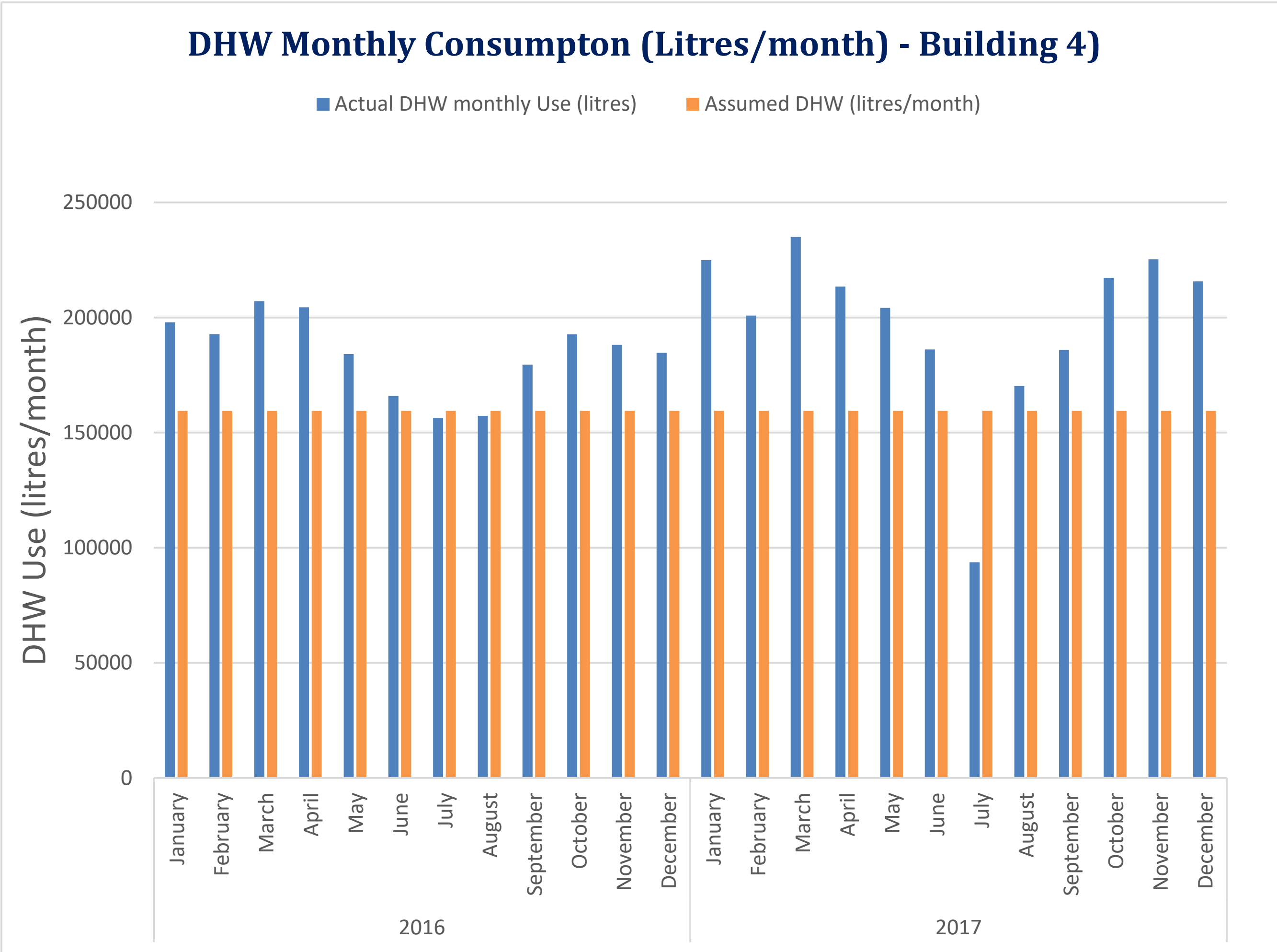


Figure 4: DHW Monthly Energy Consumption: actual vs CoV assumed consumption- Building 4

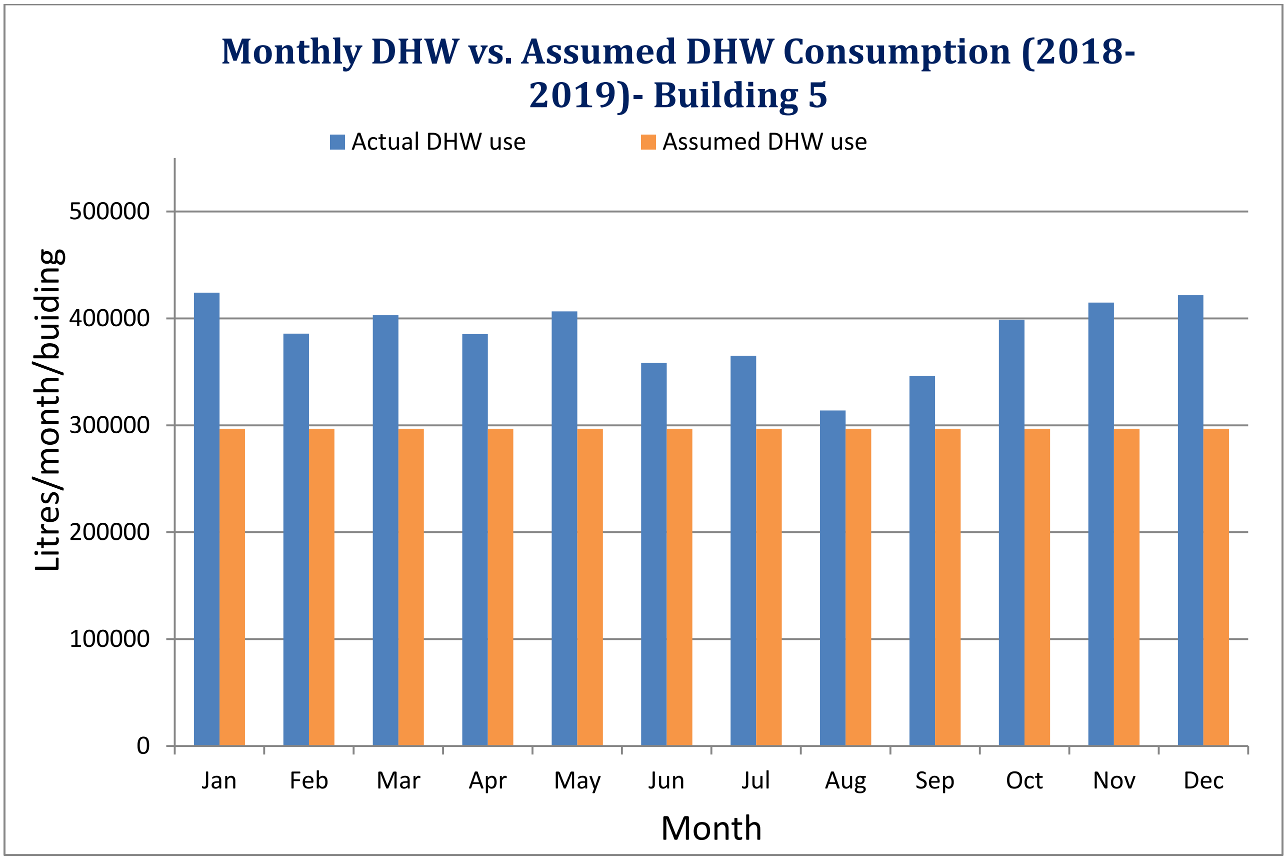


Figure 5: DHW Monthly Energy Consumption: actual vs CoV assumed consumption- Building 5

Figure 6 shows the DHW energy consumption data for 28 buildings located in the Southeast False creek neighbourhood in Vancouver. Thermal energy summer data are used and converted into monthly hot water consumption use for the 28 buildings studied as shown in equation (2). The average monthly consumption for all the buildings studied is compared with the average assumed DHW consumption, as shown in Figure 6.

It is also important to note that the data collected from the Southeast False Creek NEU are thermal energy for summer data only assuming that these data are a proxy for domestic hot water heating, assuming no heating energy will be used in summer time. However, it is still possible that some of the thermal energy is used in summer by make-up air units on cool summer nights, so it is possible that the actual data skews to the high side. However, this dataset is the most indirect dataset used in this study.

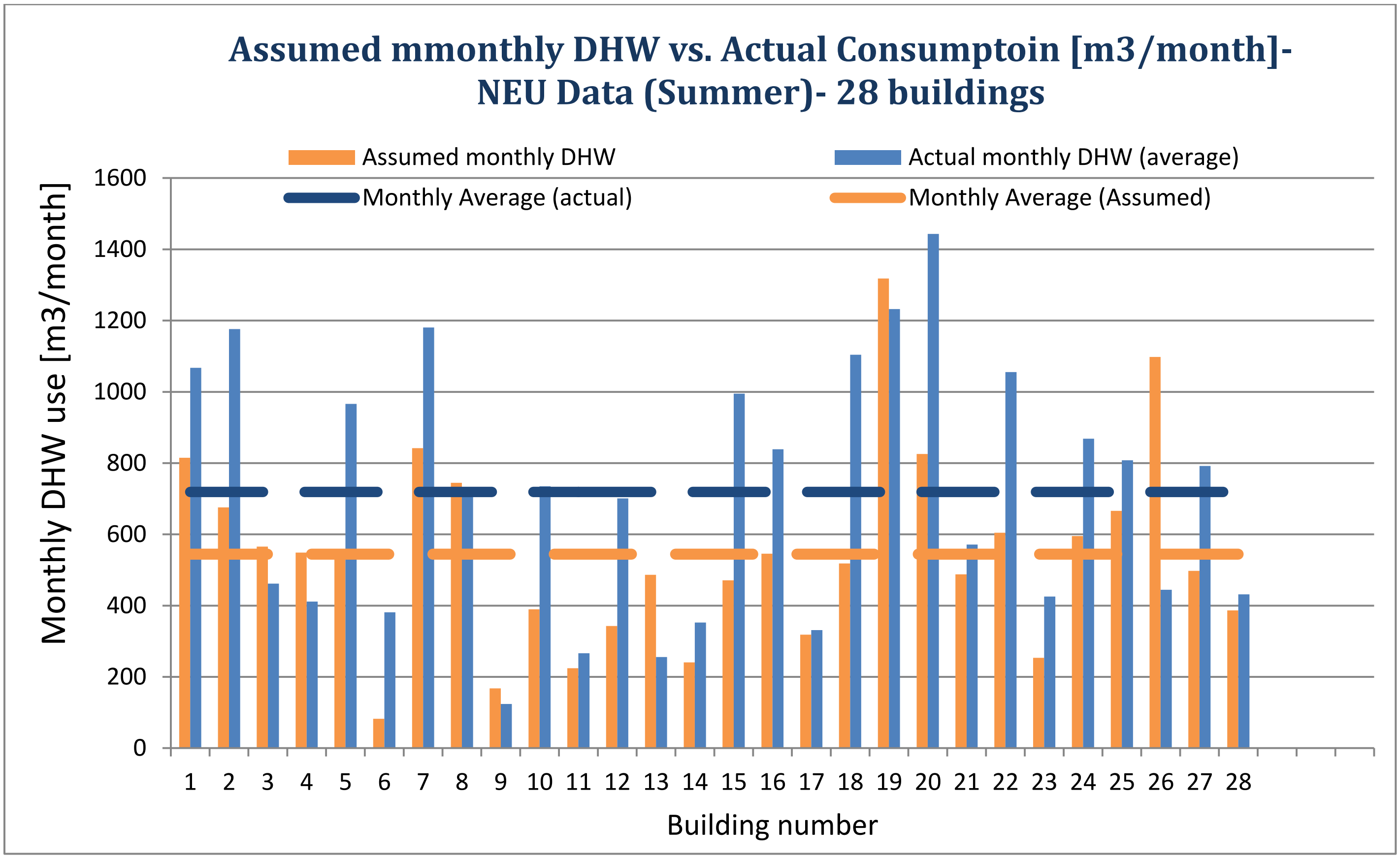


Figure 6: DHW Energy Consumption: actual vs CoV assumed consumption- Building 6-34

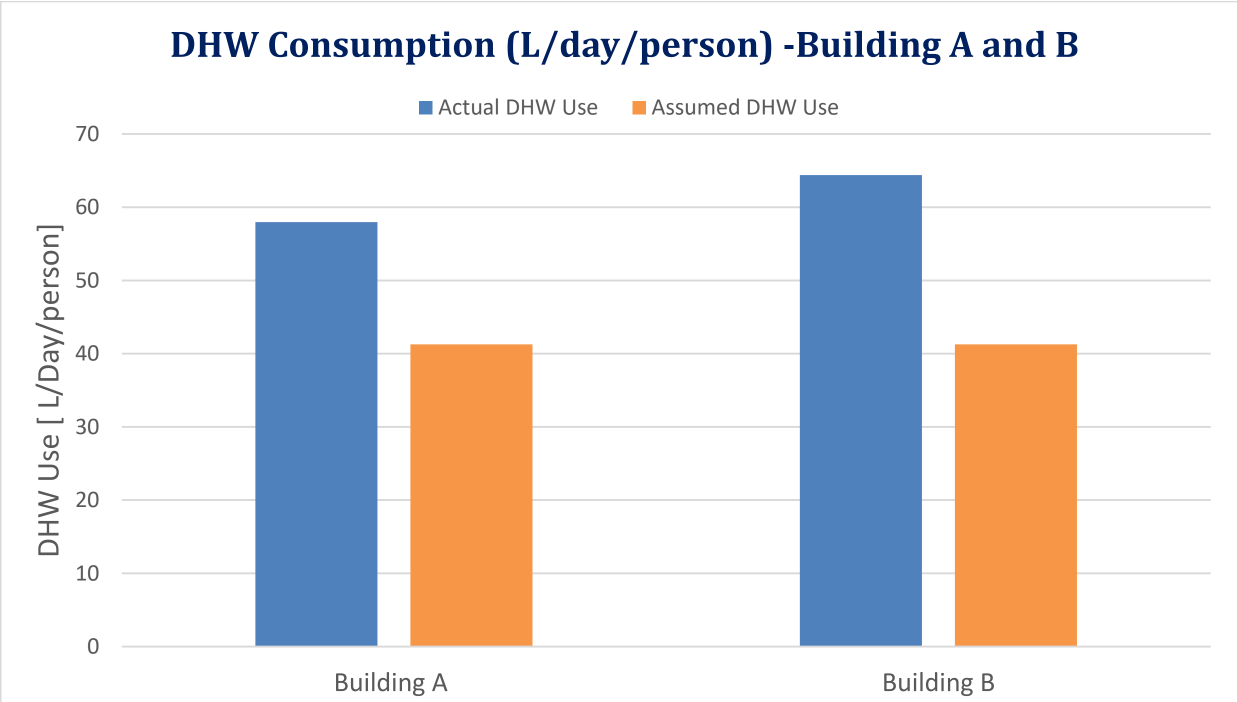


Figure 7: DHW Energy Consumption: actual vs CoV assumed consumption- Building 35-36

Figure 7 and Figure 8 show the DHW energy consumption for building 35,36 and 37. DHW use in Litres/day/person is calculated for the 3 buildings and compared with the assumed value in the energy modelling guidelines.

### 3.1.4. Proposed DHW Modelling Methodologies

The previous calibration results from the 37 buildings studied are showing that there exists an underestimation on the city of Vancouver energy modelling guidelines side. Based on the observed collected data and the calibration data analysis performed on the 37 buildings' DHW consumption data, 5 new recommendations are discussed and proposed in this study. These recommendations should be added to the current domestic hot water energy modelling assumptions in order to reflect the actual DHW consumption scheme.

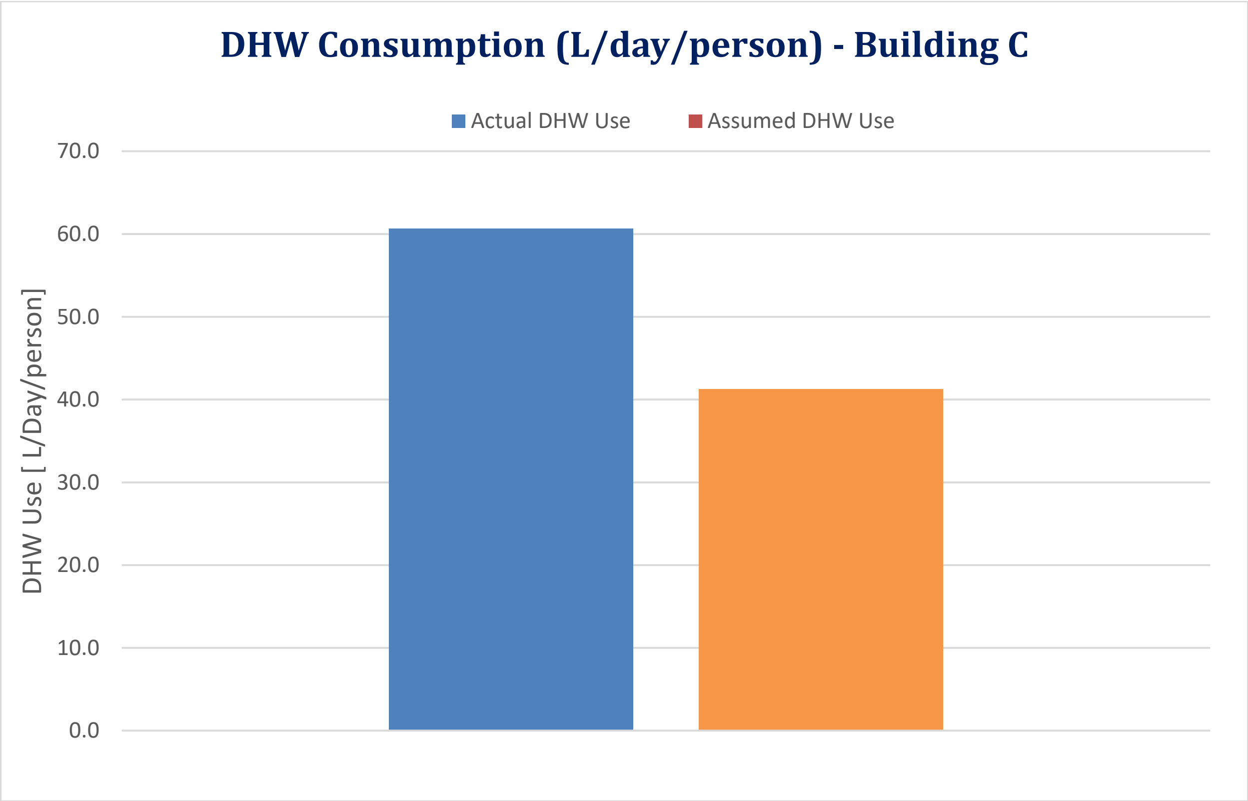


Figure 8: DHW Energy Consumption: actual vs CoV assumed consumption- Building 37

*3.1.4.1. Increasing the Peak Load for the DHW Consumption*

Calibration data analysis results are suggesting modifying the current peak load assumption for the DHW energy consumption in the CoV energy modeling guidelines to increase to 0.0021 L/s/person. Application of this proposed methodology to the current calibration curves studied will be shown in detail in later sections in this report.

*3.1.4.2. Proposing a Seasonal Multiplier to the current DHW modelling assumptions*

It is evident from the previous results that the average domestic hot water consumption decreases significantly in summertime, which means that occupants tend to use less hot water in summer months. Consequently, another important recommendation that resulted from the observed data calibration is to introduce a seasonal multiplier which is a factor that reflect the monthly variation in domestic hot water consumption throughout the year. The proposed seasonal multiplier is laid-out in Table 6. These values has been proposed based on observed data and has been inferred by fixing all other parameters and taking into account only varying the seasonal multiplier, the results have then been tested and applied again to the previous DHW curves and the results are shown in later section in this report. It is important to note that the seasonal multiplier table has been designed so that the average of all the months is always equals to 1, so that its value won't affect the other factors while calculating the annual DHW consumption, but it is important to implement it to the monthly calculations to reflect the actual monthly consumption and to accurately design all the building's mechanical equipment for seasonal variations in load.

| MONTH | SEASONAL MULTIPLIER | MONTH | SEASONAL MULTIPLIER |
|---|---|---|---|
| JAN | 1.1 | JUL | 0.8 |
| FEB | 1.2 | AUG | 0.8 |
| MAR | 1.1 | SEP | 0.9 |
| APR | 1.0 | OCT | 1.0 |
| MAY | 1.0 | NOV | 1.1 |
| JUN | 0.9 | DEC | 1.1 |

Table 6: Proposed seasonal multiplier to be added to the current Domestic hot water consumption assumptions

### *3.1.4.3. Proposing a recirculation DHW Heat Loss factor*

Previous studies have found that the domestic hot water recirculation heat losses can reach up to 45% of the total energy supplied [6]. However, this issue has always been ignored by the current building codes and standards. Using DHW mechanical data along with consumption energy data collected from building in the City of Vancouver, the energy losses associated with the DHW recirculation has been investigated. A new mechanism that should be added to the current methodology of DHW modelling is proposed and laid-out in detail in section 3.3. The proposed mechanism suggests adding a DHW loss factor which will incentivize the reduction of temperature maintenance heat losses.

#### *3.1.4.4. Proposed new Occupancy assumptions*

It is concluded from the DHW energy consumption calibration data analysis that the occupancy assumptions laid-out in the city of Vancouver energy modelling guidelines (shown in Table 7) are not always reflecting the actual buildings occupancy, based on the observed data. In order to calibrate the occupancy assumptions and recommend new values that reflect the reality in a more accurate way, occupancy data are collected from various buildings across the city of Vancouver and are used to propose new occupancy assumptions. The proposed methodology will be explained in detail in section 3.2.

#### *3.1.4.5. Proposing a submetering factor for the DHW consumption*

Another important aspect that contributes to how the domestic hot water consumption should be modelled is whether the building is sub-metered or not. Previous studies have shown that buildings sub-metering has a significant effect on decreasing the energy consumption and increasing energy savings [8],[9]. This issue is ignored in current buildings codes and standards. It is therefore important to investigate the effect of building submetering on the energy consumption of DHW.

DHW energy consumption data from both metered and un-metered buildings in the City of Vancouver are collected, and the potential energy savings from implementing building sub-metering has been investigated and laid out in section 3.4. A proposed mechanism that should be used in future versions of the City of Vancouver's energy modelling guidelines in order to incentivize building sub-metering is proposed and explained in section 3.4.

## 3.2. Occupancy Calibration Analysis

The number of persons occupying different types of units within a building is not always known exactly when creating energy models for new buildings. Knowing the exact units' occupancy is a hard thing to predict as the exact occupancy information is not always available. The City of

Vancouver energy modelling guidelines has created some assumptions to calculate the building's occupancy; these assumptions are laid-out in Table 7.

| CoV Occupancy Assumptions | |
|---|---|
| Unit Type | persons/unit |
| Studio | 1 |
| 1 Bedroom | 2 |
| 2 Bedrooms | 3 |
| 3 Bedrooms | 4 |
| 4 Bedrooms | 5 |

Table 7: CoV Occupancy Assumptions

During the process of calibrating the domestic hot water consumption and comparing actual data with the assumptions made in the CoV guidelines, it was clear that the occupancy assumptions are not always predicting the real occupancy values especially in the datasets where the exact occupancy values are known. This raises the urgency for a separate calibration analysis for the occupancy assumptions made in the city's guidelines. Accordingly, occupancy data has been collected from different sources, such as Enerpro Systems, Redwood Energy, from 5 different buildings for the purpose of this study. Using A layout of all the occupancy data gathered is shown in Table 8. Based on observed occupancy data, a new modified occupancy assumptions methodology is proposed and laid-out in Table 9.

| | Building 1 | Building 2 | Building 3 | Building 4 | Building 5 |
|---|---|---|---|---|---|
| Studio | - | - | -- | 1.2 | 1.1 |
| 1 bedroom | 1.3 | 1.3 | 1.6 | 1.5 | 1.4 |
| 2 Bedrooms | 2.7 | - | 2.5 | 2.5 | 2.2 |
| 3 Bedrooms | 4 | 4 | 3.5 | - | 2.5 |
| 4 Bedrooms | 5.8 | - | -- | - | - |

Table 8: Occupancy calibration: observed occupancy data from different buildings

Since 4 -bedrooms apartments are rarely found in new buildings, limited data are available for 4 bedrooms units' occupancy, hence, the current assumption is left as it is in the guidelines and as more future occupancy data is collected, the proposed occupancy values can be refined.

| Proposed Occupancy | |
|---|---|
| Unit Type | persons/unit |
| Studio | 1.2 |
| 1 Bedroom | 1.4 |
| 2 Bedrooms | 2.4 |
| 3 Bedrooms | 3.2 |
| 4 Bedrooms | 5 |

Table 9: Proposed occupancy assumptions

## 3.3. Domestic Hot Water Recirculation losses

In a relatively older residential building where domestic hot water recirculation system is not typically installed, waiting time for the hot water to be delivered at each fixture can be too long, especially in the units located on the farther end of the hot water storage tank. Not only the time is wasted, but water and energy too. To get hot water to reach the fixture, it can take many litres and minutes of cold to warm flow which ends up down the drain. Domestic hot water recirculation systems are then installed to maintain sufficiently heated water closer to fixtures in order to avoid wasting water and time at each time there is a hot water demand. The recirculation system will provide the hot water quicker to the fixture by returning the heated water to the storage tank, this recirculation flow rate will decrease the temperature drop in the supply piping.

A typical hot water recirculation system uses a pump to move water in a loop from the central storage tank, past branch pipes for every unit, and back to the central tank. The branch pipes are not continuously flushed with hot water but are short enough that they quickly empty of cool water when occupants open fixtures. Figure 9 illustrates a traditional system lay out.

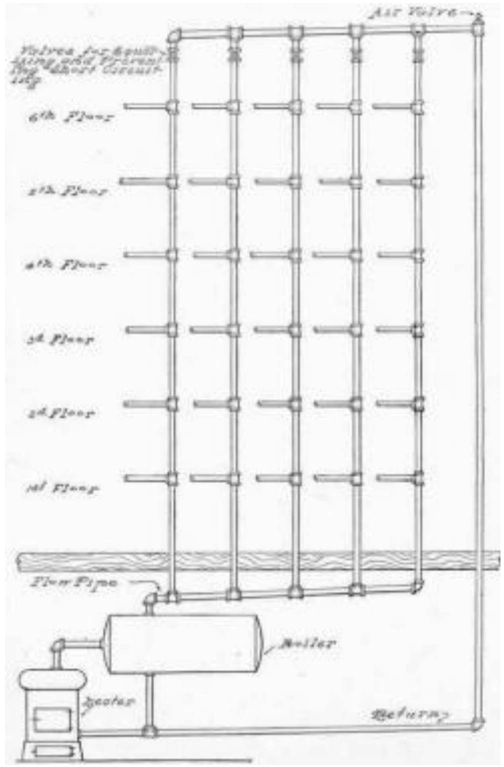


Figure 9: Typical Temperature Maintenance Design [10]

The recirculation systems biggest downside is the heat losses associated with it. Heat loss is a function of insulation and surface area. The longer the recirculation pipe and the less the insulation diameter is, the more heat is lost. Previous studied found that 30-45% of the energy supplied by the heat pumps escapes from the storage, distribution, and recirculation piping rather than used at the hot water fixtures [6]. With low water usage associated with low flow fixtures and less water-intensive lifestyles these distribution losses can account for a very high fraction of the total water heat energy.

An important conservation measure is to reduce these losses by paying close attention to the insulation of the recirculation piping. Every portion of pipe (even valves) with circulating water must be insulated. The insulation should be continuous through the supporting clamps with technology similar to that shown in Figure 10 and more attention should be paid to fitting insulation throughout the recirculating piping system.

Figure 10: Recommended Configuration for Full Pipe Insulation [6].

Although the domestic hot water recirculation heat losses can reach up to 45% of the total energy supplied, this issue has always been ignored by the current building codes and standards.

It is important to note that the studies referenced above resulted from data that have been collected in the US and studying the domestic hot water recirculation heat losses from buildings across Canada may or may not lead to slightly different results due to differences in energy rates and culture related to energy use. It is then the purpose of this study to investigate the domestic hot water recirculation heat losses from buildings in the City of Vancouver, compare it to previous studies and suggest a mechanism that can help drive incentives for reducing temperature maintenance heat losses.

Mechanical Data along with in-suite metering data for 2 strata buildings in Vancouver are collected from Enerpro systems, a Vancouver-based submetering company. The DHW is supplied from a waste heat recovery system and from regular gas boilers. The bi-monthly thermal energy consumption of the domestic hot water boiler and from the heat recovery unit along with the bi-monthly in-suite hot water consumption in litres are used to calculate the domestic hot water recirculation losses as follows:

$Q_{DHW} = \frac{V * Cp * \Delta T}{3600}$ [KWh] (3)

$Q_{loss} =$ DHWKWh + WHRKWh - $Q_{DHW.}$ (4)

% $Q_{loss.}$ = Percentage DHW Recirculation losses = $\left(\frac{\text{Qloss}}{DHWKWh+WHRKWh}\right) * 100.$ (5)

Where:

DHWKWh = DHW Energy (Boiler to DHW loop) [KWh]

WHRKWh = Waste Heat Recovery (WHR) Output Energy [KWh]

Cp = Specific Heat of Water [ KJ/Kg.K] = 4.18 KJ/KG.K

$\Delta T$ = DHW Temperature Difference [$C^o$]

= DHW Output Temperature – DCW Supply Temperature = 60 – 10 = 50 [$C^o$]

DCW = Domestic Cold Water supply temperature = $10^o$C [16]

$Q_{DHW}$= DHW Thermal Energy [KWh]

V = DHW building consumption [L]

$Q_{loss}$ = DHW Recirculation Energy Loss [KWh]

Data analysis results for the DHW recirculation losses of the studied buildings are laid-out in Figure 11. The average percentage of recirculation losses is 31%, which is very close to the previous studies results. As discussed above, the DHW recirculation heat losses and the efficient design of these systems are being ignored in current building codes and standards. It is the goal of this study to investigate and suggest recommendations that incentivize the reduction of temperature maintenance losses. Accordingly, a loss factor (LF) which account for the DHW recirculation losses is proposed and added to the current DHW modelling methodology in the CoV energy modelling guidelines. The proposed methodology suggests multiplying the current DHW consumption baseline with a loss factor (LF) that is a function of the insulation thickness of the recirculation pipes. The proposed recirculation loss factor calculation methods is shown in Table 10.

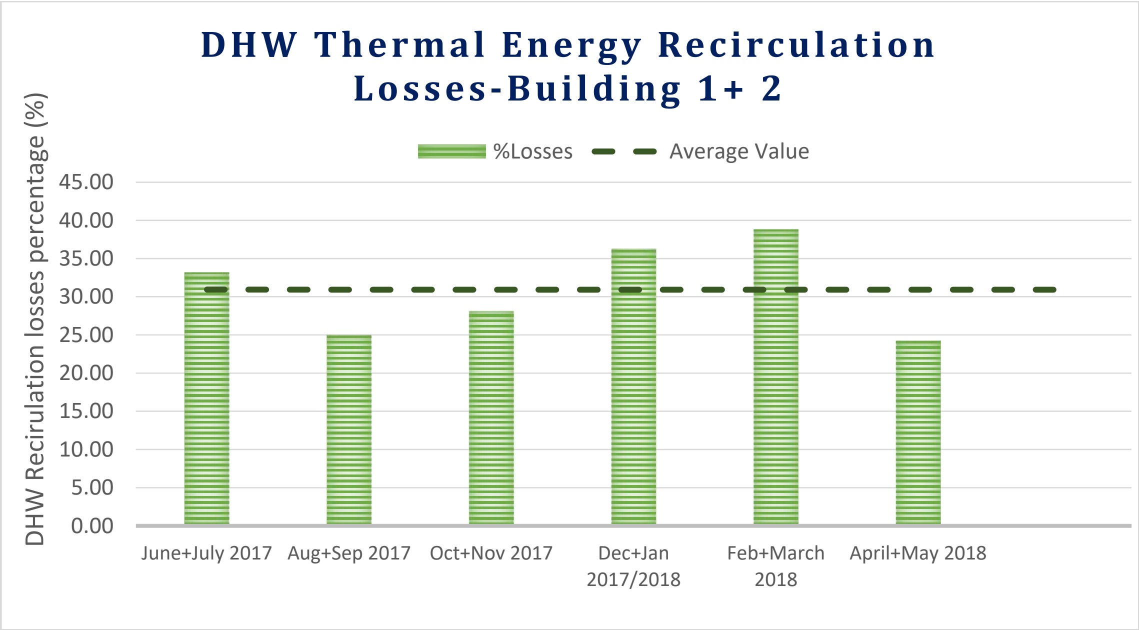


Figure 11: Domestic Hot Water Recirculation Losses Data Analysis

| Proposed Recirculation Loss Factor | |
|---|---|
| LF | Inches of Insulation |
| 2 | No insulation |
| 1.3 | ASHRAE's Minimum [11] |
| 1 | Passive House Best Practices [12]<br>or<br>no DHW recirculation system (e.g. Distributed DHW system, or heat trace on DHW piping) |

Table 10: Proposed DHW Recirculation Loss Factor

Based on the recirculation losses data observed, the 30% recirculation heat losses come from buildings that comply with ASHRAE's minimum insulation diameters for the recirculation pipelines (i.e. 1 inches of insulation for pipe diameter = 1 to 1.5 inches, and 1.5 inches of insulation for pipe diameters > 1.5 inches up to 8 inches) [11]. A loss factor of 2 is proposed to discourage non-insulating the recirculating pipelines. A loss factor of 1 (i.e. neglecting the effect of recirculation loss factor) is proposed for buildings complying with the passive house best practices or those without a DHW recirculation losses [12] The loss factor of LF=1.3 is based on observed data and on knowing the fact that the buildings studied are complying with ASHRAE's standard.

## 3.4. The Effect of Sub-metering on Building Energy Consumption

### 3.4.1. Objectives of the study

In most of the multi-residential buildings, there is usually one central energy meter and the property managers or building owners are responsible of the entire thermal energy consumption. Buildings sub-metering refers to the measurement of individual unit energy consumption and billing individual units for its own consumption. Prior studies in the literature have shown that buildings sub-metering has a significant effect on decreasing the energy consumption and increasing energy savings [9], [10]. In a previous study, it was shown that sub-metering has the potential to save space heating energy in suites by around 21% [13].

The energy savings from sub-metering is not due to the actual technology contained in the meter itself, but rather a result of sharing information with the consumer about how much they are consuming and the associated costs [13]. One of the key factors affecting the savings is the perceived ability of the customer to impact their bills. Since occupants in sub-metered buildings can impact their energy consumption and charges, they are able to change their behaviour to save energy and money.

This study aims to investigate the potential energy savings from implementing building sub-metering by using actual energy consumption data from residential buildings in the City of Vancouver and comparing the energy consumption from both metered and non-metered buildings and calculate the energy savings accordingly. Results from the data analysis will be used to develop a proposed mechanism which can be used to incentivize building sub-metering in future versions of the City of Vancouver's energy modelling guidelines.

### 3.4.2. Data analysis and methodologies

Thermal energy consumption data from 30 multi-unit residential buildings (MURBs) in the City of Vancouver South East False Creek (SEFC) neighborhood are collected and analyzed for the purpose of studying the effect of sub-metering on the building energy consumption and investigate potential energy savings. Energy consumption data along with buildings Information are gathered from sub-metering companies and from Southeast False Creek - Neighborhood Energy Utility (NEU) to distinguish between sub-metered buildings and non-metered buildings in the neighborhood. Thermal energy consumption from the last 10 years of the 30 MURBs is used to calculate the domestic hot water consumption (in litres/m$^2$). DHW consumption for the sub-metered buildings are compared against the DHW consumption of the un-metered buildings, results are shown in Figure 12.

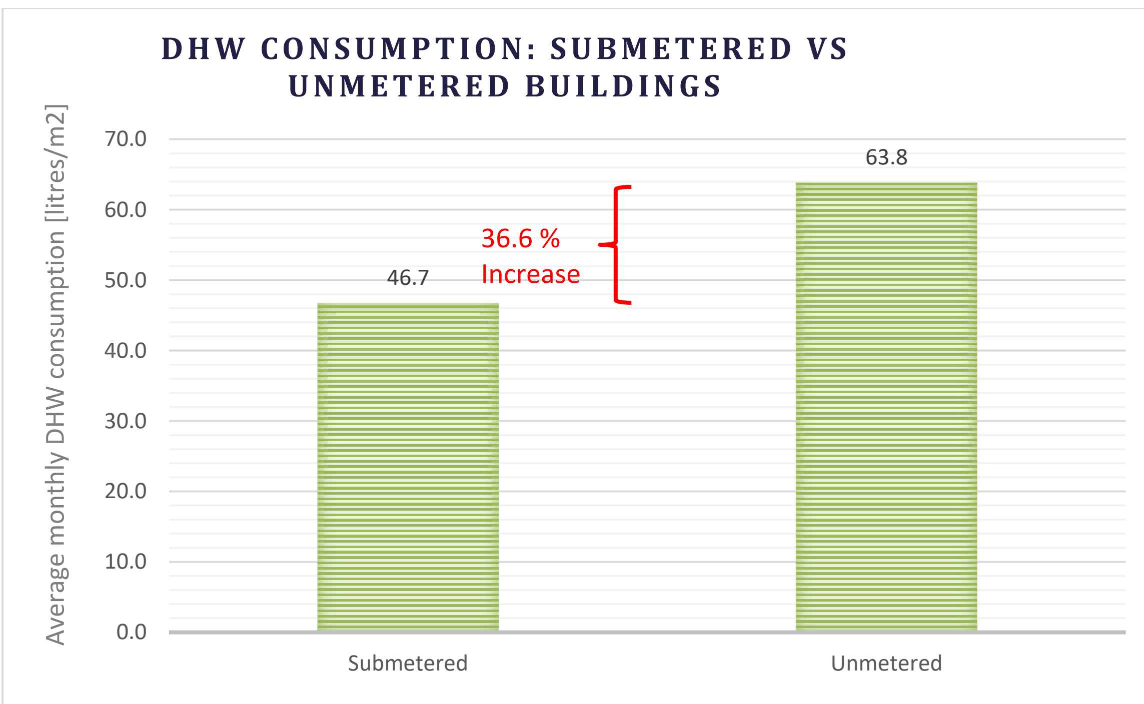


Figure 12: The effect of buildings sub-metering on domestic hot water energy consumption

### 3.4.3. Key findings and recommendations

Results are showing that buildings with sub-metering have an average monthly domestic hot water consumption of 46.7 litres/m2, while the buildings with no metering consume an average of 63.8 litres/m2 of domestic hot water per month. This indicate that building with no sub-metering have a 36.6% increase in domestic hot water consumption compared to the sub-metered buildings.

The energy savings resulting from buildings submetering can be calculated as follows:

$$\% \text{ Energy Savings} = \left(\frac{Energy\ Consumption\ (non-metered) - Energy\ Consumption\ (sub-metered)}{Energy\ Consumption\ (non-metered)}\right) x\ 100$$

$$= \left(\frac{63.8-46.7}{63.8}\right) x\ 100 = 28.4\%$$

Data analysis results are suggesting that a multiplier of 1.36 (based on 36% increase in energy consumption from non-metered MURBs) should be added to the domestic hot water baseline assumptions in order to incentivize buildings sub-metered and encourage resulting energy savings.

## 3.5. Comparing the DHW Baseline Calculations Assumptions vs. Proposed Methodology

In order to test the proposed methodologies, three of the five recommendations (explained in previous sections) are applied on the calibrated curves of the DHW consumption. The applied recommendations are: 1- increasing the peak value to 0.0021 L/s/person, 2- applying the seasonal multiplier explained in Table 6, 3- applying the proposed occupancy assumptions. The sub-metering factor is not applied on these data since all the buildings are sub-metered and recirculation loss factor should only be applied on thermal energy consumption.

Results from applying the proposed methodologies on the calibration curves are shown in Figure 13Figure 14, Figure 15, and Figure 16. It is evident from the adjusted calibration curves that the proposed methodologies are doing better job predicting the real DHW consumption.

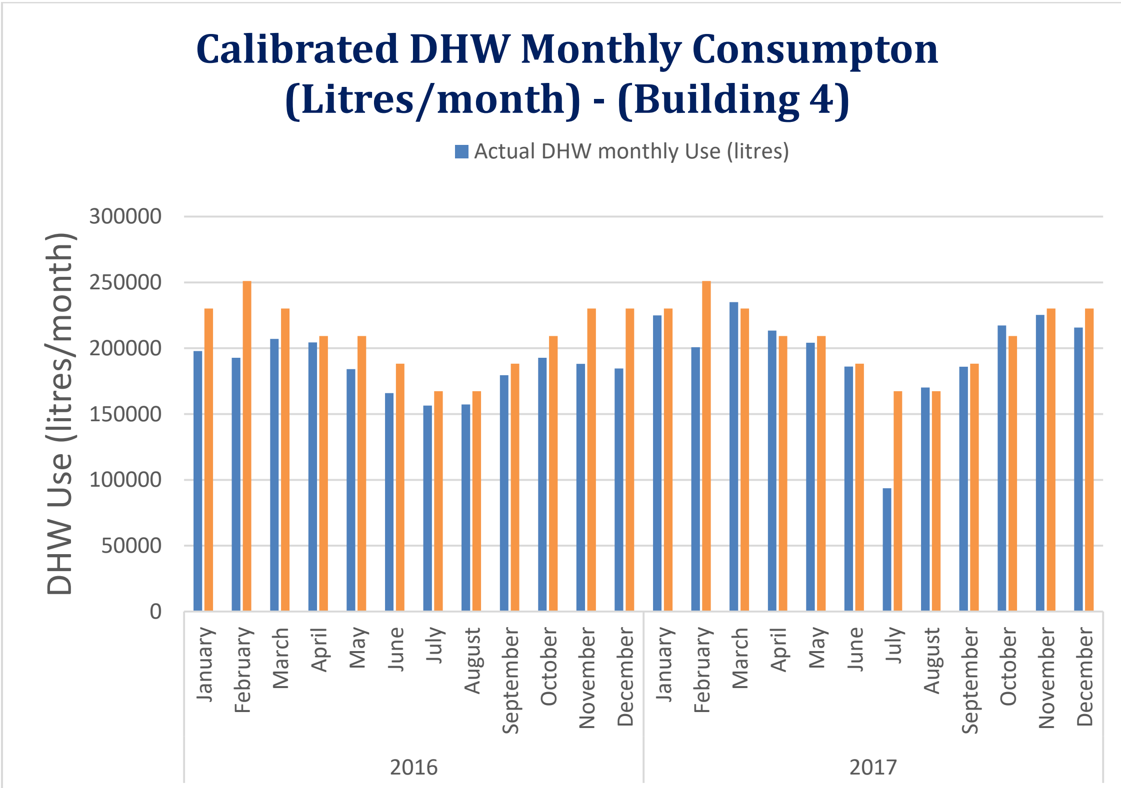


Figure 13: Calibrated DHW consumption: Applying the proposed methodologies- Building 4

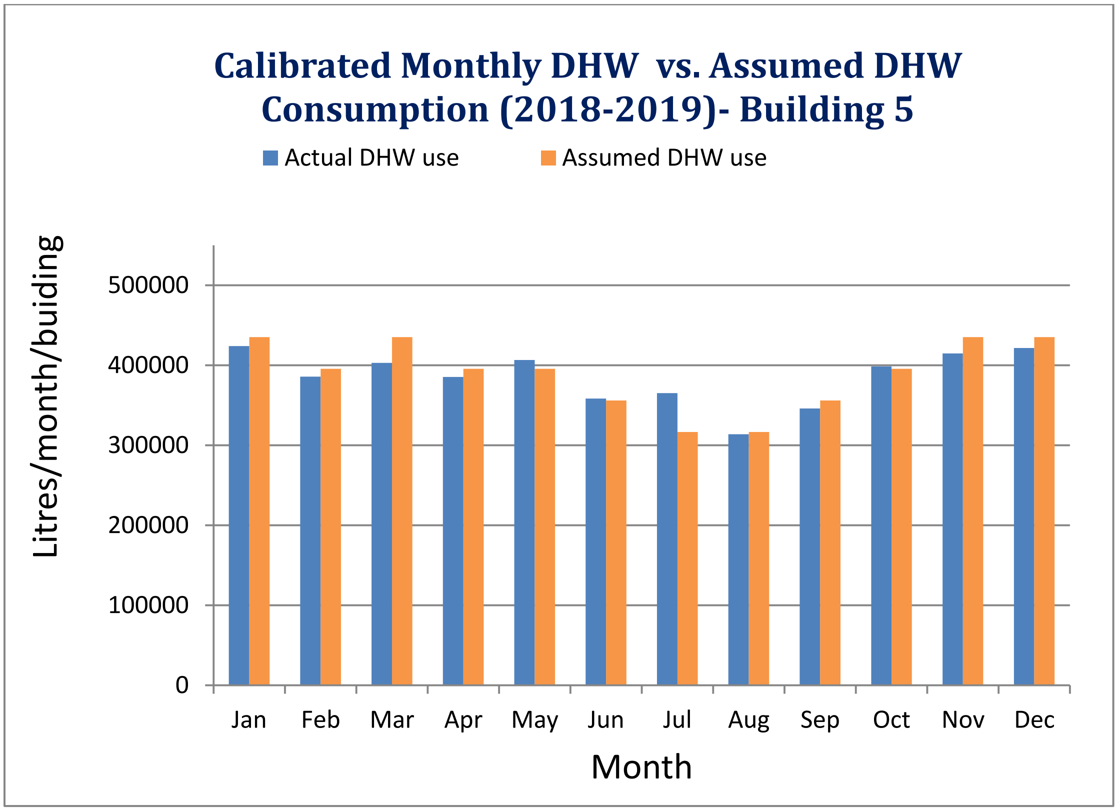


Figure 14: Calibrated DHW consumption: Applying the proposed methodologies- Building 5

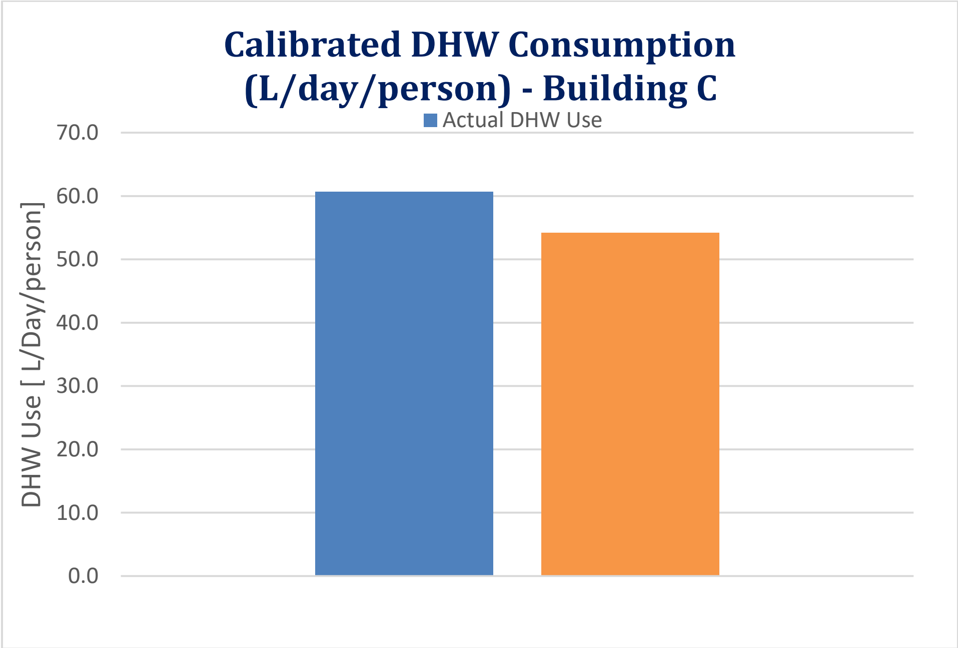


Figure 15: Calibrated DHW consumption: Applying the proposed methodologies- Building C

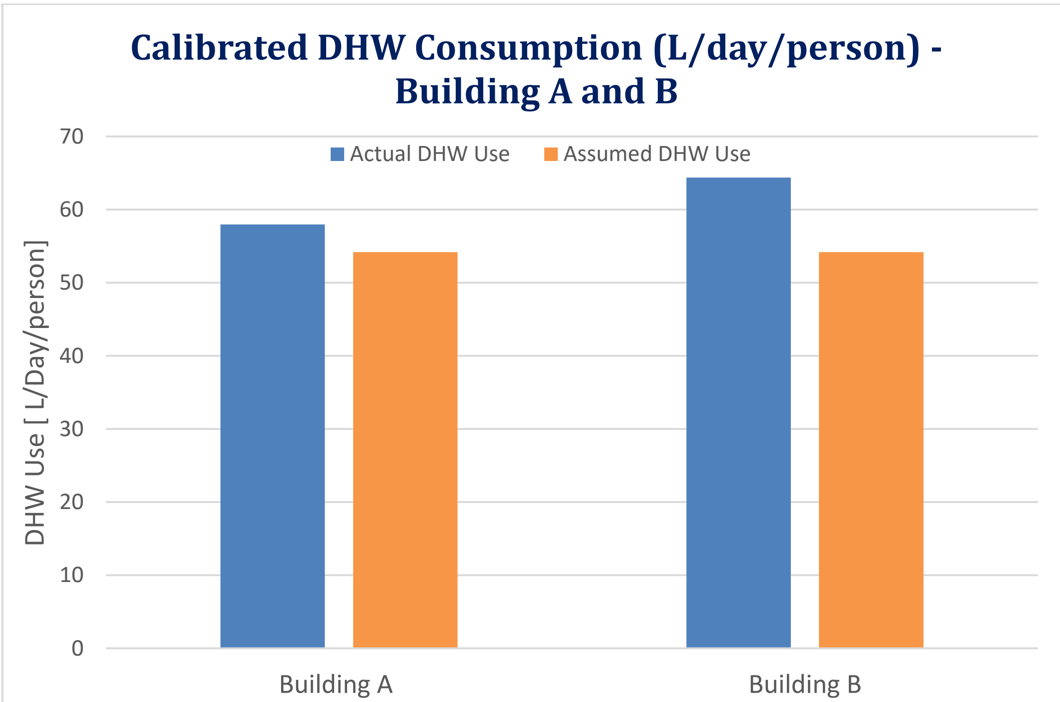


Figure 16: Calibrated DHW consumption: Applying the proposed methodologies- Building A and B

### 3.5.1. Annual DHW Building Energy Consumption: CoV Baseline vs. Proposed Assumptions

In order to compare the five new proposed factors, discussed in the previous sections, with the current DHW baseline assumptions, the annual assumed DHW energy consumption is calculated using the current CoV assumptions as the baseline and each of the new proposed modifications is added to the calculations (each factor is shown in different colour in Figure 17). In the case of building 1, using the proposed occupancy decreases the DHW energy consumption, and the other 4 factors increase the DHW energy consumption. Adding all the proposed recommendations, it is shown that the annual assumption for building 1 should be increased from ~ 27.5 KWh/ $m^2$/year to ~ 51 KWh/ $m^2$/year.

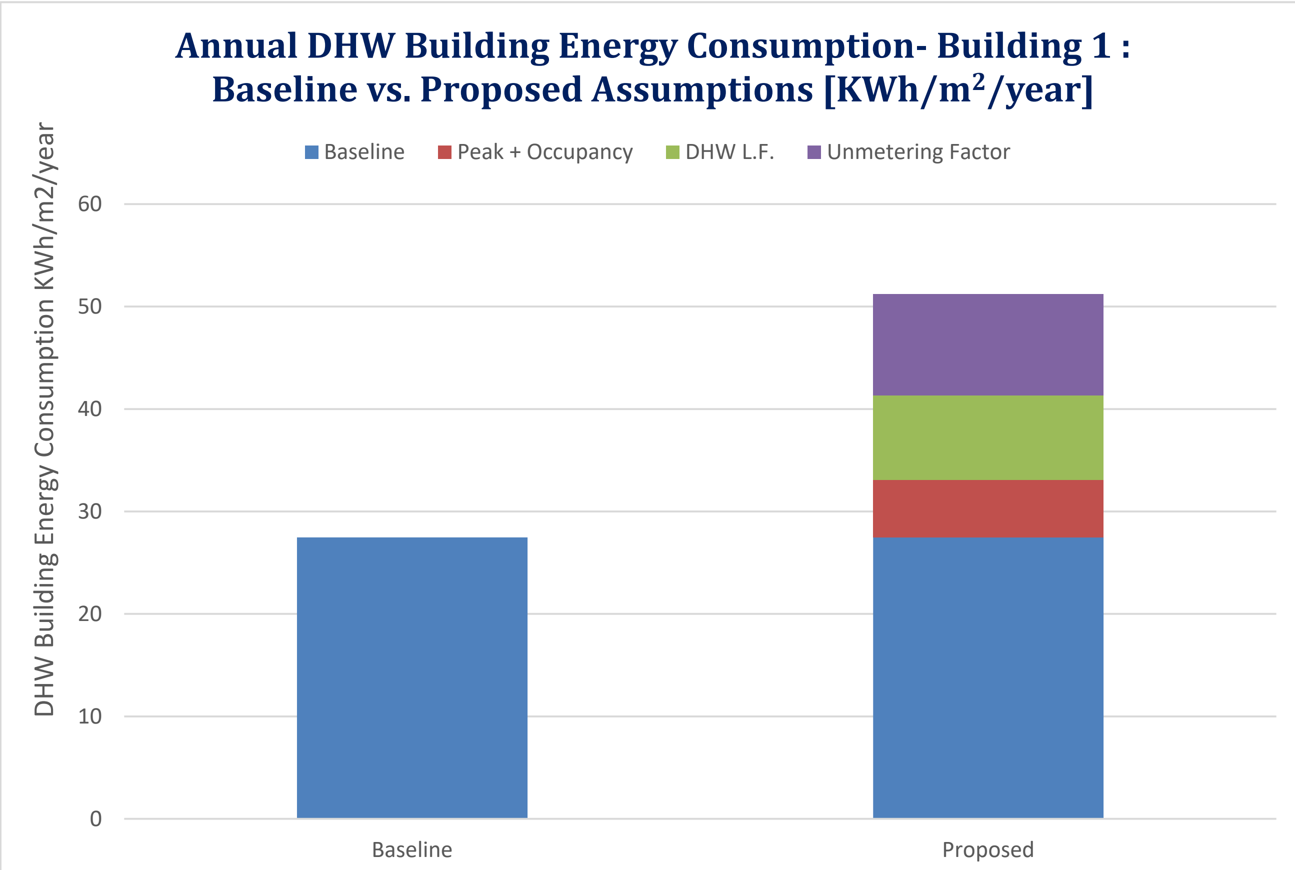


Figure 17: DHW Building Energy Consumption [KWh/m2/year]: Baseline vs. Proposed Methodology

### 3.5.2. Low Flow Fixtures

Low-flow fixtures are plumbing fixtures that are installed to reduce water consumption more than conventional fixtures. When these low-flow fixtures are installed, domestic hot water consumption will be decreased and building energy consumption will be reduced accordingly. The City of Vancouver Energy Modelling Guidelines allows further reduction in the DHW consumption assumptions if low flow fixtures are used [1]. Also, BC Building Code and Vancouver Building By-law recently mandated lower- flow fixtures as the new standard; this has reduced the credit available for standard Low Flow Fixtures, and thus inherently reduced any possible discrepancy.

Gathering information about whether or not the buildings used in this study have low flow fixtures installed was challenging. However, most of the buildings studied were built after 2000; this means that they likely had some form of low-flow fixture or devices installed. It is thus important to note that, if these low flow fixture devices were factored in the previous calibration results, the long-term performance of these devices (or whether people remove them or change-out their shower heads and fixtures) would need to be reviewed.

## 3.6. Plug Loads Consumption Analysis

Plug loads data are collected from different sources across Canada and the US. and compared with the assumed plug loads in the CoV energy modelling guidelines. A proposed methodology for the plug loads modelling is discussed and laid-out in this section.

Figure 18 shows the plug loads data collected from 4 buildings in Seattle, WA, made available for the purpose of this study by Redwood Energy [14]. Two types of units are studied: 1-bedroom units and 3 bedrooms units. The collected in-suite daily plug loads data for each building are then used to calculate the average plug loads use for each unit type in $W/m^2$. The results are showing that the CoV assumptions are underestimating the load in the 1-bedroom units and overestimating the loads in the 3 bedrooms units.

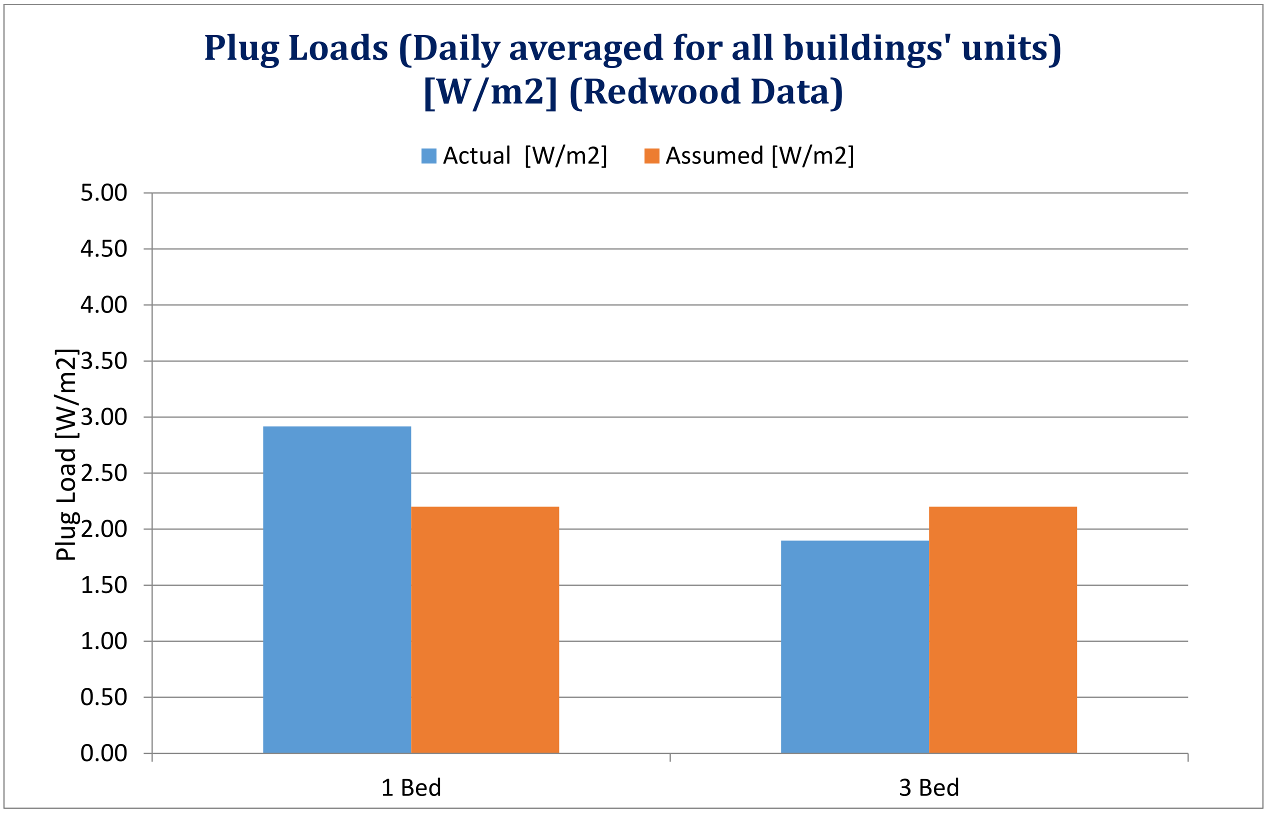


Figure 18: Plug Loads Calibration- Redwood data

The current plug loads assumptions laid-out in the CoV energy modelling guidelines recommend modeling the peak load to be equal to 5 W/m$^2$ and to be equal to 4 W/m$^2$. In order to estimate the baseline plug load assumption, the peak load should be multiplied by the fraction of load in the NECB operating schedule (Table A-8.4.3.2.1-G)[7] It is evident from the data calibration that the current assumptions of plug loads fail to predict the actual plug loads consumption. One proposed reason for that is that it takes into account the unit floor area and it doesn't take into account the number of bedrooms when estimating the plug loads. This results in either overestimating or underestimation of the plug loads.

The plug loads should depend on the number of bedrooms and not the total unit floor area as the unit floor area is not the real indication of the number of appliances and accordingly the number of people, And thus the intensity of use of those appliances, but the number of bedrooms is. For example: For the same unit floor area, a 2-bedroom apartment that has been retrofitted to a 3 bedrooms apartment, the intensity of use of the appliances will increase, and hence the plug load consumption will increase (for the same unit square meter). Thus, estimating the plug load based on the square footage of the unit can lead to two main problems:

a- If the floor area is relatively high with few numbers of bedrooms, the CoV assumptions will overestimate the plug load consumption (based on the floor area).
b- If the floor area is relatively low but with more small bedrooms, the CoV assumptions will underestimate the plug load (based on the floor area), not taking into account that the more the bedrooms the higher the number of appliances!

Applying this proposal to the results in Figure 18, the overestimation of the plug loads in the 3-besdrooms unit might be due to having high floor area for the 3 bedrooms unit, but the plug load is still estimated based on floor area and not the number of bedrooms. In the case of the one-bedroom units, this underestimation might result from having a relatively small floor area so the assumed load underestimated the actual load, although one-bedroom units will have the same number of appliances even for small floor area.

Figure 19 shows the curve fitting for the correlation between the plug loads in KWh/day and the number of bedrooms for the buildings studied.

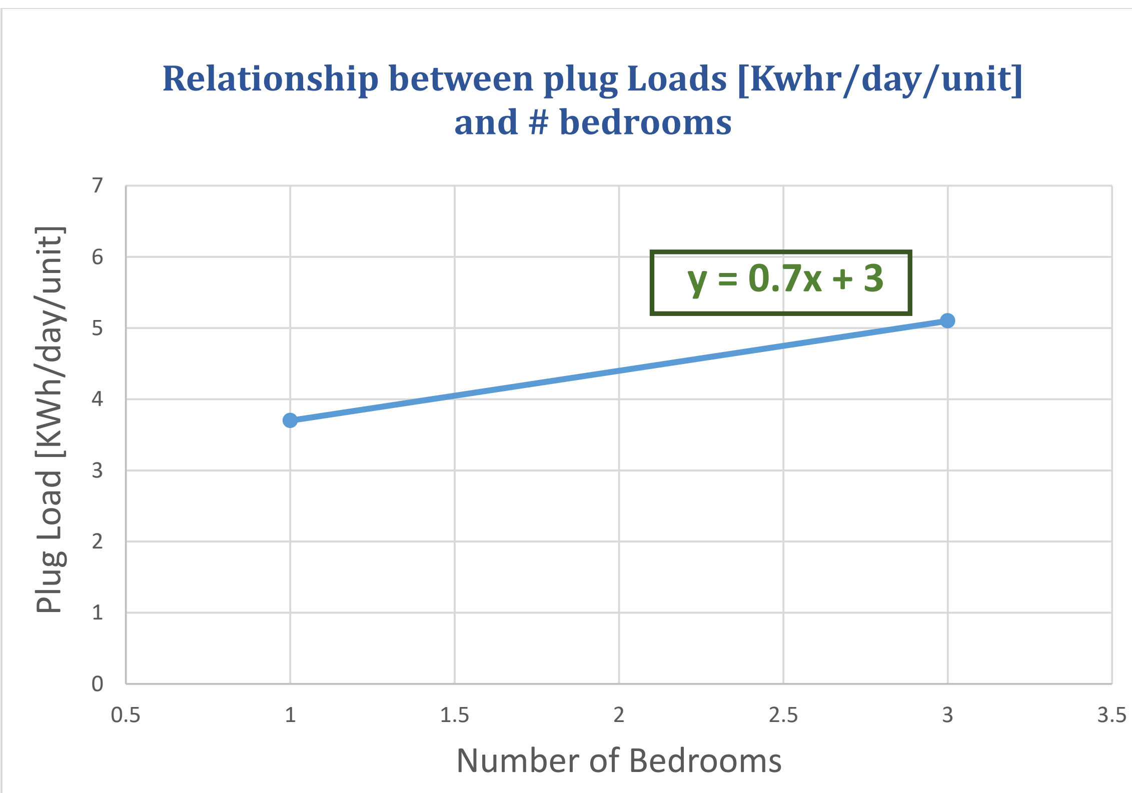


Figure 19: Proposed Correlation between the Plug Loads and the number of bedrooms

Curve fitting results in the following correlation between the plug loads and the number of bedrooms:

$$y = 0.7\,x + 3 \tag{6}$$

Where y is the estimated plug load in KWh/day and x is the number of bedrooms.

Converting the above equation to estimate the plug loads in Watt/number of bedrooms:

$$y_1 = 29.2\,x + 125 \tag{7}$$

Where $y_1$ is the estimated plug load in Watt/unit, and x is the number of bedrooms.

Applying the proposed methodology to the plug loads dataset, a comparison between the actual, the proposed and the assumed plug loads is shown in Figure 20. It is apparent from the results that the proposed methodology is doing a better job predicting the actual plug loads consumption. It is also important to note that the plug load data sources are limited, and it is not easy to find a breakdown of the unit-level plug loads consumption along with the units floor area. Since the data collected for this study are from consumption data in the US, applying the proposed correlation in buildings across Canada may or may not result in different results, due to difference in electricity rate and energy consumption cultural differences. Future collected data should be used to calibrate the proposed methodology.

It is important to mention that there are some policy implications of this proposed methodology: namely that when compared to a TEUI [in KWh/m$^2$], buildings with more units of less bedrooms will now find it more difficult to meet the TEUI limit using the proposed methodology. While this is true, it would also provide an incentive to use more efficient appliances and would better reflect actual energy consumption patterns.

Another study is made on plug loads data collected from the 2019 BC Hydro electricity consumption study [15]. Consumption data for the plug loads and lighting from 4040 buildings along with unit floor areas are collected and made available for the purpose of this study. The assumed plug loads are calculated and compared with the actual plug loads consumptions.

A description of the buildings used in this study is laid out in Table 11. Calibration results are shown in Figure 21. It is concluded from the results that the assumed plug loads and lighting are lower than actual consumption, especially in Condo units. The lighting and plug loads consumption in rental units are lower than condo units, this might be due to tenant's turnover, and the rental units usually have less appliances then the condo units, hence less estimated plug loads.

The units' breakdown are not available for the BC Hydro data study, therefore the proposed methodology of using the number of bedrooms instead on W/m2 to estimate the plug loads couldn't be applied in this study.

The results, from the BC Hydro data calibration, suggest increasing the assumed plug loads peak from 5 W/m2 to 7 W/m2 for condo units. Figure 22 shows the results of applying this increase in the peak load in condo units.

| Apartment Types | Ownership Type | #of Buildings | # of Suites | Suites per building | sq.ft. per suite |
|---|---|---|---|---|---|
| High-rise | Condo | 306 | 27218 | 89 | 907 |
| High-rise | Rental | 387 | 29447 | 76 | 847 |
| Low-rise | Condo | 1011 | 30167 | 30 | 927 |
| Low-rise | Rental | 2336 | 58941 | 25 | 849 |

Table 11: Description of buildings used in the Plug loads study – BC Hydro

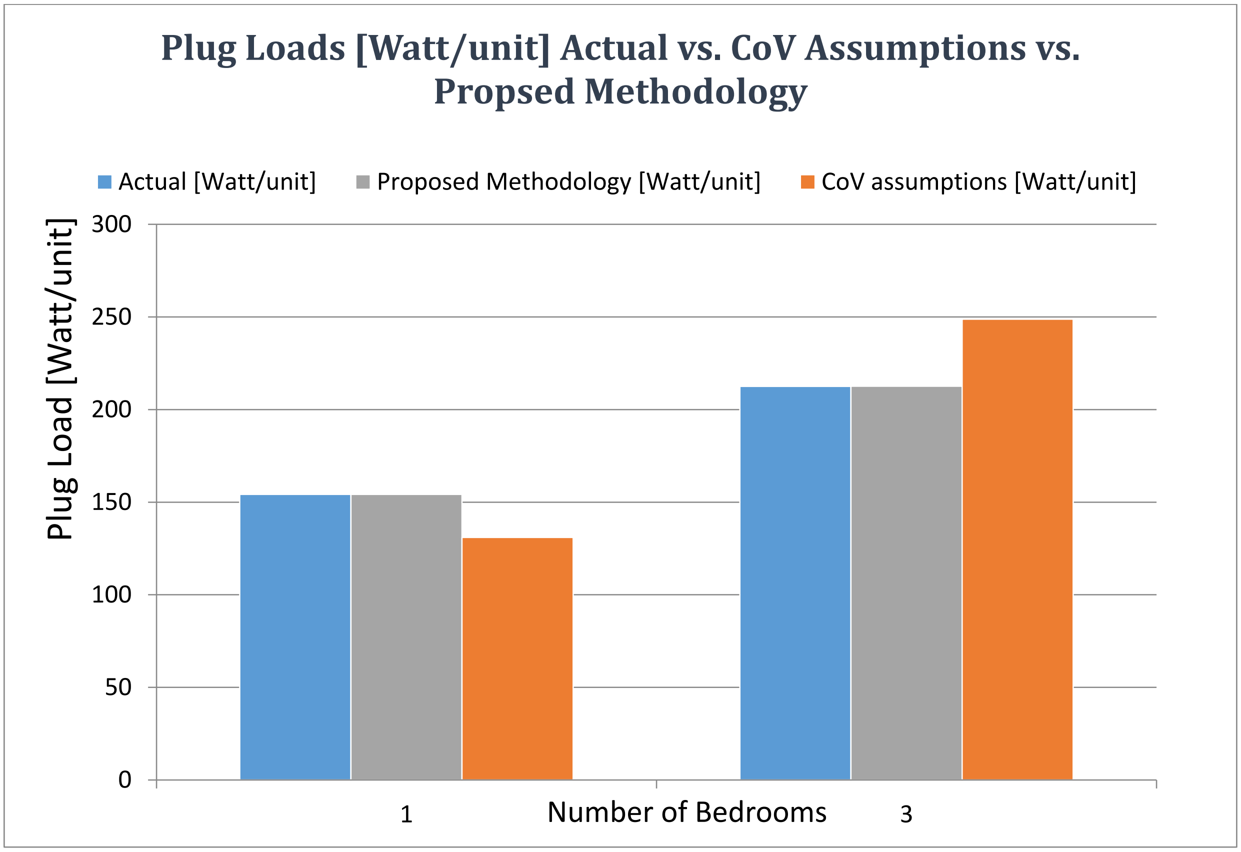


Figure 20: Comparison between actual, assumed and proposed plug loads

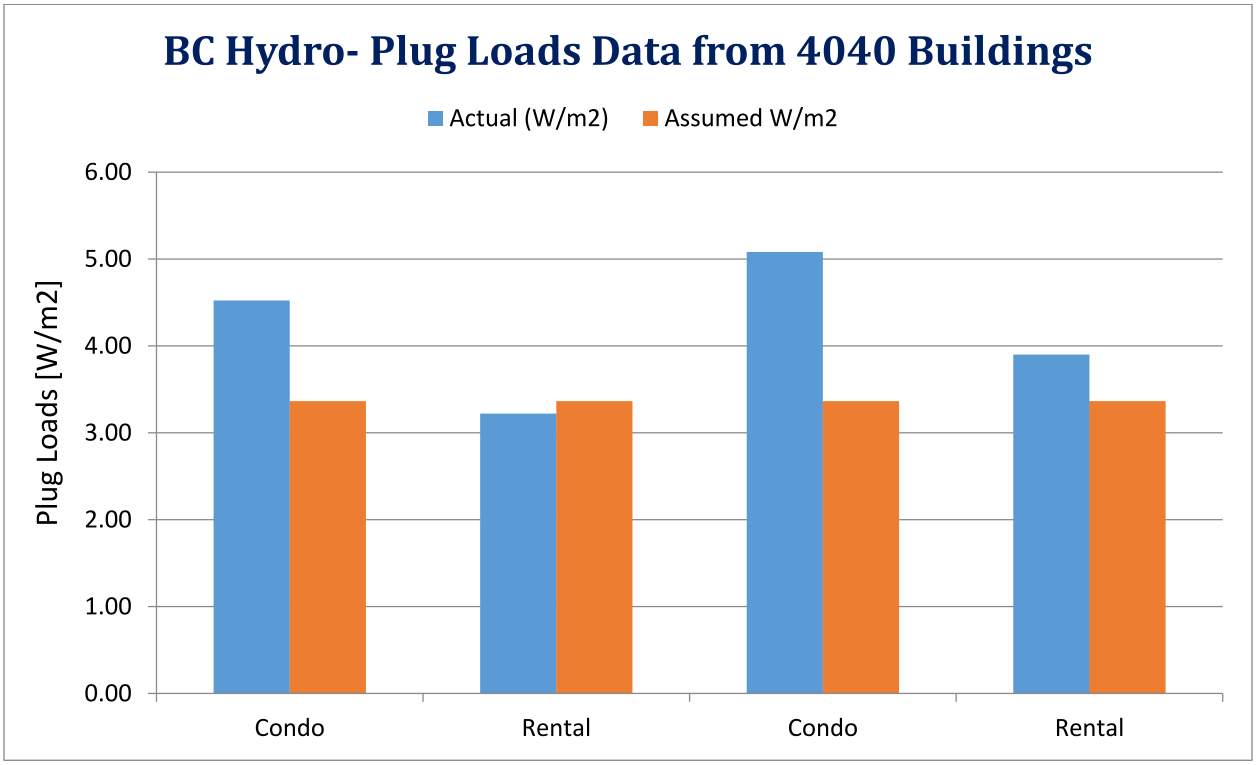


Figure 21: Calibration of Plug loads for 4040 Buildings – BC Hydro Data

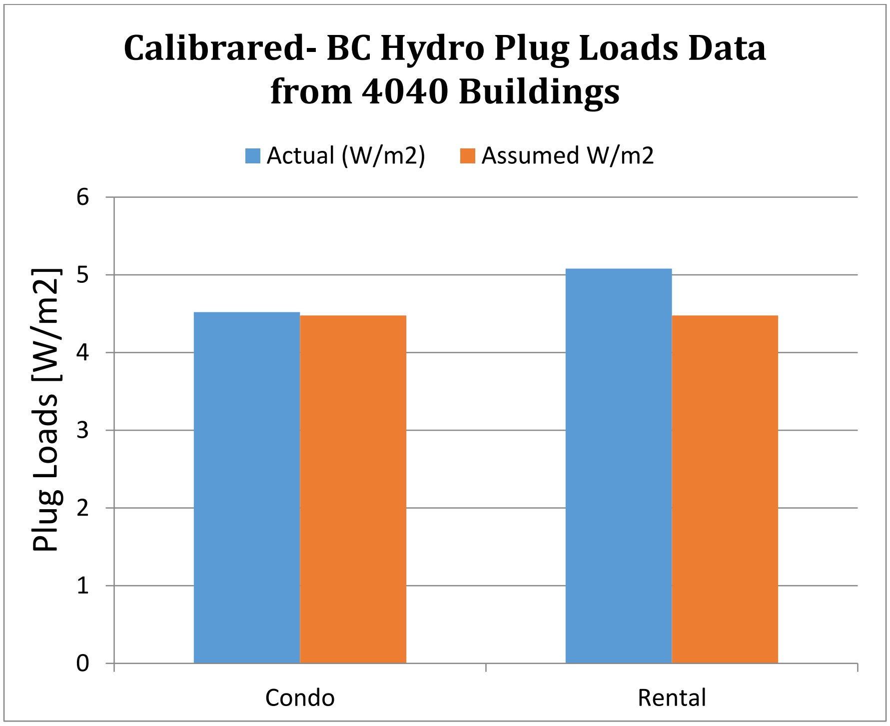


Figure 22: Increasing the plug loads peak in condo apartments- BC Hydro Dataset

## 3.7. Cooking Energy Consumption Analysis

Cooking energy consumption data are collected in 2014, 2015, and 2016 by Redwood Energy Company. Redwood Energy is a leading company in zero net energy housing. Their projects, which range from cottages to high-rise residences, are all-electric affordable zero-net energy housing [14]. Cooking energy consumption data from 2 different buildings are used in this study. The buildings description and units' floor areas are laid out in Table 12.

| Units breakdown/floor areas [ft$^2$] | Building 1 | Building2 |
|---|---|---|
| 1 Bedroom | 1109 | 730 |
| 2 Bedrooms | 1162 | 919 |
| 3 Bedrooms | 1481 | 1204 |
| 4 Bedrooms | - | 1445 |

Table 12: Buildings description for the cooking energy study

### 3.7.1. Proposed Peak Value for the CoV's Cooking Energy Assumptions

The City of Vancouver Energy Modeling Guidelines assumes a peak load of **1 W/m2** for cooking energy consumption (plug loads peak should be assumed 5 W/m2 if an electric stove is used, and 4 W/m2 if there are gas-fired cooking appliances) [1].

The cooking consumption peak along with the NECB schedule are used to calculate the assumed cooking energy consumption in [W/m2] for the studied buildings. The unit-level monthly cooking energy consumption data from all the buildings studied, in KWh, are converted to W/m2 for each unit type using the unit floor area and the breakdown of unit types per building for each building. A comparison between the assumed and the actual cooking energy consumption, in W/m2, is shown in Figure 23.

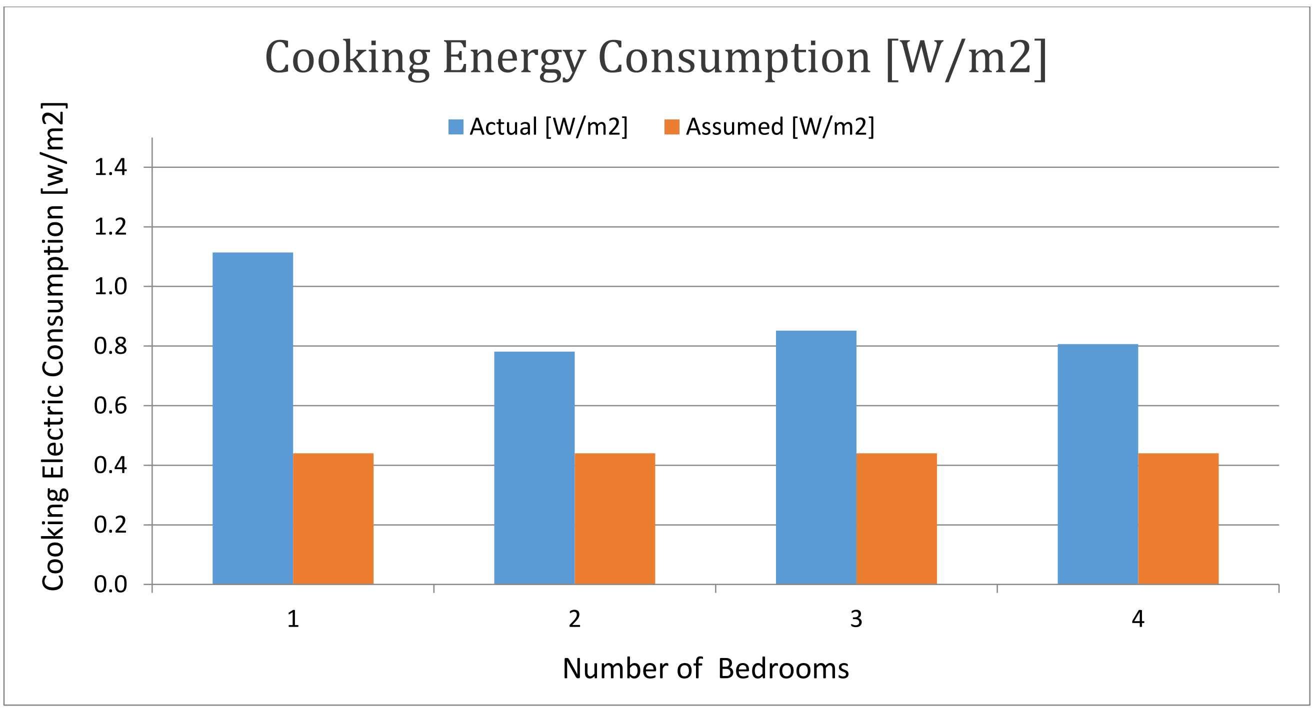


Figure 23: Cooking Energy Consumption study: assumed vs. actual consumption [W/m2]

It is evident from Figure 23 that the City of Vancouver's assumptions are underestimating the cooking load. One proposed improvement to the current Energy modelling guidelines assumptions is to increase the assumed peak load for cooking energy. Based on the data calibration results, a new peak of **1.8 W/m2** should be used to reflect actual cooking energy consumption. Figure 24 shows a comparison between the proposed assumption and the actual cooking energy consumption. It is apparent that increasing the peak load from 1 to 1.8 W/m2 improves the cooking energy use prediction.

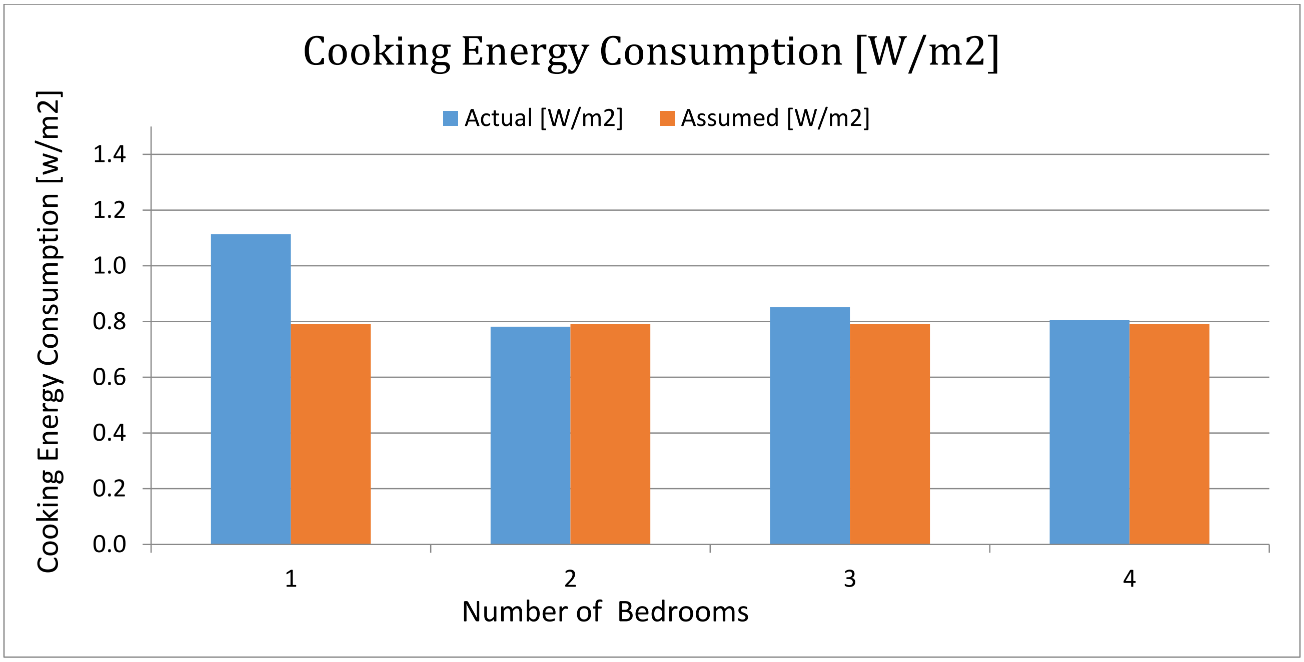


Figure 24: Proposed assumptions for cooking energy use

### 3.7.2. Proposed Methodology to the current's cooking energy assumptions: Correlating the cooking load with the number of bedrooms

Predicting the cooking energy consumption based on the unit floor area might not be the most accurate approach, as the floor area is not always a good predictor of the amount of energy consumption, in contrast with the unit number of bedrooms. If the unit floor area is too high or too low (with the same number of bedrooms), the current CoV assumptions might overestimate or underestimate the cooking energy load, respectively. For example, a 2 bedrooms apartment with a 'higher than the average' floor area, will have an overestimated cooking energy assumption, while a smaller 2 bedrooms apartment will end up having an underestimated cooking load. The number of bedrooms is a better indicator of the occupancy and accordingly, a better indicator for the cooking load.

Therefore, a new proposed methodology to the CoV's current cooking energy consumption assumptions is to correlate the cooking energy consumption with the number of bedrooms instead of using the floor area in the prediction. A correlation between the cooking energy consumption and the number of bedrooms is inferred from the observed data fitting and shown in Figure 25.

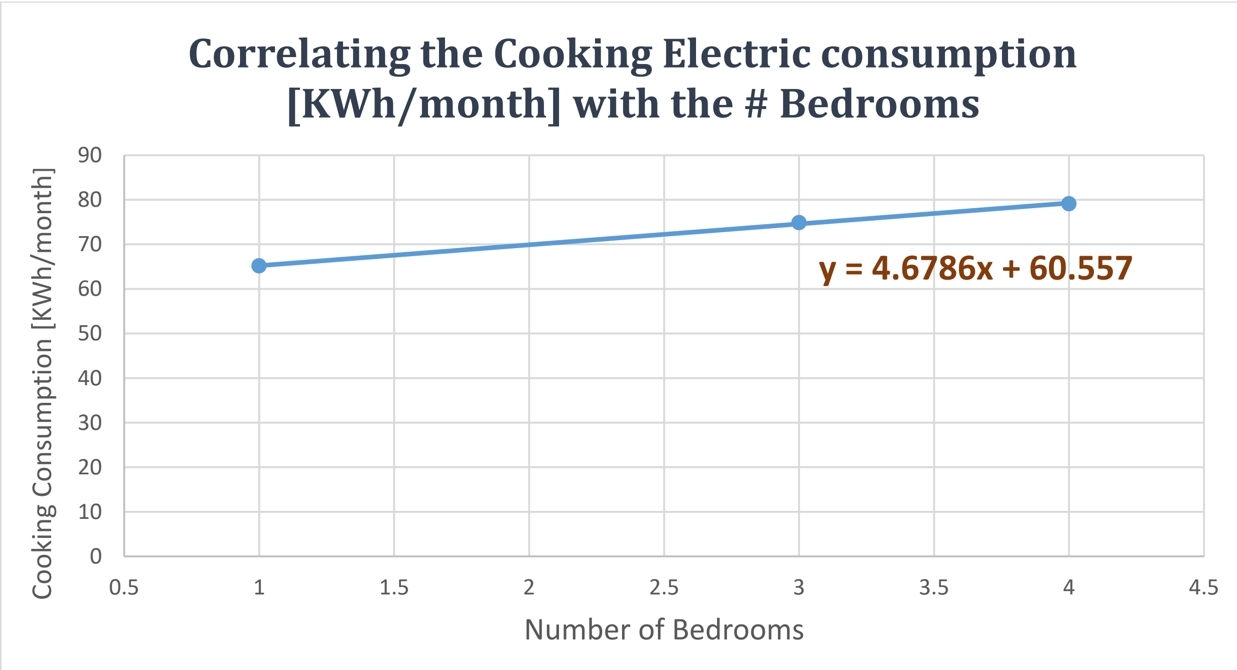


Figure 25: Correlating the cooking energy consumption with the number of bedrooms

The proposed correlation between the cooking energy consumption and the number of bedrooms is as follows:

$$y = 4.67\,x + 60.6 \qquad (8)$$

Where:

y=cooking energy consumption [KWh/month/unit]

x= number of bedrooms

Converting the above equation from KWh/month/unit to Watt, the proposed correlation will become:

$$y = 6.4\,x + 83 \qquad (9)$$

Where:

y= cooking electric consumption [Watt/unit]

x= number of bedrooms

Applying the proposed methodology to the cooking energy data, the actual, proposed and assumed cooking energy consumption in Watt/unit are compared and shown in Figure 26.

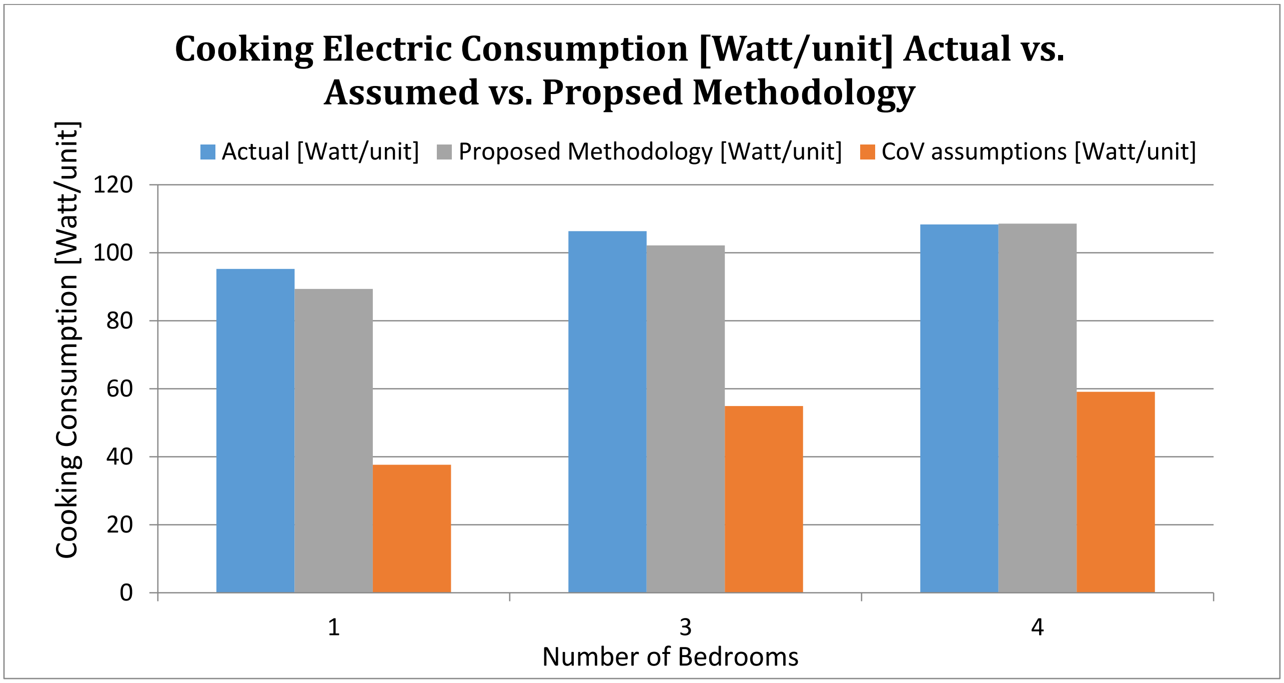


Figure 26: Comparison between actual, assumed and proposed methodology for cooking energy consumption [Watt/unit]

### 3.7.3. Percentage Cooking Electric Consumption

The CoV energy modelling guidelines assumes a cooking load of 1 W/m2 and a total of 5 W/m2 for plug loads and cooking loads, this is equivalent to an assumed 20% cooking load of the total plug loads. It is important to calibrate this assumed percentage using real cooking and plug loads data. Actual plug loads and cooking loads datasets have been collected, cleaned and parsed for the purpose of this study. Averaging the results for all unit types, the actual cooking energy consumption is 36% of the total plug and cooking loads.

Using the calibrated value to infer a new proposed cooking load peak, i.e. 36% of a total of 5W/m2 plug loads gives a cooking load peak of 1.8 W/m2, which is the same peak value inferred from data observations.

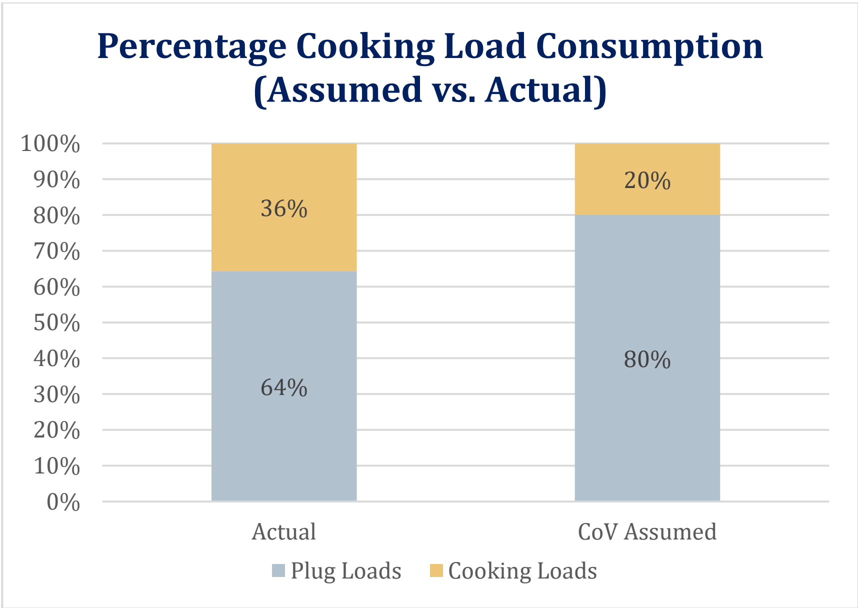


Figure 27: Comparison between actual and assumed cooking loads and plug loads percentages

Although correlating the cooking energy consumption with the number of bedrooms seems to be a more accurate approach in terms of reflecting the actual energy consumption, it is seen from the above figures that increasing the cooking consumption peak load to 1.8 W/m2 or using the proposed cooking percentage of 36% of the plug loads, has a more salient effect on the calibration, as the calibrated correlation in Figure 25 has a relatively low slope.

Since the proposed methodology that relates the plug loads consumption with the number of bedrooms has already been developed, it is recommended to use the proposed cooking percentage of 36% (of the total plug loads) in order to improve the cooking energy predictions and better reflect the actual energy consumptions.

It is also important to take into account the limitation of the cooking consumption data available, if more data is collected in the future, it will play an important role in refining the proposed methodology.

## 3.8. Space Heating Demand Analysis

The space heating demand is currently often assumed to be a constant value for the entire building, with little thought of unit-level variability. In Step 2 of BC Energy Step Code, the space heating is assumed to be 45 KWh/m2. However, this value also includes ventilation heating along with unit space heating. The purpose of this study is to calibrate this value and investigate the variability of the unit-level heating demand using actual heating energy consumption data from residential buildings in the City of Vancouver. Unit-level monthly heating energy consumption data in KWh along with the unit floor areas for 3 different buildings are collected and analyzed. A description of the buildings studied is laid out in Table 13.

Since, the heating demand data collected only includes space heating, ventilation heating demand should be added to these values in order to be able to compare it with the assumptions made in BC energy step code. Currently, the ZEBP assumes a heating demand of 20-35 % of the total heating demand (depending on if buildings have HRVs and their efficiencies) [3].

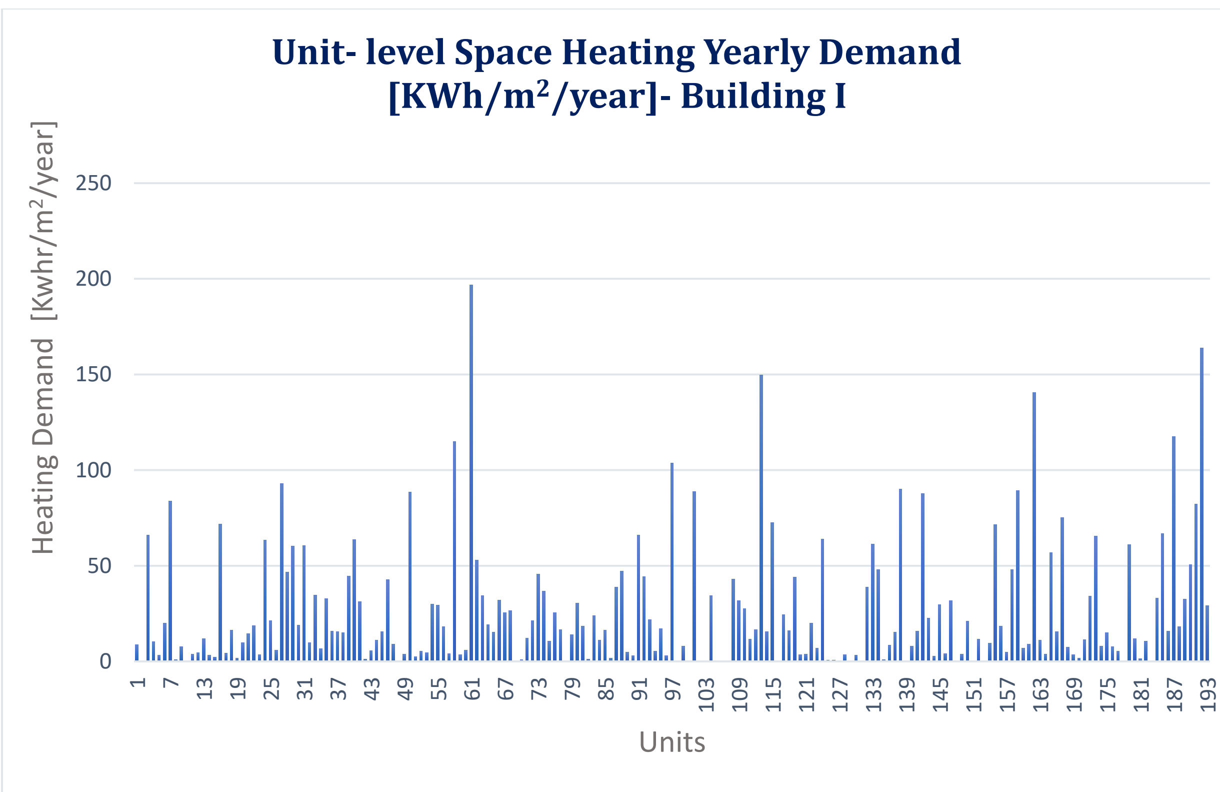


Figure 28: Yearly Unit- Level Space Heating Demand [KWH/$m^2$] – Building I

The annual unit-level space heating demand in $KWh/m^2$ for buildings I, II, and III are shown in Figure 28Figure 30Figure 32. The results are showing a wide variation of space heating demand across different units within the same building. The monthly variation in space heating demand for building I and II is shown in Figure 29Figure 31. The results are showing that the space heating can go as low zero. It is important to note that cold water consumption data shows nearly that all the units are occupied (i.e. the very low space heating demand data are all coming from occupied suites).

The average yearly unit-level space heating across all the buildings studied has also a wide variability spread. Figure 33 shows the variation in the yearly space heating demand between the 3 buildings; the results are showing that the average space heating demand is **25 $KWh/m^2$/year.**

As discussed, this value doesn't include ventilation heating. Hence, in order to compare these average values, the ventilation heating percentages are added as follows:

Building 1 total heating demand = 32.5-38 $kWh/m^2$
Building 2 total heating demand= 22-25.5 $kWh/m^2$
Building 3 total heating demand= 40.5-47.3 $kWh/m^2$

The average of the total heating demand for all the buildings studied is then: **31.7-36.9 kWh/m2**, which is still less than the step 2 limit of **45 KWh/m2.**

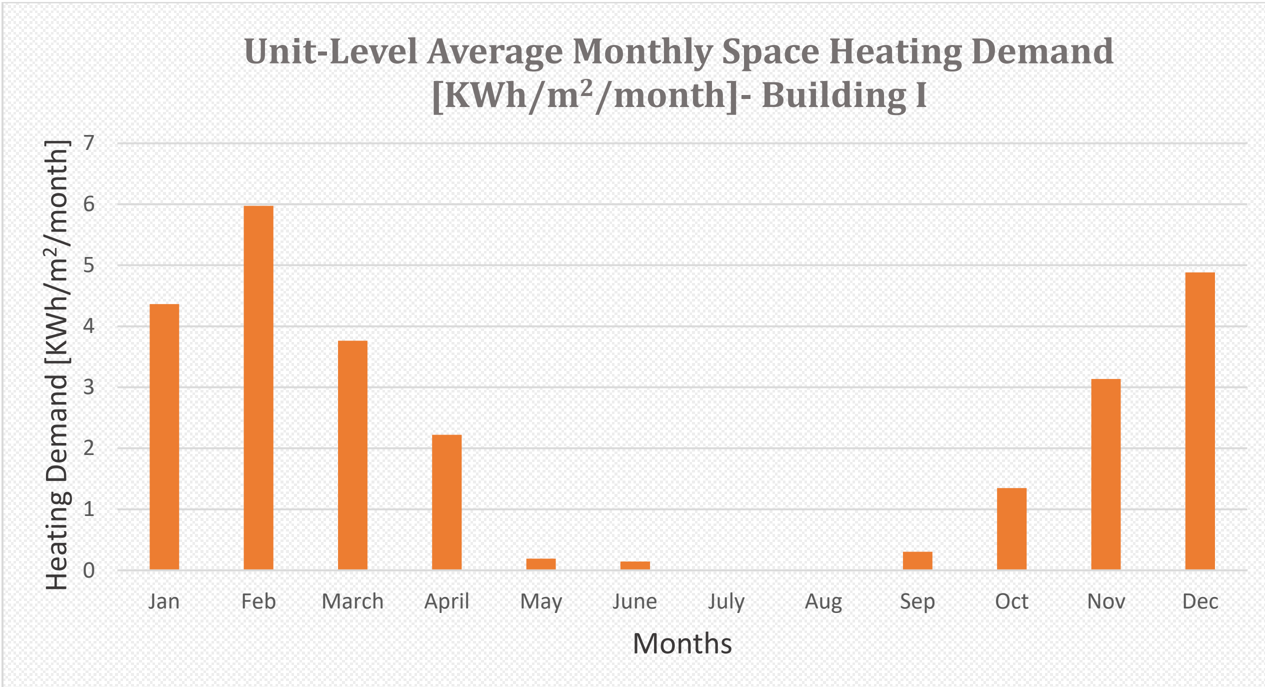


Figure 29: Monthly Variation in Space Heating Demand – Building I

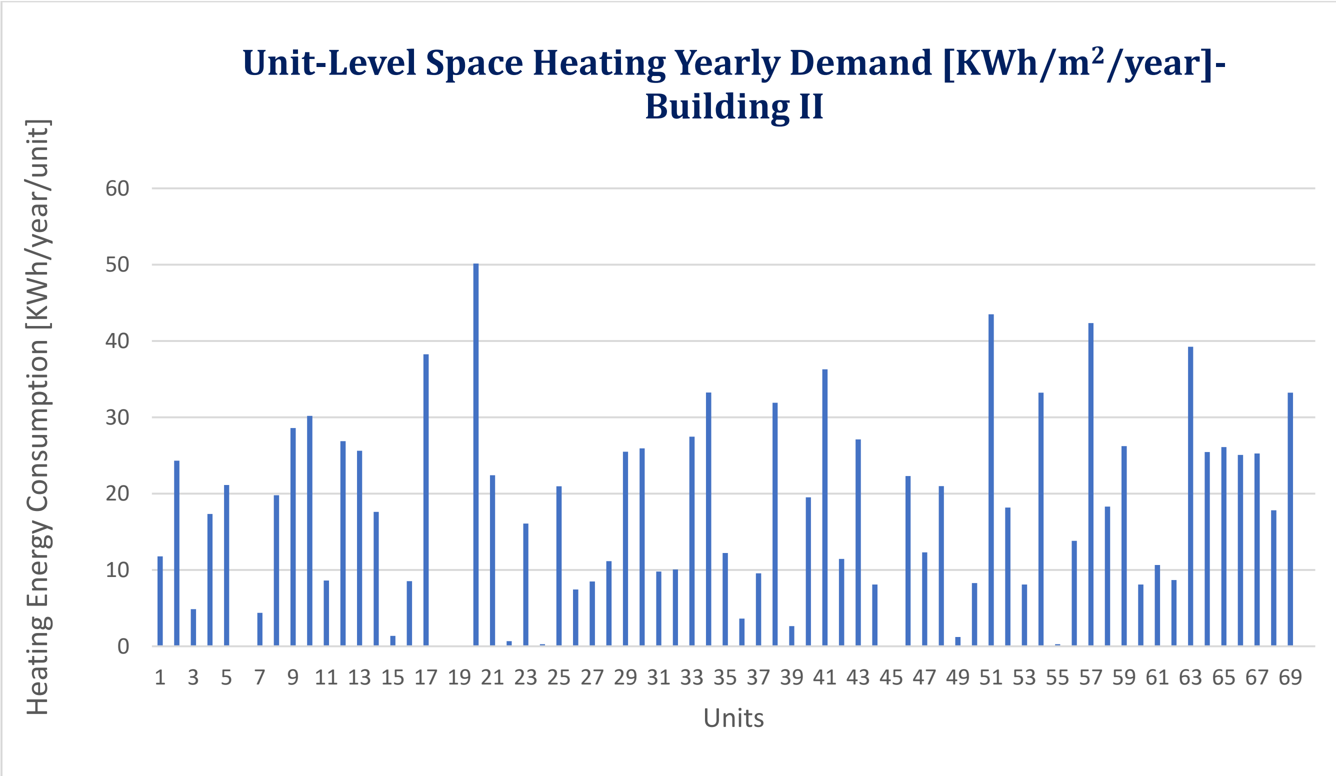


Figure 30: Yearly Unit- Level Space Heating Demand [KWH/$m^2$] – Building II

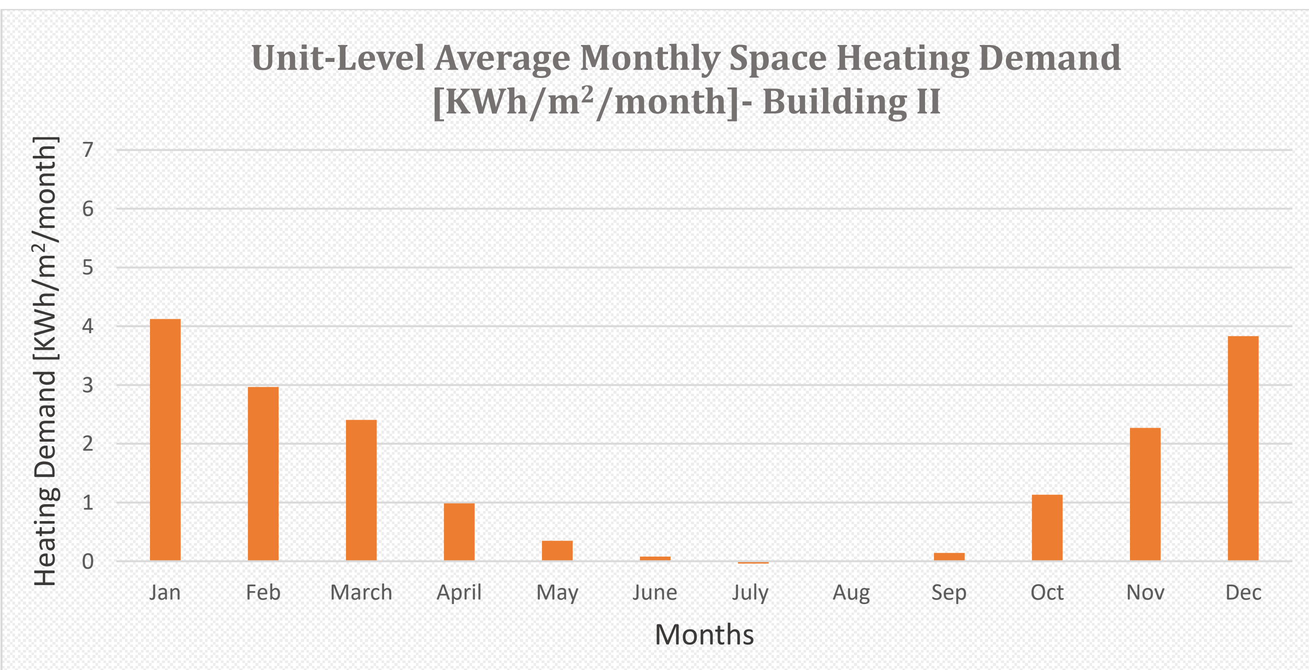


Figure 31: Monthly Variation in Space Heating Demand – Building II

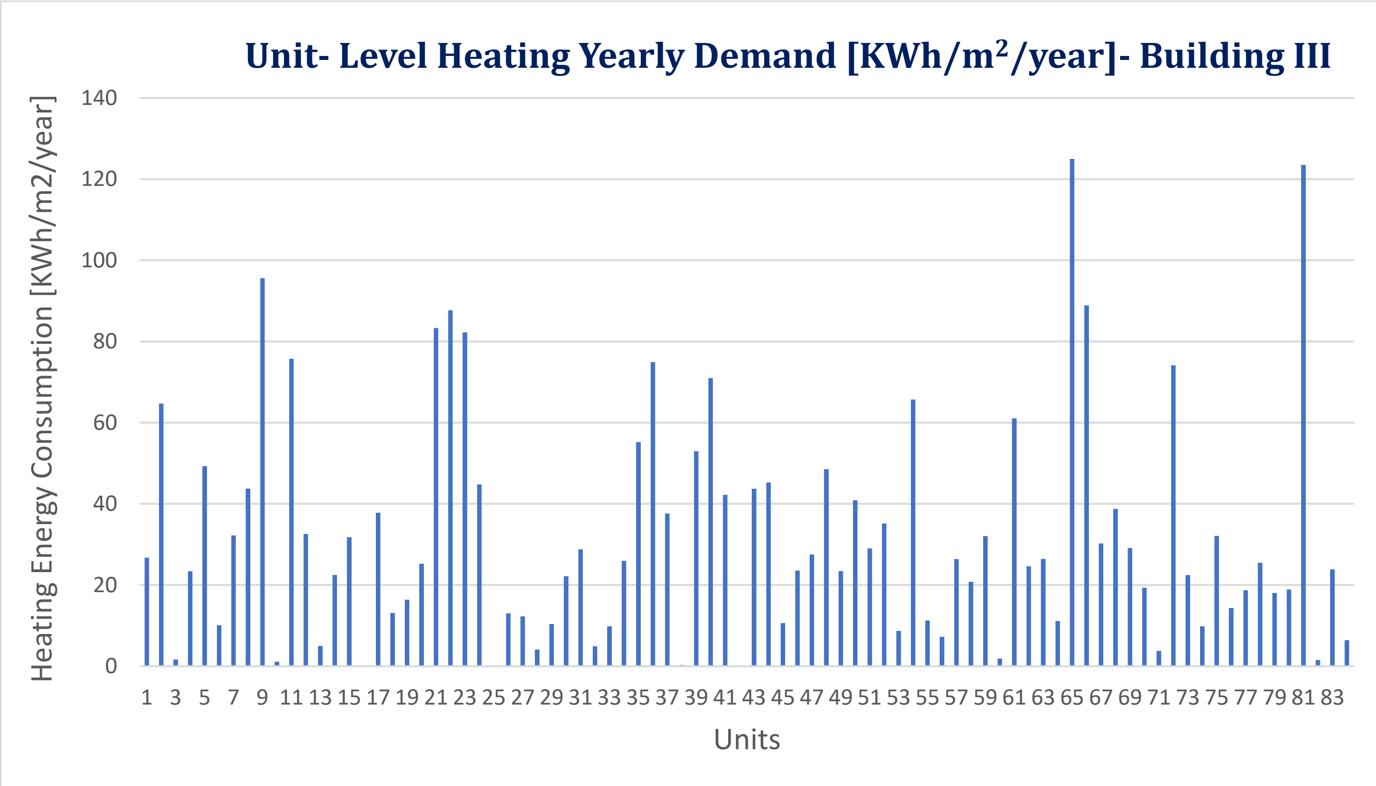


Figure 32: Yearly Unit- Level Heating Demand [KWH/m$^2$] – Building III

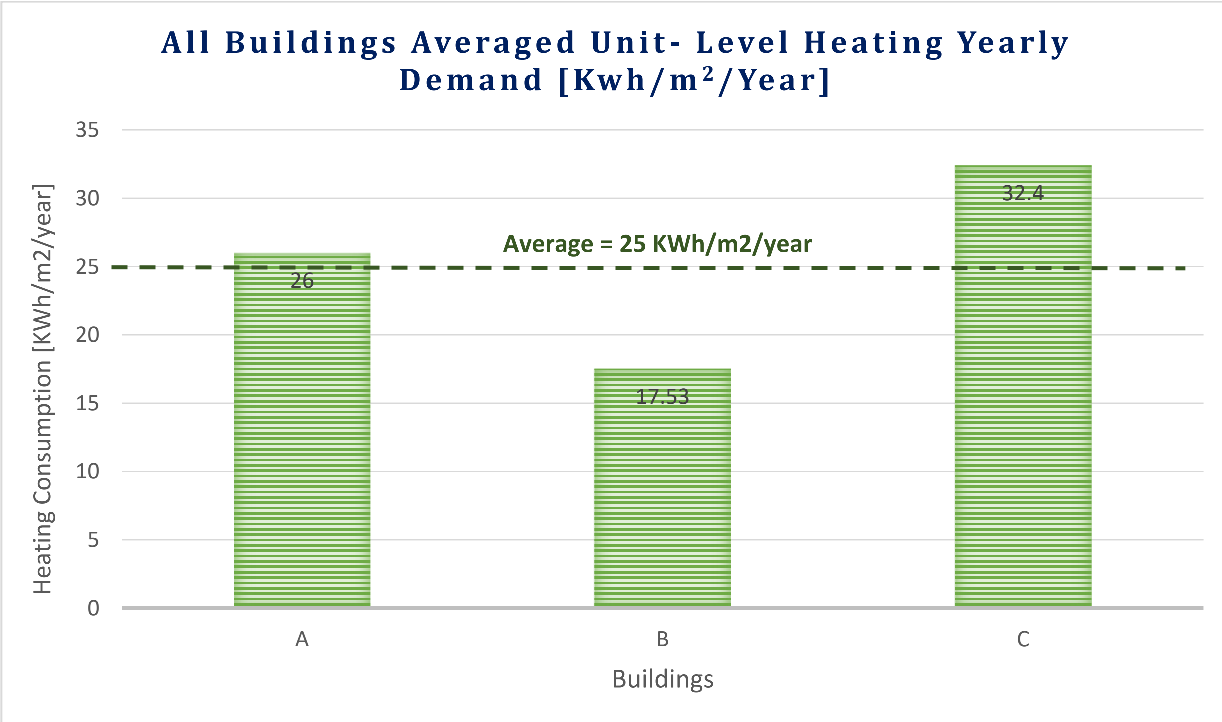


Figure 33: Variation in space heating demand across all the buildings

Results from the yearly space heating demand are showing an interesting wide spread of heating demand across the units within the same building. Further data analysis is made on the observed data in order to evaluate the probability distribution functions of the unit-level space heating demand and infer their means and standard deviations. Unit-level heating energy data from the 3 buildings are used to fit the probability density functions using MATLAB. Figure 34Figure 35Figure 36 show the probability density function of the unit space heating in KWh/m$^2$/year for building I, II, and III respectively.

| Building | Number of Units | Neighbourhood | Building Floor Area (m$^2$) |
|---|---|---|---|
| Building I | 192 | UBC | 10,431 m$^2$ |
| Building II | 70 | Kitsilano | 4858.3 m$^2$ |

| | | | |
|---|---|---|---|
| Building III | 84 | False Creek | 3810 $m^2$ |

Table 13: Heating Demand Analysis: Buildings Description

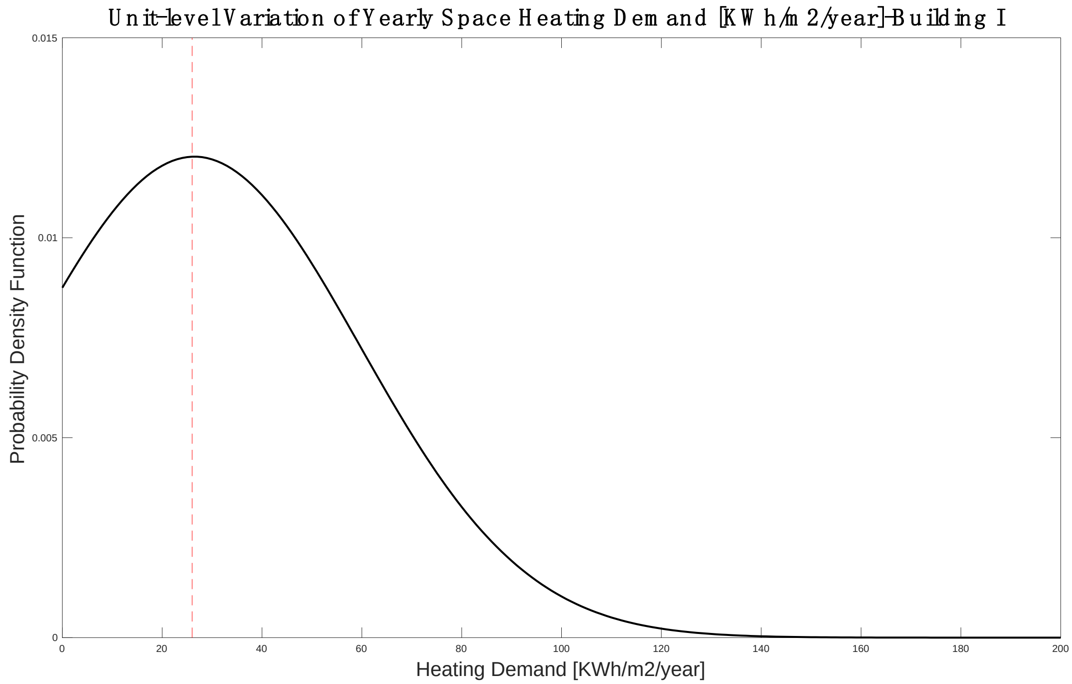


Figure 34: Probability Density Function of Unit-level Space Heating Demand- Building I

The probability density function curves are showing a wide spread of variation across all the buildings units. The average standard deviation of all the buildings studied **is σ= 24.45 KWh/$m^2$/year**, this high value of standard deviation indicated that there is a very high variation of space heating demand across a single buildings' units**.** This probability distribution curves are also showing that the unit-level space heating demand can very much go as low as zero. This wide variation in space heating demand is an ignored issue in the current buildings' codes and standards. This wide variation in the space heating, especially in the case of low heating demand, is a salient problem that could result in overheating problems. Especially when applying passive house practices (e.g. well insulated building envelope, high values of air tightness...etc.), this will very well result of overheating problems.

It is also important to note that, aside from the wide variation in the heating demand, the mean of the unit-level space heating demand is significantly lower than the targets of Step 2 of the BC Energy Step code (the results are showing an average of **31.7-36.9 KWh/m$^2$/year (**after adding the ventilation heating), while Step 2 has a space heating and ventilation target of **45 KWh/m$^2$/year**.)

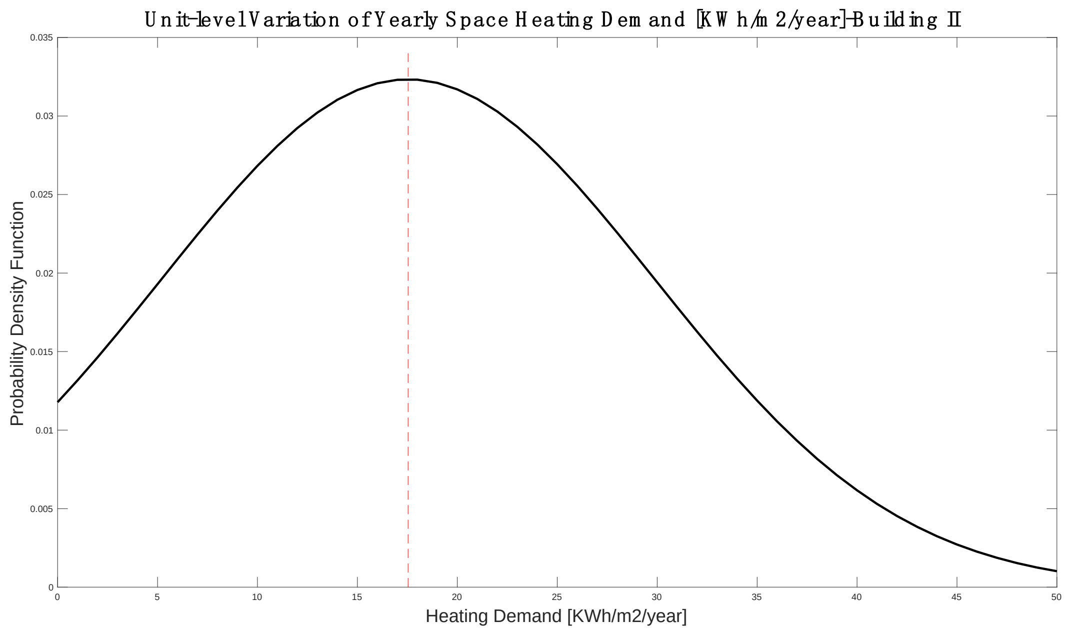


Figure 35: Probability Density Function of Unit-level Space Heating Demand- Building II

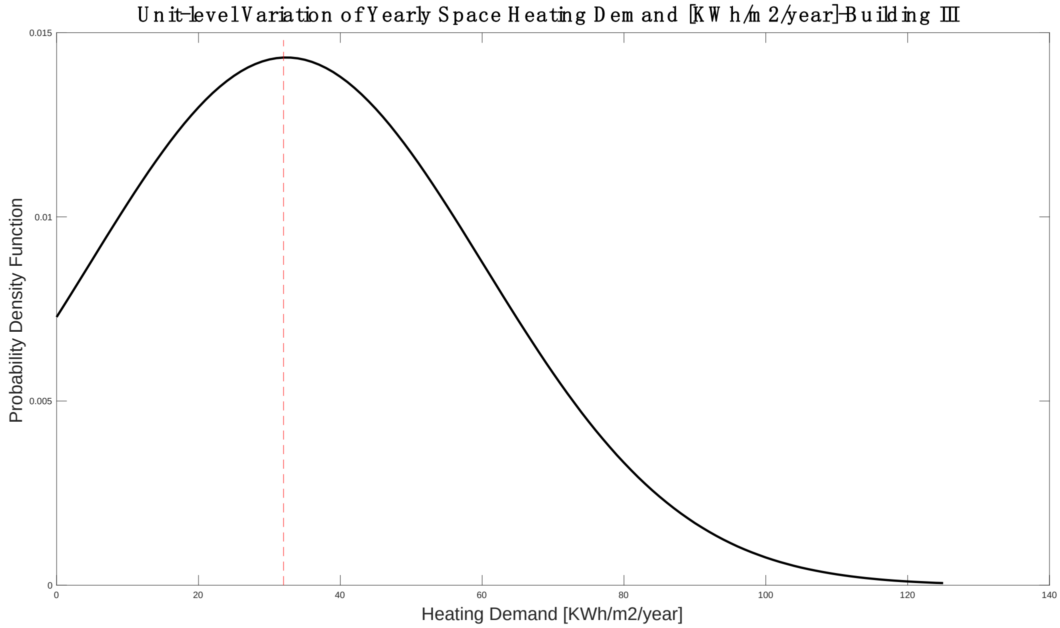


Figure 36: Probability Density Function of Unit-level Space Heating Demand- Building III

In order to calibrate the space heating assumptions modelled in the BC Energy Step Code, the average standard deviation inferred from all the probability density function deduced from the studied buildings, is used to estimate the probability density function of the BC Energy step code assumptions. The average standard deviation has been applied to a mean of 45 KWh/m$^2$/year assumed value and the resulting probability density function is shown in Figure 37. Results are showing that the unit-level space heating demand can go as low as zero, which might lead to common overheating problems, especially in passive house buildings. The calibration results are suggesting taking into account this wide spread of variation in space heating demand across different units within the same building.

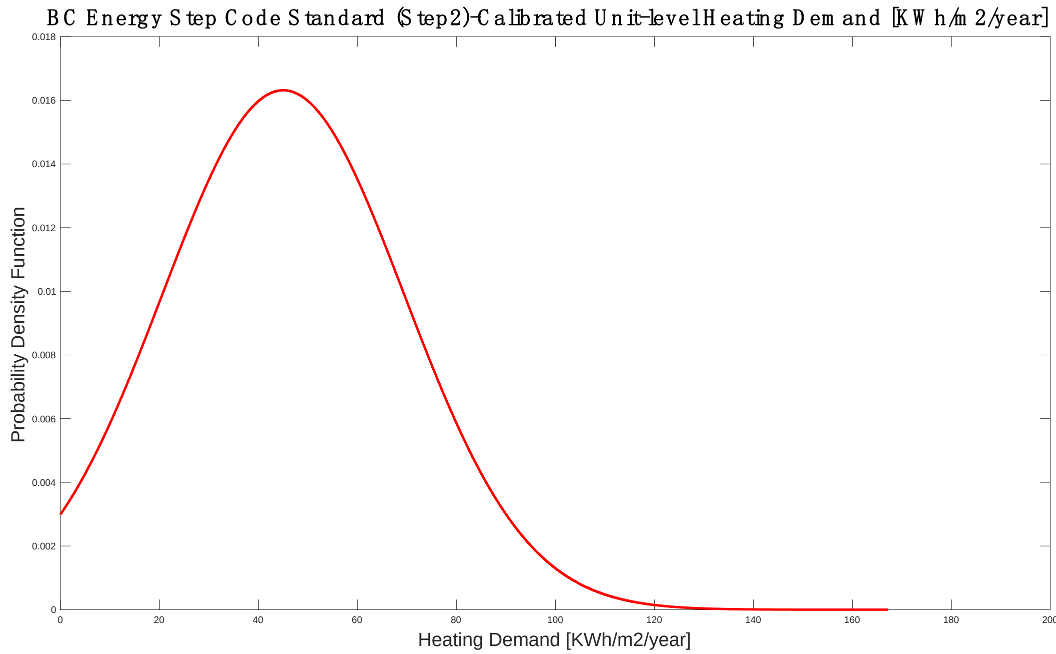


Figure 37: BC Energy Stop Code – Step 2 Calibration of Unit Level Yearly Heating Demand [KWh/m2]

It is important to note that all buildings will experience some variation between suites due to varying solar exposure, and this would be reflected in energy models. However, the data variation is shown in the results is very high that there are likely large variations in occupant behaviour, plug loads, and temperature set points, none of which are currently reflected in energy models and code compliance, but which should be considered when evaluating potential for overheating problems or when estimating a range of likely occupant energy bills

## 4- Conclusions and Recommendations

This research study proposes novel methodologies that are recommended to be added to the current BC building codes in order to improve the buildings energy consumptions predictions and to accurately reflect the occupant building loads. The energy modelling assumptions laid-out in the City of Vancouver Zero Emissions Building Plan (ZEBP) and the provincial BC Energy Step

Code are investigated by calibrating these baseline assumptions using actual building energy consumption data.

Energy consumption data for residential buildings in the City of Vancouver are collected from different sources, such as sub-metering companies, energy providers and research centres. With a special focus on occupant-driven building's loads, energy consumption data for domestic hot water, space heating, cooking energy consumption, plug loads and lighting are gathered and analyzed for the purposes of the study. Data analysis results are revealing significant discrepancies between the actual energy consumption and the assumptions made in the buildings codes, key findings and recommendations for next steps are developed and summarized as follows:

The domestic hot water consumption (DHW) assumptions made in the CoV Energy Modelling Guidelines (EMG) are underestimating the actual DHW consumptions. Based on the observed collected data and the calibration data analysis performed on the 37 buildings' DHW consumption data, 5 new recommendations are proposed. These recommendations should be added to the current domestic hot water energy modelling assumptions in order to reflect the actual DHW consumption scheme. The current peak load assumption for the DHW energy consumption in the CoV energy modeling guidelines should be increased from 0.0016 L/s/person to 0.0021 L/s/person. A seasonal multiplier is proposed to be added to the current DHW calculations in order to reflect the monthly variation in domestic hot water consumption throughout the year. The proposed seasonal multiplier values have been proposed based on observed data and have been inferred by fixing all other parameters and taking into account only varying the seasonal multiplier, the results have then been tested and applied again to the previous DHW curves. The seasonal multiplier table has been designed so that the average of all the months is always equals to 1, so that its value won't affect the other factors while calculating the annual DHW consumption, but it is important to implement it to the monthly calculations to reflect the actual monthly consumption and to accurately design all the building's mechanical equipment for seasonal variations in load.

A novel mechanism which adds a DHW recirculation losses factor is developed. This loss factor depends on the thickness of insulation used in the recirculation piping and it will incentivize the reduction of temperature maintenance heat losses.It is concluded from the DHW energy consumption calibration data analysis that the occupancy assumptions laid-out in the city of

Vancouver energy modelling guidelines are not always reflecting the actual buildings occupancy, based on the observed data. Accordingly, occupancy data has been collected from different sources from 5 different buildings for the purpose of this study and a new modified occupancy assumptions methodology is proposed in order to improve the occupant's energy consumptions predictions.

A detailed study that aims to research the potential energy savings effects from building sub-metering in residential buildings in Vancouver is conducted. It is concluded that building sub-metering can results to up to 28.4% energy savings. A proposed mechanism that should be used in future versions of the City of Vancouver's energy modelling guidelines is proposed in order to incentivize building sub-metering and encourage energy savings.

The plug loads and lighting consumptions are calibrated on different residential buildings. The results are showing that the CoV assumptions are underestimating the load in the 1-bedroom units and overestimating the loads in the 3 bedrooms units. A novel mechanism is proposed that suggest correlating the plug loads consumption to the number of bedrooms and not the unit floor area. The proposed correlation has been tested on the data observed and the results are showing a better energy consumption prediction.

A detailed study on the cooking energy consumption is conducted and data from different buildings are used to calibrate the assumptions made in the CoV EMG. It is concluded from the results that the current assumptions fail to accurately predict the real cooking energy consumption A proposed methodology that estimates the cooking energy consumption as a percentage of the plug loads (i.e. correlating the cooking energy consumption to the number of bedrooms too) is developed.

The unit-level annual space heating demand is investigated and compared with the assumptions made in the BC Energy Step Code. The calibration results are showing a wide variation of space heating demand across different units within the same building. The annual space heating demand average of all the buildings is calculated and compared with the value in step 2 of BC Energy Step Code. The average of the total heating demand for all the buildings studied is: 31.7-36.9 kWh/m2, which is less than the step 2 limit of 45 KWh/m2. In order to calibrate the space heating assumptions modelled in the BC Energy Step Code, the average standard deviation inferred from all the probability density function deduced from the studied buildings, is used to estimate the probability density function of the BC Energy step code assumptions. The average standard deviation has been applied to a mean of 45 $KWh/m^2/year$ assumed value and the resulting probability density function is showing that the unit-level space heating demand can go as low as zero, which might lead to common overheating problems, especially in passive house buildings. The calibration results are suggesting taking into account this wide spread of variation in space heating demand across different units within the same building.

The key findings developed in this research suggest improvements and recommendation on the current version of the City of Vancouver Energy Modelling Guidelines and the Zero Emissions Building Plan (ZEBP). These recommendations might be included in version 3.0 of the Energy Modelling Guidelines to be published by the City of Vancouver in 2019 or 2020, and might be included in a proposed new national standard for energy modelling guidelines to be developed by the Canadian Standards Association with the CoV Energy Modelling Guidelines as a foundational document.

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