Addressing the Energy Simulation Performance Gap

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Executive Summary

This report looks to shed light on the problems that are preventing the improvement in our energy modeling capabilities, and the actions that should be taken to overcome them. With the need for drastic action to address climate change, programs are being put in place to incentivize the constructing of high-performance buildings. Some programs, like LEED, are based on a checklist of design interventions, while The BC Energy Step Code and REAP are performance-based programs that require buildings to meet a certain level of performance. Energy models are used to evaluate the energy performance of a building for these programs, which is logical as it is the best way to predict energy consumption before a building is built, but it also means that we want our energy modeling capabilities to be as strong as possible. There is an issue known as the “performance gap” which means that the energy usage that the model predicts can vary significantly from the final performance of the building, and the steps and methods needed to reduce these performance gaps are covered in this report.

To explore the issues surrounding energy modeling, a model was made for a residential building on UBC called Webber House. When an energy model does not match the building’s final energy usage, a model calibration is performed to identify which modeling parameters did not accurately represent the building. Calibrating the energy model for Webber House was not possible due to a lack of hourly energy consumption data and sub-metering of space heating and DHW thermal loads. A sensitivity analysis was created to show the relative importance of several energy modeling parameters on the energy output of a model to inform which areas of the modeling guidelines should be looked at more closely. It was found from the sensitivity analysis that an energy model is significantly more sensitive to the daytime set point temperature than any other parameter

Several recommendations were made that will support the development of better energy models. The first course of action would be the implementation of hourly energy metering. This would allow for the fine tuning of model parameters which will allow us to determine which parameters are not properly reflecting the building. Sub-metering of DHW and space heating is also critical as these loads must be separate for proper model calibration. Furthermore, making metered building data more accessible to developers, researchers, and policymakers would mean these steps could be implemented more quickly.

Introduction

It is generally the case that developing a high-performance building will cost the developers more money than developing a building that just meets the region's building codes. However, reducing the energy usage of the built environment is a critical step in our fight against global warming, and programs have been developed to incentivize the construction of high-performance buildings. One such program is called the BC Energy Step Code[1], which is a compliance path in the BC building code where developers can achieve code compliance by proving that their building meets a certain level of performance. Currently, municipalities can choose whether or not they require developers to meet Energy Step Code requirements, but by 2022 it will be mandatory across BC. This is a performance-based program, which means the compliance path is based on the end performance of the building rather than the specific design elements that were put into it. The performance of a Step Code building is assessed through the use of a professionally constructed building energy model and an airtightness test. UBC includes Energy Step Code requirements in the Residential Environmental Assessment Program (REAP) [2] for new residential construction on the UBC Point Grey campus. Given that the Energy Step Code will be mandatory across BC, REAP aligns with the Energy Step Code so that both can be achieved simultaneously, however REAP allows UBC to require building elements that are not included in the Step Code.

To meet REAP and Energy Step Code requirements (and green building certification programs such as LEED or Living Building Challenge), an energy model of the proposed building will be created before construction begins. This allows for an estimation of the building's energy usage before it is created. However, modelers, developers, and other building stakeholders would like to better understand the accuracy at which energy models estimate building performance. This inaccuracy is due to the "performance gap" between the energy model's predictions and the actual amount of energy a building uses once it's been built.

This performance gap can be reduced by calibrating the energy model, which is done by creating an energy model of an existing building and tweaking the model parameters to create energy estimates that match the building's actual energy usage. This may sound trivial as one could randomly change parameters until it matches the buildings energy usage. However, precautions must be taken to ensure that the correct parameters are being changed so that the new model can be applied to different buildings. Once a model has been calibrated, it can be used to update the guidelines that developers follow when constructing these models, and will result in better estimations of the energy usage across large populations of buildings. However, creating a calibrated energy model does not occur frequently as the process requires high-frequency energy metering data that is often not implemented in buildings.

The objective of this report is to explore potential causes of the performance gap that commonly occurs in BC building projects, and in doing so, discover shortcomings in our guidelines and our building practices that are preventing the construction of better buildings through energy modeling. This report also looks to provide non-energy modelers with a background on issues surrounding energy modeling so that the importance of the proposed policy changes can be properly understood. The report discusses why a proper model calibration cannot be carried out in this study, which led to a sensitivity analysis

1. The BC Energy Step Code is part of the BC Building Code. Cities can voluntarily require Energy Step Code now, by 2022, it will be mandatory. https://www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/energy-efficiency/energy-step-code
2. The University of British Columbia, Residential Environmental Assessment Program (REAP) 3.1 (BC, Vancouver, 2018) https://planning.ubc.ca/vancouver/sustainability-operations/green-buildings/reap-3.1

being conducted instead. The sensitivity analysis indicates which model parameters affect the building's energy usage most significantly, which in turn indicates which sections of the modeling guidelines have the highest impact on building performance. The modeling of electrical energy consumption (e.g., lighting and plug loads) was not included in the scope of this project so that the reader's focus could be directed towards the more complicated issues of modeling thermal energy usage (space heating and DHW).

This report looks at Webber House, a residential building at UBC, as the subject of a case study. This building was chosen as it represents a typical residential building that was not designed specifically for energy model creation and calibration, and problems that arise when modeling this building will likely be present in a large portion of the building population.

What is an Energy Model?

In today's building industry, developers need to construct buildings that achieve a specific level of environmental performance. Designing buildings using best practices for energy efficiency will generally result in a high-performance building. However, the energy usage of a building is significantly affected by the buildings local environment and orientation to the sun. An energy model allows developers to determine if the energy reducing measures they plan to implement will be sufficient at the specific location they plan to build.

An energy model uses a simple 3D computer model of the building, consisting of only the building's exterior and interior walls, exterior windows, and objects that could cast a shadow on the building (balconies, trees, surrounding buildings, etc.). The modeler then tells the energy modeling program (examples include Archsim, OpenStudio, and Trace) information about the building that will affect its energy usage. The program requires a wide range of information, including but not limited to the types of walls and windows used, the building's temperature set points, when occupants will be in the building, and the airtightness of the façade. Finally, the program takes the 3D model and the specifications for the building and combines them with a local average weather file, which is sent to a program called EnergyPlus which estimates the thermal and electrical energy usage of the building. The resolution of the predicted energy consumption can be yearly, monthly, daily, or hourly. Figure 1 shows the CAD model that was developed for Webber house, while figure 2 shows the Archsim interface.

Seeing as the performance of a building design is evaluated using an energy model, the guidelines that are followed when creating an energy model must also be accurate. If an energy model, on average, underpredicts the final energy usage of buildings, the population of buildings that used the guideline will use more energy then predicted. The usage of The City of Vancouver Energy Modelling Guidelines Version 2.0[3] is a requirement of the BC Energy Step Code, so the importance of having an accurate energy modeling guideline is very high.

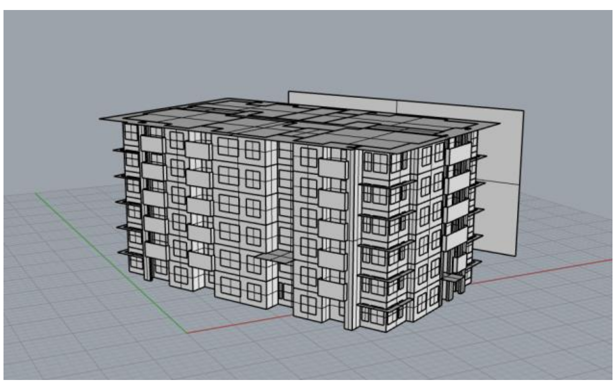

Figure 1: Webber House energy modeling geometry

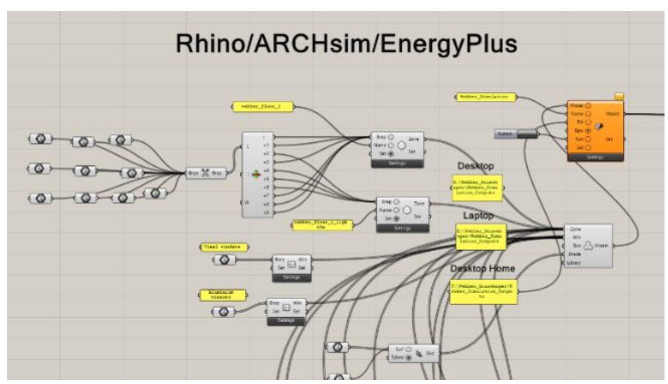

Figure 2: A snapshot of how information is shared in Archsim

3. The City of Vancouver, Energy Modelling Guidelines, (BC, Vancouver, 2018) https://guidelines.vancouver.ca/E006.pdf

Strengths and Weaknesses of an Energy Model

It's important to understand why anyone bothers to create a complete energy model when methods exist that can estimate building energy usage more quickly. The main strength of an energy model is its ability to create an accurate, high-resolution estimate of the space heating requirements of a building. Modeling the physical interactions that determine energy usage would be prohibitively difficult to do by hand or in excel. An energy model takes into account the amount of solar energy that enters the building as the sun moves across the sky at a specific location, the amount of heat conducted through the façade based on the insulation and size of the walls and windows, how airflow moves heat around the interior of the building based on room dimensions, the amount of heat produced by lights and equipment, and many other factors. Even if a developer was constructing a building identical to an existing building in Vancouver, it would likely still be an unreasonable assumption that the two buildings will require the same heating loads, as energy requirements are significantly impacted by shadows produced by its surrounding and the building's orientation.

Energy modeling software has been developed over decades to accurately model all these complicated interactions. Other methods of predicting heating requirements include excel based programs like the Instantaneous Energy Calculator[4] developed at UBC and degree day heating calculations. However, these methods calculate energy based on generic relationships connecting building geometry and energy usage, and as stated before, any inaccuracy gets increasingly significant as your planning project increases in scale.

Besides space heating requirements, water heating and electrical usage are the other two functions commonly associated with energy models. Although models can predict these loads, the calculations used to estimate these values can be quickly replicated in Excel. This is to say that the calculations energy models use to predict water heating and electricity are not nearly as sophisticated as those used to predict space heating, and better methods of estimating these values exist. The best method is to look at existing buildings with similar lighting and/or domestic hot water (DHW) systems, as the energy usage of these systems don't depend on building orientation, location, or geometry. Creating an excel spreadsheet to do these estimations is also a good alternative as you will likely have more control over the parameters of the calculation, but that can depend on the energy modeling program used.

ENERGY MODEL STRENGTHS AND WEAKNESSES

Strengths

- Can handle the complicated thermal interactions that dictate space heating loads
- Can easily be modified once created

Weaknesses

- Can take a while to create
- Better methods exist of estimating electrical and water heating loads

4. Johnson, G; Dahmen, J; Ostrow, S; Hsieh, J, Instantaneous Energy Calculator, (BC, Vancouver, 2011) https://www.civil.ubc.ca/publications/instantaneous-energy-calculator-energy-flow-analysis-buildings

Simulation Methods

Webber House is a 6 story residential building located on the Endowment Lands on UBC campus. It has 6 suites on each floor and a 2 story underground parking garage. All the construction characteristics of the building were taken from the main architectural plan. These characteristics include room sizes, floor, wall, roof, and window constructions, insulation values, and window sizing and locations. Webber house does not use its own HVAC equipment to meet its DHW and space heating demands on site. Instead, it is supplied energy from a district hydronic energy system. However, the simulation results shown in the next section predicts the final thermal energy demand of the building, which is the amount of heat the building needs to operate, which is less than the amount that needs to be produced due to distribution inefficiencies. The amount of electricity or fuel needed to produce this heat can be calculated using conversion and distribution efficiencies for different parts of your HVAC system.

The model parameters that were not included in the architectural plan were obtained by following The City of Vancouver Energy Modelling Guidelines Version 2.0. This guide provides some background on energy modeling and dictates most of the model's parameters, including occupancy, plug loads, lighting, DHW, infiltration rates, ventilation rates, and thermal bridging, among other things. The modeling guidelines then refers the modeler to the NECB 2011[5] guidelines for the model's schedule inputs. These guidelines were followed precisely as one of the project objectives is to determine inaccuracies in the guidelines and correct for them. Even though Webber House reports its energy usage as a combination of DHW and space heating, figure 4 shows space heating data with the DHW load removed. The importance of having distinct DHW and space heating values, and the method used to separate them are shown in the following sections.

The purpose of these simulations are to see how closely the energy modeling guidelines match the actual energy usage of the building, and to determine the sensitivity of the simulation results to different input parameters. One measure that was taken to reduce uncertainty between the modeled and actual results was comparing 2017 building data to a 2017 weather file. Year-specific weather files are hard to obtain but they are required for calibration. When calibrating an energy model, you need the hourly changes in the model's energy usage to match the hourly changes that occurred in the building. These values can only be compared if the weather that the model uses is the same as the weather that actually occurred when the meter data was taken.

5. National Research Council Canada, NECB 2011 https://www.nrccnrc.gc.ca/eng/publications/codes_centre/2011_national_energy_code_buildings.html

Simulation Results

The simulations produced energy estimates for space heating and DHW. The results of these simulations are compared with Webber's metered energy usage. Figure 3 shows the simulated energy usage breakdown when using a 2017 weather file. A pie chart of Webber's actual energy consumption was not made as Webber has incomplete space heating data for 2017.

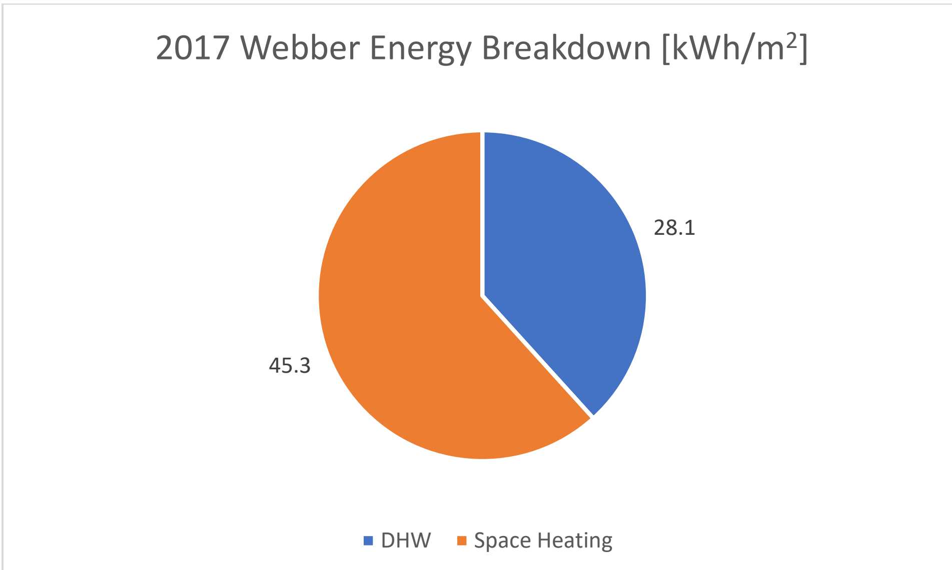

Figure 3: A breakdown of Webber's simulated 2017 energy consumption

Space Heating

Figure 4 shows the actual energy usage of the building as the leftmost blue bar. This bar first appears in May as the construction of Webber finished part way through 2017. The modeled results using the current guidelines are represented by the leftmost orange bar. The rest of the bars show various simulations configurations with one input parameter varied from the default setup. These variations allowed for the creation of the sensitivity analysis.

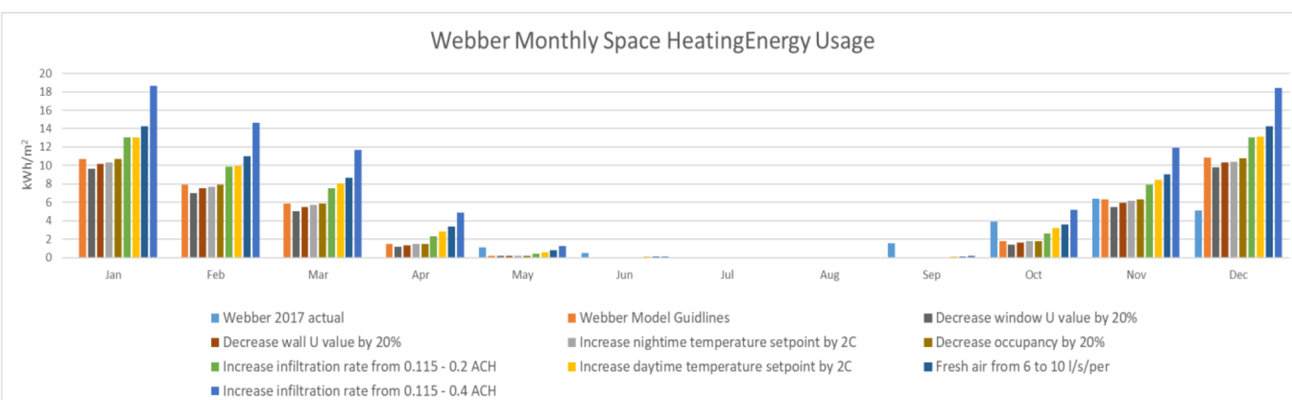

Figure 4: A comparison of Webber houses 2017 energy usage with various energy model configurations

There is an unusual pattern occurring in the actual energy use numbers. The actual energy usage is significantly higher than the modeled loads in October, about the same as the modeled results in November, and significantly less in December. This is concerning as space heating loads should increase as the months get colder. As mentioned before, the actual energy usage for space heating was estimated by removing the estimated DHW loads from the total energy usage of Webber. Inaccurate DHW load estimates are likely the cause of these results. If DHW and space heating were metered separately, we would not have to make crude estimates of the DHW loads, and we would be able to determine if patterns like this are caused by building problems or malfunctioning metering equipment.

Figure 5 compares the modeled space heating loads from 2017 with the metered space heating loads (total metered thermal energy with DHW prediction removed) from 2018. This is to give an idea of how the energy model performed to a similar year with complete thermal data.

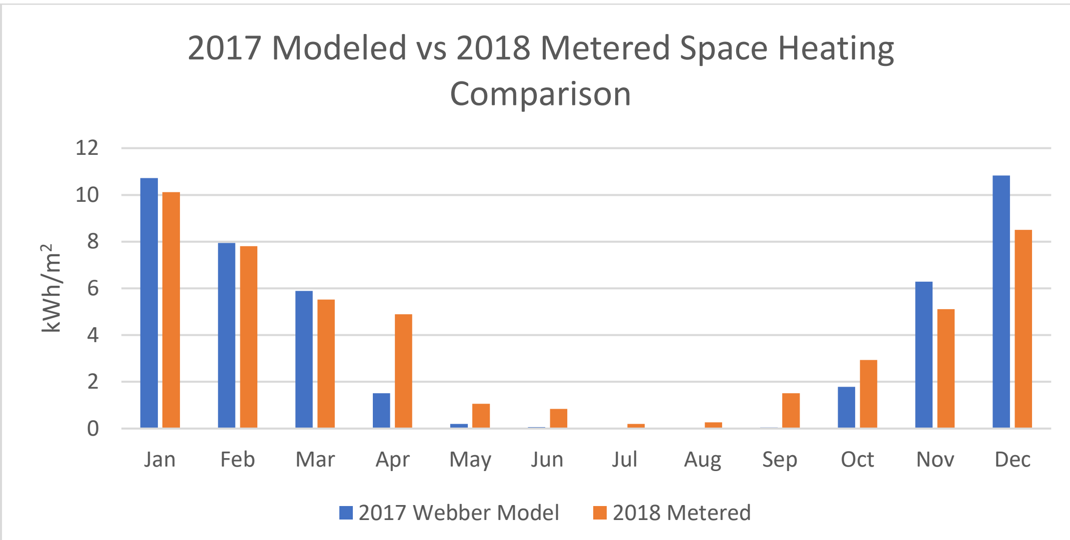

Figure 5: A comparison of Webber's modeled 2017 space heating with Webber's 2018 metered space heating

It seems that the beginning of both years were similar, but 2017 become cold later in the year but more rapidly. There is also a large discrepancy in April. This highlights the importance of comparing modeled and actual data from the same year when verifying the performance of a model.

Sensitivity Analysis

A sensitivity analysis was carried out to show how different modeling parameters affect final energy predictions, and the results can be seen in figure 6 and Appendix B. It can be seen from figure 6 that the most sensitive parameter by far is the daytime temperature set point. The daytime set point is significantly more impactful then the nighttime set point as the daytime set point represents 17 hours of the day while the night set point represents only 6 hours. The last hour is a transition set point between the two. Additional building energy interactions are at play that are causing such a high sensitivity to daytime set point temperature, however, investigating the source of these interactions was not included in this study. This means that comparing the recommended NECB 2011 temperature set point schedules to actual Vancouver residential buildings is a critical next step. The rest of the input parameters have fairly similar sensitivity values, except maximum occupancy which has such a small sensitivity that it doesn't show up on the graph.

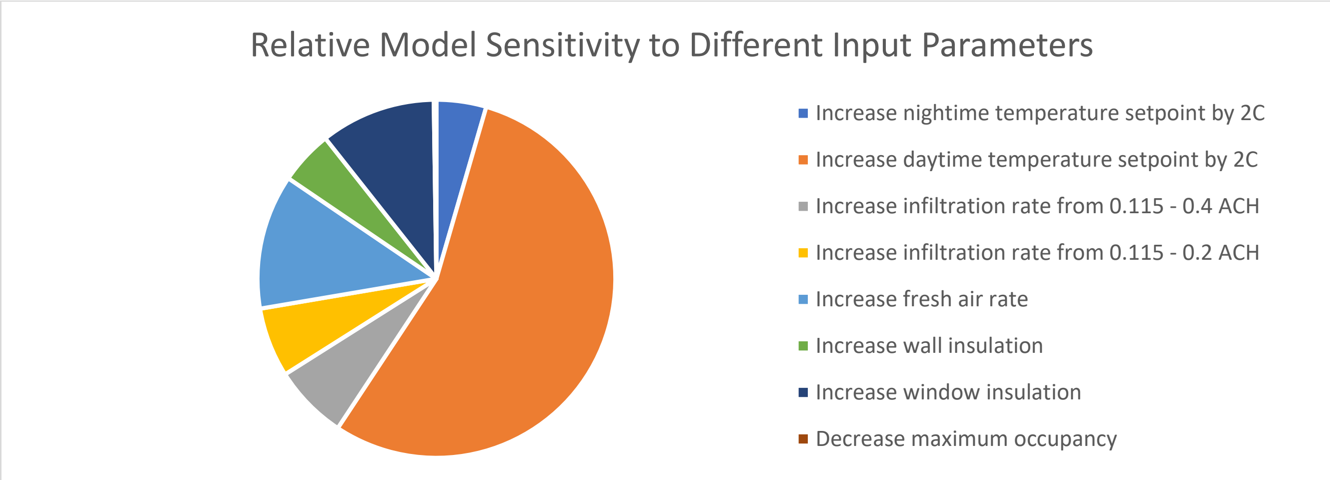

Figure 6: A chart showing the relative sensitivities of different energy modeling parameters

Domestic Hot Water

Figure 7 shows the models' estimated water heating loads and the loads that were estimated through hand calculations. The fact that DHW is not reported independently means that we can't confirm if either method is close to the actual building usage. However, both methods seem to agree with each other fairly well, and the energy model predicts a yearly consumption of 28.1 kWh/m^2/yr while the hand calculations predict 31.3 kWh/m^{2}yr, which are typical values for residential buildings. A clear problem with the energy modeling guidelines, which is discussed in a future section, is that they recommend a groundwater temperature that is much too low for Vancouver. Increasing the groundwater temperature to a more reasonable value would result in lower modeled DHW loads. This would mean that the modeled and hand estimate loads would not agree as well, but the fact that they are both estimates means that currently, we cannot determine the accuracy of either approach.

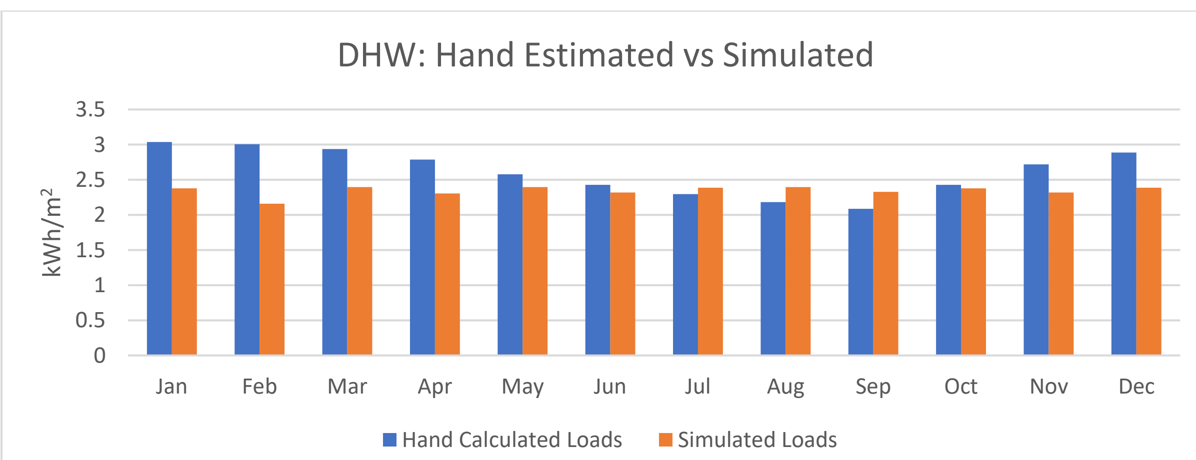

Figure 7: A comparison of DHW energy loads predicted using hand calculations and energy simulation

Discussion

The following sections discuss the key areas that need to be addressed to improve our energy simulation capabilities.

Why Do We Need Separate DHW and Space Heating Loads

The first major road bump preventing the creation of a properly calibrated energy model for Webber house is that the utility meter combines energy usage for DHW and space heating. Buildings are metered this way because a simple thermal energy usage number is all that is needed to create an energy bill. However, sub-metering is critical in creating a calibrated energy model for a building. DHW and space heating sub-metering is also beneficial as it shows whether the energy systems are functioning as they should be and allows the building manager to quickly determine which system is having issues if unexpected energy usage numbers start to appear.

When calibrating a model, lots of parameters need to be tweaked before the modeled energy predictions closely match the actual usage. This is a very complicated process. Lumping DHW in with space heating means that all the DHW parameters are adding inaccuracies to the calibration, and if the DHW calculations aren't 100% accurate, it's essentially impossible to properly calibrate for space heating because you'll never know if your results are being affected by poor space heating parameters or bad DHW predictions. Additionally, it was mentioned before that energy models don't calculate DHW energy usage very accurately in the first place. DHW and space heating loads must be metered separately so there is no ambiguity regarding the correlation between energy model parameters and actual building performance.

Hand Calculations for DHW

The best way to estimate the DHW energy usage of a new building is to look at a similar building in the same city with the same number of occupants. Having data from several buildings with the same occupancy will increase confidence in the prediction. If DHW data from buildings with the same occupancy is not available, data from buildings with higher and lower occupancies can be used to interpolate a value (estimate a value between the two values).

You may find yourself in a situation where energy modeling software and pre-existing DHW data is not available and you want to carry out a quick calculation by hand. This will also shed some light on how energy models create DHW predictions. DHW loads are estimated by combining the amount (in kilograms) of water used each month, with the amount of energy needed to raise a kilogram of water by 1^{o}C, with the temperature difference between the groundwater temperature and DHW temperature. This is shown in equation 1.

Equation 1

$$Q = m * Cp * \Delta T$$

Q = Energy [kJ]
m = Mass [kg]
Cp = Heat Capacity [kJ/kg/^{o}C]
ΔT = Change in temperature [^{o}C]

Schedules are created, both when using modeling software and hand calculations, that changes the amount of water used at any given time. The DHW schedule in NECB 2011 indicates the load changes throughout the day but assumes water usage is constant from month to month. However, energy modeling software assumes constant groundwater temperature from month to month, while figure 8 shows that the groundwater changes quite significantly.[6] This value can be controlled when using hand calculations, which is why it is preferred over modeled results when monthly changes in DHW are of interest.

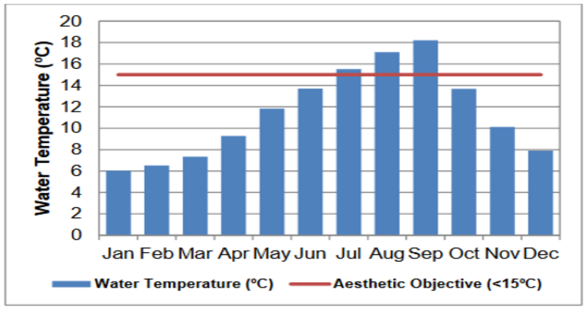

Figure 8: Vancouver monthly average water temperature

Equation 1 was used to estimate the DHW loads of the building, which were used to separate the building's total metered energy data into DHW and space heating. As can be seen in figure 4, the energy model shows that August requires zero energy for space heating. This means that the entirety of the energy requirements for that month went towards water heating. We can determine the amount of water used in August because we know the amount of energy used (Q) from the metered building data, the specific heat capacity (Cp) of water can be found online, and ΔT can be calculated by determining the temperature the building heats its water too (about 60ºC) and subtracting the groundwater temperature of that month. The separation can be seen in figure 9.

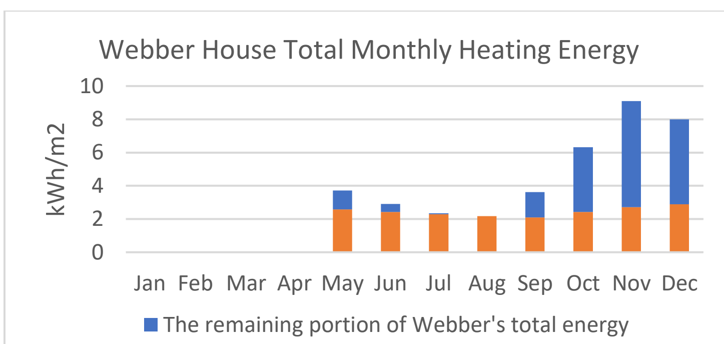

Figure 9: Breakdown of Webber's metered total monthly heating energy

It is assumed that the amount of water used each month is constant, as we don't have DHW or occupancy schedules detailed enough to inform us otherwise. Once the amount of water is calculated, the different DHW energy loads for each month can be calculated by combining the constant water usage with the ΔT for each month. Figure 9 shows the total heating loads for Webber house and the portion of the load that was determined to go towards DHW.

6. City of Vancouver, Water Utility Annual Report, 2017
https://vancouver.ca/files/cov/water-quality-utility-report-2017.pdf

A comparison of the modeled DHW energy loads and the hand calculated loads can be found in figure 7 in the results section. From this graph, the trend of increased DHW heating requirements in the winter can easily be seen in the hand calculations because of the varying groundwater temperatures, while the energy modeled results show a constant load, only changing because different months have a different number of days.

Even though steps were taken to estimate monthly DHW loads as accurately as possible, there are still significant uncertainties. Most notably, if the amount of water used in August was lower than the average water usage in other months, all the calculated DHW loads will be too low. This could be the case as Webber house is a residential building for university faculty, and a large portion of them will likely be on vacation in August. This reinforces the fact that DHW and space heating loads need to be monitored separately so that the need to estimate DHW can be avoided entirely.

The Importance of High-Frequency Energy Metering

Besides having combined DHW and space heating loads, the major issue preventing the creation of a properly calibrated energy model is that utility meters typically only provide monthly energy usage data. While monthly data can indicate how well a building is performing, it's not generally enough data to create an accurately calibrated energy model. This is because it's easy to change the model parameters to create monthly energy estimations that agree with the building's actual monthly energy usage. You can construct two different simulations that both agree quite closely with the actual building, and even though one may "technically" agree better than the other, it's impossible to be confident enough that one model is using the correct calibrations, especially if you want to change the policy surrounding energy modeling.

According to literature, "Heo et al. (2012)"[7], states that an accurately calibrated energy model can be created using a year of monthly data. However, this is an extremely complicated process. It involves determining the uncertainty of each of your modeled parameters, ranking the importance of each parameter in terms of their effect on energy consumption (much like the sensitivity analysis that was conducted), and undertaking a Bayesian calibration analysis to determine correct parameter values. It may be worth considering if this approach can be set up to apply to a wide range of buildings, and all the modeler would have to do is plug in the energy model and parameters and the computer would do the rest. As it stands however, this approach seems to be out of reach of anyone who is not highly trained in statistics.

Calibrating an energy model using hourly data is easy in comparison. When using hourly data you have to match your model's energy outputs with changes in monthly, daily, and hourly energy use. Creating a model that will accurately predict these three energy trends is much more "difficult" to achieve but this also means that if a highly accurate model is produced, there is a high level of confidence that the parameters used are correct. This high level of confidence is key, as it means that you can run your model through an optimizer program that will find the best combination of model parameters. This is not the case with monthly data, as it is easy to create several sets of parameters that create models that predict energy usage very well, and you won't be able to distinguish which model is changing variables that were already accurate. As can be seen in Figure 4, increasing the model's infiltration rate will increase monthly

7. Heo, Y; Choudhary, R; Augenbroe, G.A., Calibration of building energy models for retrofit analysis under uncertainty, (Energy and Buildings, 2012), 550-560
https://www.civil.ubc.ca/publications/instantaneous-energy-calculator-energy-flow-analysis-buildings

energy usage. If the model under/over predicts energy usage, you could create a model that closely predicts energy usage by just changing the infiltration rate. However, increasing the fresh air ventilation rate also increases energy usage and a model that closely predicts energy usage could be created by changing that variable instead. Seeing as there is only one trend that needs to be matched when looking at monthly data, you can't distinguish which model is the best if two models are similarly good at predicting energy.

The environmental impacts of accurate energy models have already been discussed in this report, but it may be unclear as to what extent we should be increasing our energy metering capabilities. Is one building recording hourly data enough? Should every building be recording hourly data? One building is not enough because a calibrated energy model needs to accurately represent a population of buildings. For example, if the building being used for calibration has an unusually high infiltration rate, then the new model will not be accurate for most buildings. Several buildings need to be researched to determine what modeling inaccuracies span over the building population.

Another question is should we invest in high-frequency metering systems for just the number of buildings required to create an accurately calibrated energy model. From an energy modeling perspective, the answer to that question depends on if having one modeling guideline for a building type, retail for example, is sufficient, or if guidelines for specific building types, such as bars or department stores, would be beneficial. It makes sense to address this in steps. First calibrate the energy model for the overarching building type, and if it is found that significant performance gaps appear to be related to a specific subset of retail buildings, consider creating a modified guideline for that subset of buildings. Additionally, the more buildings being metered allows for more accurate model calibrations as more buildings can be evaluated.

Energy metering data can also be used for applications other than energy modeling. High-frequency metering allows research of how uncommon weather occurrences affect immediate building energy usage. Having this information also gives future researches the ability to start detailed energy use research projects when the need arises. In a nutshell, monthly energy metering can be used to determine if a building is meeting its energy targets, but to actually learn something new about a building, hourly data is required.

Additionally, there are benefits to high-frequency metering that go beyond the calibration of energy models and research. The most apparent benefit is anomaly detection. If you own a commercial building, the owner loses money if the building is not performing at peak efficiency. If a piece of machinery is malfunctioning, and the metered data may show unusual energy usage numbers between 5 am to 8 am every day, the error can be quickly addressed because you know that the faulty equipment only runs during those hours. For residential buildings, residents appreciate anomaly detection as it allows them to distinguish between a high energy bill caused by excessive electricity use and faulty appliances. If you get a high monthly energy bill and all you can see is monthly data, someone will probably assume they used too much energy that month. However, if they have hourly data, they can see their baseload energy usage, and if it is a lot higher then the average for their building (which is data buildings sometimes provide), or their average from previous months, they can be confident that there is something wrong with their appliances/energy systems.

Recommendations

This section summarises the actions that are being recommended in this report and summarizes why they are important.

Hourly Metering

It might seem clear at this point that most of the responsibility for improving our energy modeling ability falls on the policymakers. REAP 3.1 currently rewards metering of space heating thermal energy consumption, hot water usage, and cold water usage. However, these are all optional credits and metering frequency is not specified. The BC energy step code does not mention energy metering at all in its requirements. A section could be added to REAP and/or the Energy Step Code that rewards buildings that implement infrastructure that will allow for the calibration of energy models. These would be optional credits, but would result in more buildings that could contribute to the development of the Vancouver Energy Modeling Guidelines.

Sub-Metering of DHW and Space Heating

A credit/requirement for the sub-metering of DHW and space heating could be added to the previously mentioned "energy model calibration section" for REAP and the Energy Step Code. Hourly energy metering may not be crucial for the development of energy models as implementing the Bayesian method of calibration using monthly data may be feasible, but having sub-metered DHW and space heating is critical, as discussed in the section titled "Why Do We Need Separate DHW and Space Heating Loads".

Mandatory Energy Benchmarking

Comparing the energy a model predicts and the amount of energy the building uses should be mandatory. It is not a time-consuming process, and it's important to identify buildings that did not live up to their model expectations. BC Energy Step Code is a performance-based standard that depends on energy modeling to confirm whether a building meets its performance goals. Although these energy models are constructed by registered professionals, it's important to have a feedback loop that confirms the performance of these models and indicates areas that need improvement. The fact that the performance gap exists means that the revision and further development of energy models is a necessary endeavor. Even if a calibrated energy model cannot be created for that building, the model can still be reviewed to see if best practices were used, and developers that appear to be cheating the system can be determined and their future building projects can be looked at more closely.

The energy benchmarking of buildings cannot be conducted if the building's energy data cannot be accessed. Projects that could forward our understanding will be less frequently conducted if researchers and government officials have difficulty acquiring this data. Utilities have established auto-upload protocols for Energy Star Portfolio Manager, [8] and cities are already looking for ways to make energy benchmarking mandatory. It is unfortunate that the portfolio manager is set up to store monthly benchmark data and currently cannot be used for hourly benchmarking. It is clear that a solution needs to be implemented to allow for more widespread hourly benchmarking. It does not need to be a system that can handle hourly data for every building in BC, but no developer will employ hourly energy

8. Energy Star, Using Portfolio Manager
https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager

metering if it can't be used for benchmarking. Updating REAP to require energy benchmarking, including requirements for hourly metering, would provide a performance evaluation of Energy Step Code and provide data that allows for calibrated modeling to better understand performance gaps.

Require the Creation of an Energy Modeling Reference Sheet in Every Construction Project

My final recommendation for improving our energy modeling ability is for developers to create a page in their main building plans that compiles all the information required to create an energy model. This will decrease the time required to create an energy model as the modeler won't have to search reports for the information, and it will reduce the probability of important modeling information being left out of the report entirely. For example, the main architectural plan for Webber included the U values for the windows and window frames, but didn't include the solar heat gain factor or the visible transmittance of the glass. These are both important for determining space heating due to sunlight penetration. A list developed based on the parameters for Archsim can be found in Appendix A, and can be further developed based on the requirements of different energy modeling programs.

Recommendations for DHW and Airflow

Despite not currently having the ability to calibrate energy models, there are some aspects of the energy modeling guidelines that stand out as being problematic. Firstly, the guidelines state that groundwater temperature should be modeled at 5ºC. This number should reflect the average water temperature over the entire year, and as can be seen in Figure 8, the monthly groundwater temperature never reaches a value that low. This temperature may have been set to compensate for Vancouver energy models under-predicting DHW heating requirements. If this is the case, it should be made clear in the guidelines. Setting the temperature to 5ºC is a solution that produces reasonable results (using this study as a reference), but it takes a parameter we have data for and changes it to something incorrect to address a calculation error we don't know the source of. One potential source of the calculation error is that Archsim outputs water heating requirements as thermal energy (the amount of heat needed to heat the water), rather than electrical energy. If a buildings water heating system is electric, there will be an efficiency loss when converting electricity to heat (or an efficiency gain if using a heat pump). It's possible that the building's electrical energy DHW requirements are being compared directly to the model's thermal energy predictions. I would not recommend changing the DHW ground temperature in the guidelines as it reflects water heating loads fairly well, but the reason for this temperature set point should be made clear to avoid future confusion.

The guidelines also recommend that fresh air requirements can be estimated from the ASHRAE 62 – 2001 report. This report recommends a minimum ventilation rate of 2.5 L/s/person. Although most Canadian building codes follow ASHRAE's recommendations, a contractor following best practices will likely utilize a much higher ventilation rate, potentially around 10 – 20 L/s/person. It would be a good idea to conduct a survey of residential buildings to determine what fresh air rate best represents the building population.

Conclusions

It is clear that the infrastructure required to test whether energy model results are accurate is lacking. The primary issues that are inhibiting the development of calibrated energy models, namely the lack of sub-metering and high-frequency metering, are caused by insufficient policy regarding the amount of building performance information developers and owners are required to monitor. Hopefully the policy changes that are mentioned in this report are reasonable and achievable. There are also areas in the modeling guidelines that are problematic, such as the ground set point temperature and fresh air requirements that can be addressed without the use of energy models.

It's important to remember that energy modeling and building performance verification aren't the only things energy data is good for. It's also great for anomaly detection which is hugely beneficial for residential and commercial buildings, and supports further research in the building sector. Globally, the life cycle of buildings accounts for about 40% of total energy use, so research in this area will be at the forefront of lowering our energy consumption and addressing climate change.

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Appendix A: Parameters Needed for Energy Models

It's important that all values are reported with their units so the modeler knows if the value needs to be changed

- ✓ Window U or R values (best if it's the total value for the glass and frame)
- ✓ Window Solar heat gain coefficient (SHGC) and Visual Transmittances
- ✓ Wall, floor, and celling sections with all material layers and their thicknesses. When listing the insulation value for the wall, indicate whether the value is specifically for the insulation layer, or the wall as a whole
- ✓ The roughness, conductivity, density, and specific heat of each material used in the primary surfaces (ground floor, exterior walls, and exterior roof)
- ✓ The amount of fresh air that will be vented to different zones, in both L/s/person and L/s/m^2 (or imperial equivalent)
- ✓ The temperature at which DHW will be heated too

There are also values that can be estimated from the modeling guidelines, but can be replaced with actual building parameters if they are available. These include:

- ✓ Lighting and appliance density by zone type
- ✓ Lighting target lux, and if lights are stepped dimmable, continuously dimmable, or not dimmable
- ✓ Maximum occupancy

Appendix B: Space Heating Sensitivity Information

Parameter Under Consideration	% change to Parameter	% change to Energy Usage	Relative Sensitivity (% change to Energy Usage / %change to Parameter)
original	0.0	0.0	
Increase nighttime temperature set point by 2C	11.1	3.2	0.3
Increasing daytime temperature set point by 2C	9.1	31.8	3.5
Increase infiltration rate from 0.115 - 0.4 ACH	247.8	92.2	0.4
Increase infiltration rate from 0.115 - 0.2 ACH	73.9	25.8	0.4
Increase fresh air rate	66.6	44.4	0.7
Increase wall insulation	20.0	5.5	0.3
Increase window insulation	20.0	12.0	0.6
Decrease maximum occupancy	20.0	0.3	0.0