



**STUDY REPORT SR 277/5 [ 2012 ]**

# **BEES** **INTERIM REPORT**

**Building Energy End-Use Study - Year 5**

## **MODELLING DETAIL ANALYSIS**

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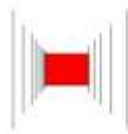
# **BUILDING ENERGY END-USE STUDY (BEES) YEAR 5: MODELLING DETAIL ANALYSIS**

## **BRANZ Study Report SR 277/5**

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## **Reference**

Gates, A., Cory, S., and Donn, M. (2012). Building Energy End-Use Study (BEES) Year 5 Interim Report: Modelling Detail Analysis, BRANZ Study Report 277/5, Judgeford.



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# PREFACE

Understanding how energy and water resources are used in non-residential buildings is key to improving the energy and water efficiency of New Zealand's building stock. More efficient buildings will help reduce greenhouse gas emissions and enhance business competitiveness. The Building Energy End-use Study (BEES) is taking the first step towards this by establishing where and how energy and water resources are used in non-residential buildings and what factors drive the use of these resources.

The BEES study started in 2007 and will run for six years, gathering information on energy and water use through carrying out surveys and monitoring non-residential buildings. By analysing the information gathered, we aim to answer eight key research questions about resource use in buildings:

1. What is the aggregate energy and water use of non-residential buildings in New Zealand?
2. What is the average energy and water use per unit area per year?
3. What characterises the buildings that use the most energy and water?
4. What is the average energy use per unit area for different categories of building use?
5. What are the distributions of energy and water use?
6. What are the determinants of water and energy-use patterns e.g. structure, form, function, occupancy, building management etc?
7. Where are the critical intervention points to improve resource use efficiency?
8. What are the likely future changes as the building stock type and distribution change?

Understanding the importance and interaction of users, owners and those who service non-residential buildings is also an important component of the study.

For the BEES study, non-residential buildings have been defined using categories in the New Zealand Building Code, but in general terms the study is mainly looking at commercial office and retail buildings. These vary from small corner store dairies to large multi-storey office buildings. For more information on the building types included in the study please refer to BRANZ report SR224 Building Energy End-use Study (BEES) Years 1 & 2 (2009) available on the BEES website ([www.branz.co.nz/BEES](http://www.branz.co.nz/BEES)).

The study has two main methods of data collection – a high level survey of buildings and businesses, and intensive detailed monitoring of individual premises. The high level survey initially involved collecting data about a large number of buildings. From this large sample, a smaller survey of businesses within buildings was carried out which included a phone survey, and collecting records of energy and water use and data on floor areas. The information will enable a picture to be built up of the total and average energy and water use in non-residential buildings, the intensity of this use and resources used by different categories of building use, answering research questions one to four.

The detailed monitoring of individual premises involves energy and indoor condition monitoring, occupant questionnaires and a number of audits, including: appliances, lighting, building, hot water, water, and equipment.

This is a study of the BEES modelling conducted by the Centre for Building Performance Research. The studies are distributed between three reports. This first report documents the outcomes of a study identifying which aspects of energy simulation models that must be carefully quantified to ensure accurate energy performance modelling.

The second report (Cory, Munn, Gates, & Donn, 2012) explores the means by which computer modelling might be used to determine optimum building energy performance. The third report (Creswell-Wells, Donn, & Cory, 2012) applies the results from the first and second reports to examine the likely energy and environmental effects of the proposed urban form in the Christchurch central city draft plan.

# SUMMARY

- Detailed geometry can improve a building energy model's reliability by 5% to 15%
- Default HVAC values seem sufficient for annual energy consumption reliability for modelling
- Modelling ventilation rates accurately is critical to creating an accurate model.

This report presents the outcomes from the modelling component of the BEES project identifying the level of detail needed for energy simulation modelling of non-residential buildings. The study aim was to identify which aspects of energy simulation models must be carefully quantified to ensure the accuracy of energy performance modelling. The first step investigated the level of detailed geometry required in building model templates as well as the range of heating, ventilation and air conditioning (HVAC) systems that are available to use when modelling a building. The second part expanded on this, through a sensitivity analysis comparing the results with various data collected from BEES buildings to identify the influence each input can have on the modelling. This second part was intended to identify which input parameters have a major influence on the final calculated energy performance, and thus which need particular care in the modelling process.

The significance of modelling detail on energy performance and of the parameters in the sensitivity analysis can be judged by comparing the changes to those suggested by ASHRAE (2002). This ASHRAE Guideline proposes that when calibrating any energy calculation model against real building performance data, an acceptable tolerance of accuracy is  $\pm 5\%$  for monthly data or  $\pm 10\%$  for hourly data.

Two building geometries (open plan and cellular strip) using five different levels of detail were modelled. The results showed that the more detail applied to the model, the closer the results match the actual building energy consumption. The overall conclusion for both buildings modelled was that the highest level of detail (Level 5) provided the most reliable results as they most closely matched the actual building's energy consumption. Level 5 detail required modelling of the exact geometry and zone layout of the building and careful modelling of the as-built HVAC equipment.

Although the Level 5 detail provided the most reliable results, Level 4 was almost as reliable, but required much less effort, and hence time, in the modelling process. This was due to the use of default HVAC equipment values requiring much less data than in the detailed HVAC modelling. The reduction in reliability of the Level 4 model was approximately 10% less in comparison to the Level 5 model (on a month by month basis). Overall, Level 3 detail of modelling is recommended when considering the time and ease of modelling in combination with the reliability of the calculated outcomes.

The ability to match the modelled building with the actual data from measured BEES buildings was different for the two forms. The large open plan built form model better matching the actual data than the cellular strip model. Given only two geometries were modelled, further investigation will be needed to confirm if some built form geometries are more reliable than others.

It was identified that detailed geometry can improve a model's reliability by 5% to 15%; based on a comparison of the initial template model and models with increasing levels of detail. In the second part of this research, a sensitivity analysis tested the influence that six scenarios have on energy performance. The six scenarios tested are based on modelling aspects relating to the building design and operation which are likely to influence overall building performance. For example the fresh air ventilation rates.

Scenario 1 tested occupancy schedules. It was found that having all occupants within the building between 8am and 5pm made little difference in comparison to a stepped occupancy rate which mimicked the lighting schedule. The greatest difference between the models tested was 2%.

Scenario 2 tested weighted schedules. These had up to a 6% influence on the annual energy consumption in comparison to using a building's average schedule. Ventilation rates in Scenarios 3 and 4

were based on the CO<sub>2</sub> measurements recorded within the building. The difference between using an average or maximum inside-recorded CO<sub>2</sub> measurement to calculate the ventilation rates provide 35-55% difference in annual energy consumption compared to the standard template. This is evident for all model types tested. Modelling ventilation rates accurately is clearly critical to creating an accurate model. A standard per-person ventilation rate applied to the whole building provided results closest to the building's actual energy consumption.

When testing the influence of the location, and therefore the difference in outside CO<sub>2</sub> levels, to calculate the ventilation rates up to 60% difference in annual energy consumption was identified. This is the difference of being in a city or a rural location. If CO<sub>2</sub> calculations are used to provide a ventilation rate, it is recommended to use the maximum recorded inside CO<sub>2</sub> level and the correct location as these aspects have a large impact on the model's energy consumption.

Scenario 5 tested the insulation levels within the construction of the models. The surprising conclusion was the level of insulation in the wall was unlikely to have a large effect on the overall energy performance simulation.

Scenario 6 identified that if the energy intensive server room had the loads applied evenly across the total building floor area, then the calculated annual energy consumption differed minimally, within 1%. This suggests that the way a server room or other energy intensive rooms are modelled has very little effect on the overall building energy performance. If the intensive zone loads are modelled as happening in one small room or as spread evenly across the whole floor area they make a minimal difference to the overall energy performance.

For four of the six scenarios tested, the template geometry with default HVAC values (Level 4) provided annual energy consumption results that were closest to the real building's energy consumption. The other two scenarios identified that the template model with detailed HVAC equipment values provided the closest results. This suggests that the conclusions from part one about the significance of the template geometry may not always be the case.

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# GLOSSARY

ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
BEES	Building Energy End-use Study
CBPR	Centre for Building Performance Research at Victoria University's School of Architecture: the research team responsible for developing the computer modelling tools for the BEES research.
COP	Coefficient of Performance
CS	Cellular Strip geometry - a built form geometry modelling template developed by the BEES modelling team
EnergyPlus	Computer simulation software to calculate building energy performance
HVAC	Heating, Ventilation, and Air-Conditioning, a generic term applicable to all buildings
Ideal Air Loads	An HVAC system model that provides results of the ideal heating and cooling energy requirements to keep a space within set temperatures
OP5	Large Open Plan geometry - a built form geometry modelling template developed by the BEES modelling team
OpenStudio	Software plugin for SketchUp to allow EnergyPlus files to be created
Plug Loads	The energy 'load' placed on the building by the operation of equipment, such as computers, printers – typically, equipment that 'plugs in'.
R-value	Measure of thermal resistance of a material ( $\text{m}^2 \text{ K/W}$ )
Schedules	Method of controlling the times modelled loads are in-use
SketchUp	Software used for modelling EnergyPlus files

# 1. INTRODUCTION

This report documents the outcomes into a study of the level of detail used in energy simulation modelling. The study focuses on identifying aspects of energy simulation models that must be carefully quantified to ensure accurate modelling of the energy performance. Two aspects of modelling are examined: the level of detailed geometry; and detailed models of heating, ventilation and air conditioning (HVAC) systems required for accuracy. The measure of accuracy is the real energy use of two commercial buildings: a case study whose information was gathered especially for this study, and a BEES monitored building.

A second stage of the study expanded on these models by doing a sensitivity analysis of various data collected to identify the influence they can have on the modelling. This second part was intended to identify which input parameters have a major influence on the final calculated performance, and thus which need particular care in the modelling. This study found that the most important aspect of the models that must be included was the assumed ventilation rates. The next most important aspect was the way in which the schedules were modelled.

As the building models in this study were reliant upon assumed insulation levels in roof, walls and floor, the significance of an erroneous assumption about the presence of minimum code insulation levels was tested. The difference between simulated performance given construction with an air cavity and construction with minimum code insulation was also assessed.

Other modelling aspects tested for their influence on the predicted energy performance were:

- Creating a 'typical model of all occupants as in the building between 8am and 5pm or compiling a much more accurate stepped occupancy rate which mimicked the measured lighting schedule;
- Modelling the high energy intensity of a server room as a separate energy intensive zone or as an averaging of the server energy use across the total building floor area.

The ultimate goal of this project was to test and refine the modelling procedures and templates for the analysis of the BEES data on energy performance of existing New Zealand buildings.

## 2. PART ONE: MODELLING DETAIL

Part one documents the methodology and results of using template models when modelling commercial buildings. It focuses on the calibration of HVAC systems within the template models. Specifically, part one tests five levels of HVAC modelling parameter detail; this is to identify how much detail is required to produce reliable energy simulation results. The study used a practice building that is not a part of the BEES monitored buildings to test and develop a methodology. This methodology was then applied to a monitored BEES building as a final confirmation of its validity.

This report expands on the calibration process reported in *BEES Simulation Template Documentation* (Cory, S., Gates, A., Donn, M., 2011). It focuses on the calibration process undertaken to develop the templates from a theoretical state, to a tested, refined and dependable state. Results of testing refined the templates and an analysis of the procedure formulated a best practice energy modelling guide for use during the concept stage of design.

### 2.1 Research Question

The primary aim of this study is to answer the question: *how much building information needs to be collected to construct an accurate computer-based energy model?*

### 2.2 Scope of this Study

The scope of this study focuses on testing different levels of detail when using template models to construct a building. The main focus is with the HVAC systems but it also includes a comparison between 'template' and 'detailed' geometry modelling methods.

The results from each test level are compared to actual energy consumption, both electricity and gas for real buildings.

### 2.3 Energy Modelling

Energy modelling for buildings, in both new and renovation-based projects, is fundamental for forecasting energy-related performance of a design, providing valid evaluation of that design's feasibility. This allows for scrutiny and modification of the design at a stage where alterations are least costly (Bellenger, 2011).

As part of the BEES project investigation of building energy simulation practice in New Zealand found that computer-based representations (models and simulations) of energy performance in buildings were either too slow to compile or too inaccurate compared to reality, to be reliable. It was also found that despite a common interest throughout the industry in standardised, calibrated modelling guidelines, a lack of such information existed (Cory, S., Gates, A., Donn, M., 2011).

#### 2.3.1 Purpose of the Templates

As a means of providing this modelling knowledge and improving energy performance estimation in terms of speed and accuracy, generic templates were created. The templates were formulated to embody common circumstances of existing buildings and current/best design practice within the New Zealand context. This technique enables templates to be adjusted (in terms of geometry and HVAC detail) to reflect the subject building while still retaining generic elements pivotal to accuracy but which take time to model.

#### 2.3.2 Summary of Modelling Types

The modelling methods that have been used in this study have been defined as either 'detailed' or 'template' models. The following is an explanation of these two modelling methods:

**Detailed:** Built with a new (blank) file, this method requires extensive data on the subject building (technical drawings, material properties, services schedules and so on) which can be difficult to acquire and time consuming to dissect. Modelling itself demands considerable detail and time to ensure accuracy; often it can lead to anomalies across the inputs causing errors and delays.

**Template:** Pre-built and ready to use, the templates were built to incorporate data collected from BEES. The models incorporate properties and input values that are consistent with current building practices. Using a template to model a subject building only requires the correct (i.e. most appropriate in terms of building type, materials, and layout) template to be selected and then stretched or modified to match the subject building's floor area and number of levels.

Built into these definitions is the understanding that templates provide a quick way to generate reliable energy performance simulations that are representative of real buildings. Whilst not as precise as detailed models, they are intended to provide predictions that are sufficiently representative of likely real performance that major design decisions can be justified by their outputs.

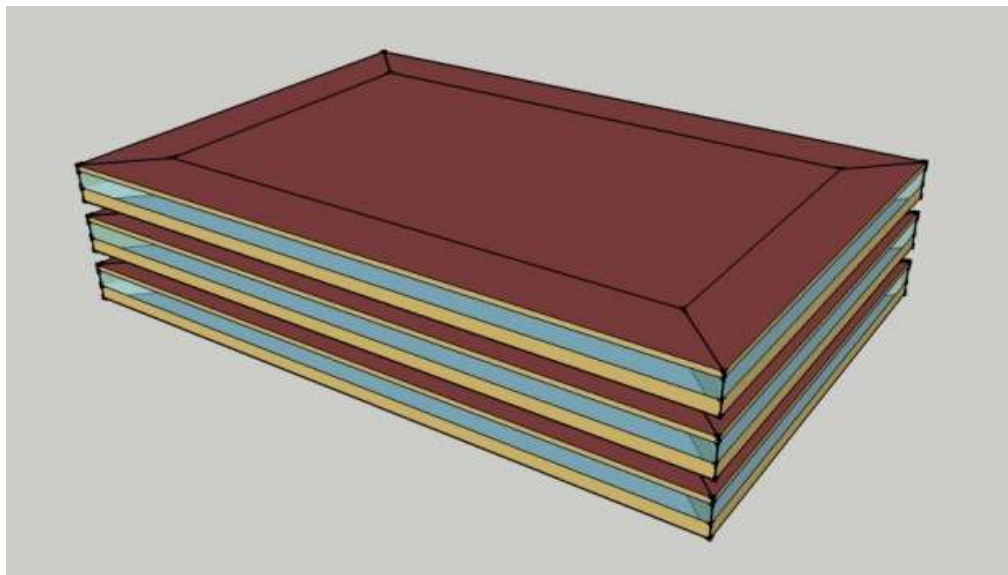
### 2.3.3 The 'Template' Model Used

The large open plan (OP5) template described in *Template files for commercial building stock energy simulations* (Cory, Hsu, & Donn, 2009) was used for the practice building while the cellular strip (CS) building was used to represent the BEES monitored building. These templates best represent the built form of the buildings being modelled.

#### 2.3.3.1 Large Open Plan (OP5)

The OP5 template represents standalone, multi-storey, daylit buildings. OP5 consists of five zones – four perimeter zones and one core zone – analogous to, and appropriate for, most office buildings.

Figure 1 shows a three storey version of the OP5 model. The lines on the roof delineate the four perimeter zones from the large core zone. Typically, these perimeter zones are a maximum of 7m deep. Thus, a building with a core zone which has no wall connection to the outside world will be typically larger than 14m x 14m in plan.



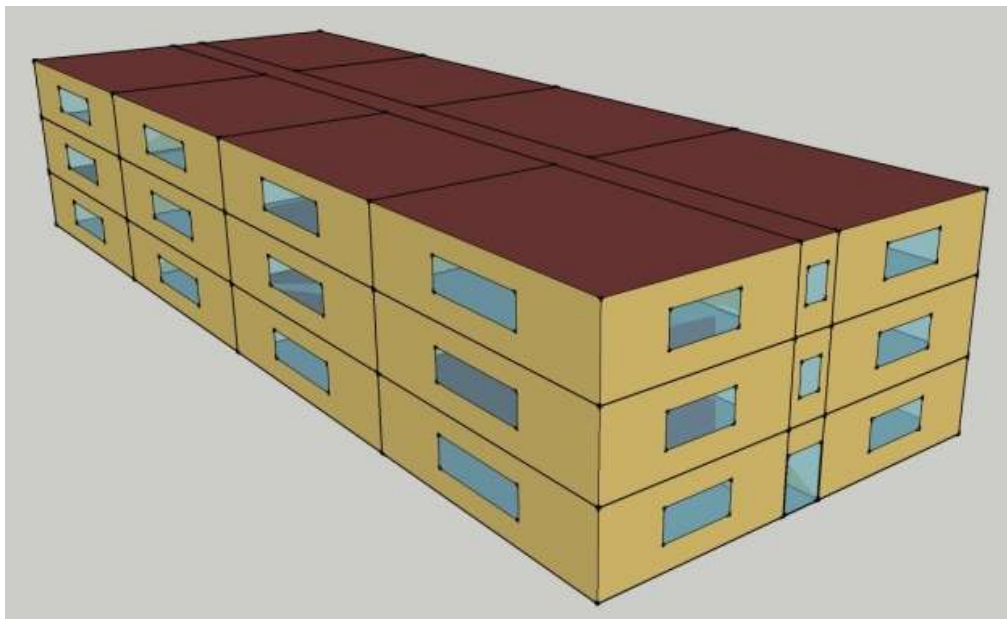
**Figure 1: Large Open Plan (OP5) Model**  
(Cory, Hsu, & Donn, 2009)

*NOTE: buildings of more than three storeys are not normally modelled past three storeys in energy simulation programs such as OpenStudio/EnergyPlus. The top and the bottom floor have roof or floor connections to the outside world. The intermediate floor has only connections through the walls to the outside as the floor and ceiling are connected to other conditioned spaces. Standard practice is to simply multiply this intermediate floor energy use by the number of intermediate floors in a multi-storey building to match the energy use of the actual building.*

#### 2.3.3.2 Cellular Strip (CS)

The CS template represents standalone, multi-storey, multi-zone, cellular buildings. It is appropriate for modelling office buildings which consist of many defined thermal zones and central hallways.

## 2.4 Methodology



**Figure 2: Cellular Strip (CS) Model**  
(Cory, Hsu, & Donn, 2009)

The research methodology comprised a four step process. Step 1 used a Wellington building to test the calibration of energy simulation data against measured energy data. Energy use data was collected independent of the BEES study. Step 2 repeated this calibration process for a BEES building. Step 3 varied the modelling detail for the building model to establish the level of detail needed for accurate modelling. The final step produced a checklist for the BEES team to identify the minimum data needed from each BEES detailed case study to ensure that the modelling team could produce accurate models.

To answer the research question, at each of the first three steps, five levels of detail were tested when modelling the buildings. Both the practice building and the BEES buildings were modelled at the same five levels of detail. In the analysis of the levels, the results from all five have been compared to the real building's energy consumption.

### 1: Identification of Key Components from the Practice Building

The practice building was intended to identify key components pivotal to the data gathering and modelling process. Undertaking this process in its entirety, as well as determining what was needed, also exposed areas of difficulty and aspects that complicated the process without any benefit.

## 2: Modelling the BEES Building

The modelling method developed from the practice building was applied to a BEES building to confirm the reliability of the modelling detail used. The process was expected to be more efficient with this building due to it already being developed and tested on the practice building.

### 3: Determining the Level of Modelling Detail needed for Reliability

After modelling the BEES building, a comparison against the practice building could be made to confirm which level of detail was 'best' in terms of reliability and ability to represent the performance of the real building. The comparison could also identify differences between the level of modelling stages to identify the ease of modelling in terms of user perception and time.

### 4: Refinement of Data Gathering/Modelling Procedure and Output 'Checklist'

Using the modelling methods, a schedule or 'checklist' tool for efficient collection of relevant/specific building information was produced for use by the BEES personnel who would carry out the site visits. This tool will be used to gather data quickly, easily and effectively. A by-product of this is the guide published for public use with the templates themselves.

#### 2.4.1 Practice Building

To determine what the possible outcomes of this study could be prior to applying it to a BEES monitored building, a practice building was used to develop the methodology. The practice building allowed for the development of a useful data gathering and modelling process. The practice building also determined two key factors: firstly, what level of detail was necessary to model in order to generate results that are representative of the real building energy performance; and secondly, what data was required to be collected from a building to attain and produce the identified level of modelling detail.

The five levels used for modelling are presented in Table 1. Level 1 used the basic template adjusted to match the scale and orientation of each real building, with the energy use of the building calculated as an 'Ideal Load'. 'Ideal loads' describe the energy that must be delivered to the zones in the building for heating, cooling and lighting, but have no information on the energy that is consumed by the HVAC equipment that must deliver this energy to the zones.

Level 2 has the same template-based geometry as Level 1 modelling, but has an HVAC system delivering the heating and cooling to the zones. The HVAC system is installed with just the default values from EnergyPlus for the equipment definition.

Level 3 is identical to Level 2, but the HVAC system is more precisely defined with detailed input values. Levels 4 and 5 are identical to Level 2 and 3, but with detailed geometry and thermal zone definitions based upon careful analysis of the building plans.

**Table 1: Levels of Modelling Detail**

Level	Geometry Type	HVAC Type
1	Template	Ideal Loads
2	Template	Default Values
3	Template	Detailed Values
4	Detailed	Default Values
5	Detailed	Detailed Values

## 2.5 Calibration of the Templates

This section defines and explains the template calibration process. It illustrates exactly how the templates were tested against analogous models of the same situation and then against real building data. It follows

the process used to refine and authenticate the templates identifying issues, successes and results of the study.

### 2.5.1 Practice Building

The aim of using a practice building was to determine the process of modelling different levels of detail and identify which level was most effective (accuracy of model versus effort required on the model) for the modelling process.

The selected practice building was a Wellington-based office building. The practice building has the following features:

- Period built: 1970s
- Strata: S4 (3,500 m<sup>2</sup> to 8,999 m<sup>2</sup>)
- Height: 12 storeys
- Setting: Commercial (mainly office use)
- Primary Material: Concrete
- Window Material: Aluminium/Metal – single glazed
- Template built form classification: large open plan (OP5)

The data collection and modelling methodology comprised three stages under two categories:

- Data Collection:
  - 1) Site visit
  - 2) HVAC equipment research
- Modelling:
  - 3) Computer modelling of building

#### 2.5.1.1 Site Visit

A site visit to the practice building, accompanied by the building manager, produced the following information:

- Photos of plant equipment (chillers, boilers and hot water cylinders);
- Photos of the manufacturer's plaques/installation details of each of the major plant items; and
- Notes on the make and model of each of the major plant items.

There were difficulties in identifying the 'make' and 'model' of some of the plant equipment. For example, the manufacturer's plaque could not be found for the boilers. As a result, performance data for that specific boiler could not be obtained until a request for that information was answered by the building manager. This type of problem can be expected for any model of a real building.

#### 2.5.1.2 HVAC Equipment Background Research

- Operation manuals/BMS settings:
  - Temperature set points;
  - Fresh air intake rates;
  - Equipment makes/models;
  - Operational schedules.
- Review of manufacturer data:
  - Plant performance values.
- Plans:
  - For detailed geometry modelling.

At this stage, specific information about the practice building was needed in order for the completion of the model of the installed HVAC plant equipment. A simple internet search was sufficient to obtain performance values for the chiller and boiler in order to create an accurate HVAC model in EnergyPlus.



To complete the modelling, additional data was required from technical drawings of the building. Plans, sections and HVAC-related drawings were obtained from the Wellington City Council Archives. Resorting to the Archives for information is not ideal in terms of time (appointments require a 24-hour waiting period and are subject to availability); and incur a fee. Were this building data available from the building manager the modelling would prove much more efficient.

#### 2.5.1.3 Modelling of the Building

The third step in the process was to construct the building models described in Table 1. The five models were constructed using EnergyPlus and OpenStudio (the EnergyPlus interface plug-in for Google SketchUp). The purpose of constructing five different versions of the same building was to test various levels of detail systematically. The test sought to determine the best balance between the reliability of results and the amount of effort required to construct the model. The five models comprised two different levels of detail of building geometry and three levels of detail of HVAC plant definition.

OpenStudio images of the two different geometries can be found in Appendix A. The EnergyPlus input lists of the HVAC systems assigned to the models are displayed in Appendix B.

It was anticipated that with each level of detail increase the calculated energy consumption would 'improve' by becoming closer to actual building performance. The goal was to establish what level of 'improvement' was associated with each increase in detail.

The following is a summary of each of the five levels of detail. The summary explains the intent and creation of each model.

### 2.5.2 Level 1: Template Geometry plus Ideal Air Loads HVAC

Level 1 uses the template geometry and an ideal air loads system to represent the building and its heating and cooling loads.

At this initial level (Level 1, as well as Levels 2 and 3 following) the built form of the model was constructed in OpenStudio using the large open plan (OP5) building template model. By applying the process outlined in the *Process To Modelling in EnergyPlus* (BRANZ, 2012b), the template was scaled to the same total floor area as the subject building. Ideal air loads are already assigned to each zone within the model, meaning no additional modelling was required for this aspect.

This modelling method is the simplest and quickest method used when modelling a building.

### 2.5.3 Level 2: Template Geometry plus Default HVAC

Level 2 used the template geometry explained in Level 1, but modelled a complex HVAC system that is installed in the building instead of the ideal air loads to calculate the heating and cooling loads. The HVAC system for this building consisted of fan coil units assigned to each modelled zoned, supplied by a chiller and a boiler. The system uses the fan coil unit HVAC system template (with default EnergyPlus modelling parameters) developed in another study (Gates, 2012). Refer to Appendix B2 for EnergyPlus inputs set for the Default HVAC system.

With pre-constructed templates that contain the HVAC systems, the level of difficulty modelling this stage of detail is no different than Level 1.

### 2.5.4 Level 3: Template Geometry plus Detailed HVAC

The third level also makes use of the geometry used in Levels 1 and 2. The difference with this model is the input values associated with the HVAC system. Instead of using the default values provided within EnergyPlus, collected performance values are used. The values that are replaced include the efficiency and capacity values of the various HVAC components.

This level of detail makes use of the collected data from the building during the site visit. For a list of the detailed HVAC inputs used, refer to Appendix B2.

### **2.5.5 Level 4: Detailed Geometry plus Default HVAC**

OpenStudio was used to model the detailed geometry for Level 4. To ensure that the correct input parameters were maintained, the OP5 template built form was used with the geometry removed. When modelling the geometry, the building plans obtained from the building manager for the practice building and from BEES site visits for the second building were used to determine size, form and appropriate thermal zoning.

The HVAC system within this model is the same as that described for Level 2.

### **2.5.6 Level 5: Detailed Geometry plus Detailed HVAC**

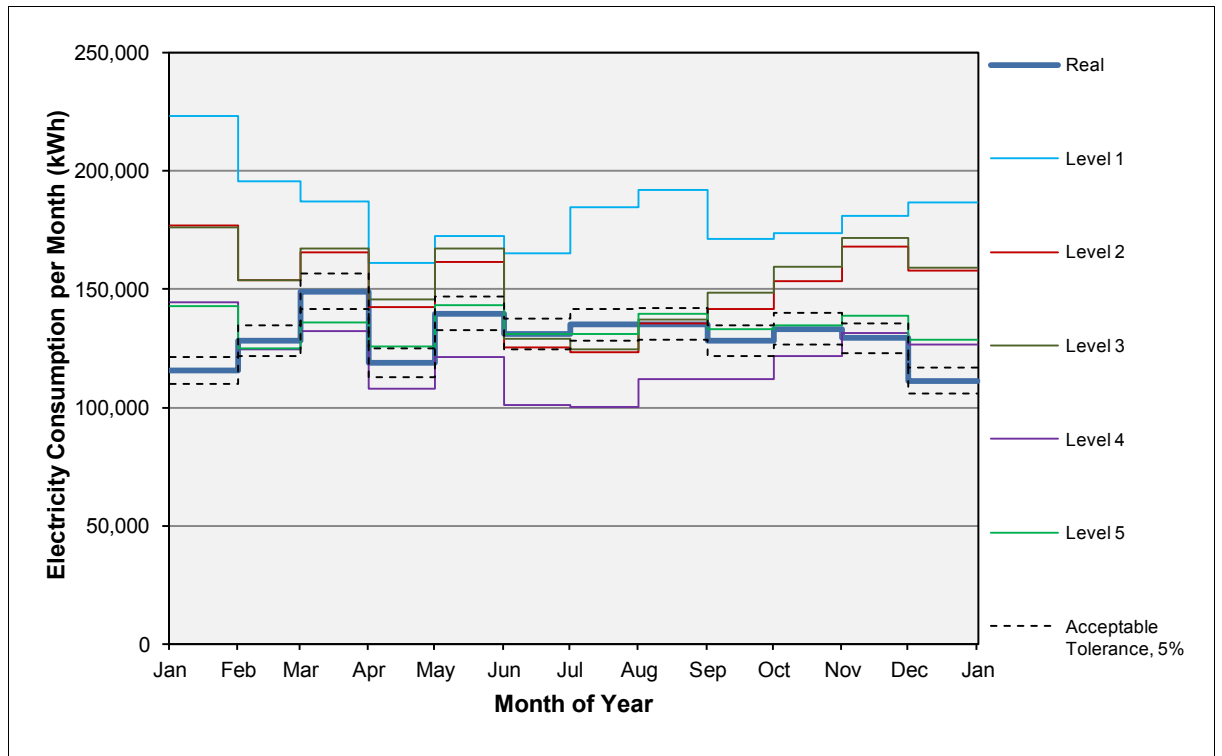
Taking the detailed geometry developed in Level 4, the HVAC system used in Level 3 was assigned to the practice building and to the BEES building model. Due to the additional zones and the different zone naming used, assigning the HVAC system required careful attention to avoid modelling errors. Aspects such as zone names were updated. For the majority, a copy-and-paste method between the two files could be used.

Because of the level of detail within this modelled stage, additional aspects not covered in the other levels could be employed. For example, a variable temperature thermostat based on the inside air temperature could be assigned to the zones requiring it. Modelling these additional inputs not used at the previous levels required the greatest amount of time due to the model complexity. From a user's perspective, it was thought that the effort required might not be proportional to the output benefits. This study sought to identify the actual benefit from this level of detail in the building and HVAC modelling detail.

## **2.6 Practice Building Results**

The calculated results from all five levels of modelling of the practice building are illustrated in Figure 3: . Each level is put into perspective by comparing it to the actual building's energy. As a percentage difference from the actual energy consumption for electricity, the information is summarised in Table 2.

### 2.6.1 Graphs and Tables



**Figure 3: Monthly Electricity Comparison for each Modelling Stage – Practice Building**

Table 2 displays the total annual percentage difference in electricity consumption from real building data. Figure 3 shows the same data graphically. The dotted line in the figure shows the ASHRAE (ASHRAE , 2002) recommended  $\pm 5\%$  margin of acceptability for matching monthly energy data; hourly the match margin of acceptability is  $\pm 10\%$ ; an annual acceptable margin of error tolerance is not provided.

**Table 2: Percentage Difference from Real Building Data – Electricity Consumption**

Month	Level 1	Level 2	Level 3	Level 4	Level 5
January	93%	53%	52%	25%	24%
February	53%	20%	20%	-3%	-3%
March	25%	11%	12%	-11%	-9%
April	36%	20%	23%	-9%	6%
May	24%	16%	20%	-13%	3%
June	26%	-4%	-2%	-23%	0%
July	37%	-9%	-8%	-26%	-3%
August	42%	0%	1%	-17%	3%
September	34%	10%	16%	-13%	4%
October	30%	15%	20%	-8%	1%
November	40%	30%	33%	2%	7%
December	68%	42%	43%	14%	16%
<b>Annual Difference</b>	<b>42%</b>	<b>17%</b>	<b>19%</b>	<b>-7%</b>	<b>-4%</b>

### 2.6.2 Discussion of Results

Each level of increased detail resulted in an increase in accuracy towards the actual building electricity consumption. Two different approaches to levels of detail in the model were tested: 1) scaling a generic geometry template to approximate the form and energy zones within the building (Levels 1, 2 and 3); 2)

providing increasingly detailed descriptions of the actual energy consuming equipment for HVAC. Pivotal to the objectives of these templates is the effort exerted on the modelling. The templates needed to provide accurate, reliable simulations but needed to do so with minimal time and difficulty. This factor was also examined. The following is a summary of the results from each modelled Level of detail; these are placed alongside the workload costs for producing this level of detail.

Level	Benefits	Workload
1	The calculated electricity consumption from the model was 42% greater than reality. This is most likely due to ideal load settings producing heating and cooling energy at an efficiency ratio of 1:1 (i.e. 1 kW of electricity would produce 1 kW of heating or cooling energy), indicating low efficiency.	The initial production of the template geometry may incur some issues in terms of abiding to EnergyPlus rules and getting the model to simulate successfully. This will depend on the user's experience and knowledge of the program. EnergyPlus devices are easily modified from 'default' (which is what the templates were initially set to) to 'ideal' loads and simulation time is short. Overall, Level 1 is simple to construct but the geometry needs to be absolutely correct and running smoothly in order to be used easily in Levels 2 and 3 also.
2	A far more accurate consumption, down to 17% difference on an annual basis, was predicted. This can be attributed to the application of the more specific HVAC system matching the type of system in the real building. The HVAC system was modelled only with the default EnergyPlus values as input.	This was the quickest and simplest level to use. Simply coupling the template geometry used in Level 1, with the HVAC inputs from the original file and simulate. Level 2 was as easy to construct as Level 1 but much more accurate
3	A very similar result to Level 2, with a 19% difference on average across the year. This is most likely due to major HVAC detail factors only being applied to two zones.	The difficulty level was much higher for this model. It had the same geometry as level 1 and 2 but the HVAC detailing in EnergyPlus can be prolonged and tedious, especially if the HVAC system is complex or if the building consists of many zones.
4	Another significant increase in accuracy was found; down to a 7% annual difference. This suggests employing greater geometry detail is discernibly beneficial to the model's reliability.	The detailed geometry model can range in difficulty depending on complexity of the building, and is more likely to present simulation errors than earlier template geometries. However, experienced OpenStudio technicians should not find this to be the case. EnergyPlus data can be applied as easily as the copy-and-paste from the Level 2 default model (and zone references updated). Level 4 would be as, if not more, simple than Level 3 to construct.
5	Again a more accurate result was realised. Averaging 4% greater consumption over the year than the real building data, Level 5 detail provided a level of accuracy within the 5% acceptable tolerance pre-defined for reliable modelling.	This stage was significantly harder than all other stages, despite utilising Level 4 geometry. As realised in the practice run, the more detailed HVAC zones there are (detailed geometry will have more zones than the template geometry), the longer it will take to link EnergyPlus input fields correctly. The practice building included a particularly complex HVAC system which proved very difficult to model across a large number of zones.

## 2.7 Personal Assessment of Modelling Levels

Table 3 illustrates the modellers' personal perspective when modelling a building using each level of detail. The star ratings are the inverse of each other: low reliability is one star, and low difficulty is five stars. The purpose is then to allow the two star ratings to be added together: high reliability (five star) plus low difficulty (5 star) would provide a ten star (excellent) rating; thus low reliability and high difficulty would be a 2 star (poor) rating.

**Table 3: Comparison of Reliability vs Difficulty for each Level of Detail**

Detail Step	Reliability	Difficulty	Total
Level 1	★	★★★★★	★★★★★
Level 2	★★	★★★★★	★★★★★
Level 3	★★	★★	★★★★
Level 4	★★★★	★★★	★★★★★
Level 5	★★★★★	★	★★★★★

Where:

**Reliability:**

★	Unreliable
★★	Not very reliable
★★★	Moderate
★★★★	Good
★★★★★	Very high

**Difficulty:**

★	Very difficult
★★	Difficult
★★★	Some issues
★★★★	Simple
★★★★★	Very easy

This rating system indicates Levels 2 and 4 are the more beneficial in terms of reliability and difficulty. However, reliability of the model must be weighted higher than difficulty, as quality of results is paramount. **In this case, Level 4 would be considered the most effective and efficient detail level to model.**

Level 4 provides a quick and reliable model and demonstrates the potential for further detail to be added to HVAC inputs in EnergyPlus. For example, it did not require excessive additional work/research to obtain significant factors/figures such as a chiller 'Coefficient of Performance (COP)' and 'condenser type'; or a boiler 'fuel type', 'capacity' and 'efficiency' value. These added details would effectively increase the reliability of a Level 4 model closer to that of a Level 5 model.

## 2.8 Identification of Integral Steps and Information

In order to increase the efficiency of the data gathering and building modelling process, key elements were identified from this study of the 'Practice Building'. The accuracy of the model is improved if the following data is collected:

- 1) Obtain as-built plans, sections, HVAC schematics and HVAC plant/equipment specifications from the facility/property manager. This makes the detailed geometry modelling process considerably more accurate and easy. Relying on archives or an internet search is time consuming and, typically, current or as-built drawings and information cannot be found.
- 2) If the building/facility manager does not have or cannot offer these datasets:
  - Take photos of HVAC plant manufacturers' plaques, identifying make and model (for chiller, boiler). Undertake an internet search of these plant items. Additionally, take photos of other HVAC components such as ducting, vents, air handling units, chilled beams etc for simplified identification of HVAC system type.
  - For technical drawings, an internet search may find plans etc but is not likely nor is it likely to be a reliable source. Local archives will provide access to documents but is an expensive and time-consuming avenue. **Gathering data from the building/facility manager is by far the most efficient means of acquiring required (and reliable) information.**
- 3) Analyse gathered information prior to modelling. For an efficient, accurate modelling process the following points should be identified:
  - **Building type** (in order to select the most appropriate template – e.g. OP5 template). Select from the template types illustrated, described, and available to be downloaded from the BEES website (BRANZ, 2012a).
  - **Construction type** for the building (so materiality can be applied through SketchUp to the entire model using 'default constructions' tool), in terms of:
    - Ground floor;
    - Intermediate floors;
    - Roof;
    - Intermediate ceilings;
    - External walls;
    - Internal walls;
    - External windows;
    - Internal windows;
    - External doors; and
    - Internal doors.
  - **HVAC system type**, so correct HVAC template can be applied (e.g. chilled beams, etc).
  - For most beneficial results, **HVAC plant specifications and performance values** as follows:

HVAC Plant Type	Unit	Related Information Required
<b>Boiler</b>		
Nominal Thermal Efficiency	W	Natural gas, coal, diesel etc
Nominal Capacity		
Fuel Type	°C	
Hot Water Design Set Point		
<b>Chiller</b>		
Coefficient Of Performance (COP)	W/W	COP = 3.516/ (kW/Ton)
Capacity	W	Air/water/evaporative cooling
Condenser Type	°C	
Cold Water Design Set Point		

- **Schedules** used in the building. Schedules will vary depending on building type and function. Following is a list of schedules required:
  - Lighting;
  - Occupancy; and
  - Electric Equipment.

- 4) Measure/calculate floor areas.
- 5) Create geometry in OpenStudio for Level 1 model (template geometry with ideal loads HVAC) completely, before looking at EnergyPlus inputs. This will provide a reliable baseline model which can be 'saved as' for Levels 2 and 3 also. Once the geometry is identical and set for each level (1-3), then specific EnergyPlus inputs can be assigned.
- 6) This also applies to geometry modelling in Level 4 (detailed geometry with default loads HVAC). Build the model in OpenStudio (using as built plans and data) and 'save as' for Level 5. Then move into EnergyPlus inputs for each individual model afterwards.

## 2.9 BEES Building: Applying the Modelling Method

Having developed and tested a modelling methodology on a practice building, a BEES building was used to test the same process and levels of detail applied in the practice building modelling process. The BEES building had the following construction features:

- Period Built: 1970s;
- Strata: S4 (8027 m<sup>2</sup>);
- Height: nine storeys;
- Setting: Commercial (Office);
- Primary Material: Concrete;
- Window Material: Aluminium/Metal with Single Clear Glazing; and
- Built Form Template Classification: Cellular Strip (CS).
- HVAC system type: Variable Air Volume with electric heating coils.

As with the practice building, the BEES building also followed the methodology of using three stages, separated into two categories:

- Data Collection:
  - 1) Site visit/information from the BEES team; and
  - 2) HVAC equipment research.
- Modelling:
  - 3) Computer modelling of building.

The difference with the second attempt was that all collected building data such as floor plans, HVAC system data and schedules were obtained from the facility manager and the BEES team. This meant that a site visit was not essential to collect information. This enabled far more efficient gathering of resources and meant information was current for the operating building.

Modelling of each level of detail for the BEES building followed the same process and steps as explained for the practice building. The results of the five levels of detail show a similar trend to that seen with the practice building.

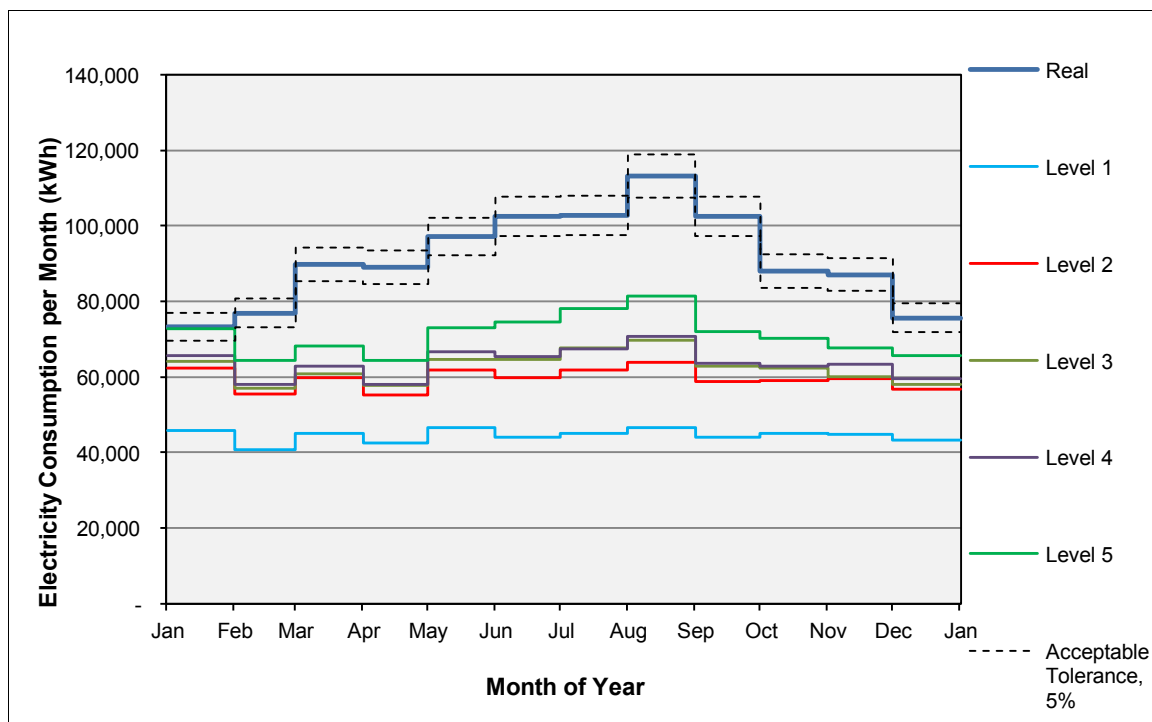
## 2.10 BEES Building Results

Figure 4 illustrates the results of each of the modelled levels relating to the actual building's energy consumption. The overall trend shows that as more detail is added to the model, the results become closer to the performance of the actual building. These results are highlighted in Table 4 which presents the percentage difference from the actual building to the modelled levels. Unlike the practice building results, the primary issue with this building is that all of the models underestimate the building's energy consumption.

Because the seasonal trend that can be seen within the results is similar to the actual building, it is assumed that the underestimated energy consumption is due to plug or lighting loads being too low when assigned to the models. This is highly likely in the Level 5 model.

The model and level of detail that least matched the real building's performance was Level 1. Without any seasonal trends identified in this model, it suggests that heating and cooling loads being calculated in the model are constant throughout the year.

The greatest difference between the BEES building and the practice building is the geometry built form that was selected. Although this was selected because it best matches the actual building, the results illustrate that the different building types influence how well the models can replicate the actual building's energy consumption. To confirm this and test the other built form templates not used, further investigation will be required.



**Figure 4: Monthly Electricity Comparison for Each Modelling Level BEES Building**

**Table 4: Percentage Difference from Real Building Data – Electricity Consumption**

Month	Level 1	Level 2	Level 3	Level 4	Level 5
January	-38%	-15%	-13%	-10%	-1%
February	-47%	-28%	-26%	-25%	-16%
March	-50%	-33%	-32%	-30%	-24%
April	-52%	-38%	-35%	-35%	-28%
May	-52%	-36%	-33%	-31%	-25%
June	-57%	-42%	-37%	-36%	-27%
July	-56%	-40%	-34%	-34%	-24%
August	-59%	-43%	-38%	-37%	-28%
September	-57%	-43%	-39%	-38%	-30%
October	-49%	-33%	-29%	-28%	-20%
November	-49%	-32%	-31%	-27%	-22%
December	-43%	-25%	-23%	-21%	-13%
<b>Annual Difference</b>	<b>-51%</b>	<b>-34%</b>	<b>-31%</b>	<b>-29%</b>	<b>-22%</b>



### 2.10.1 Discussion of Results

Similar to the practice building, modelling the BEES building has seen an improvement in accuracy from Level 1 through to Level 5 in both monthly and annual energy consumption.

The main concern with the BEES building results is that they are not as reliable as the practice building results are. Only one month was within the acceptable tolerance for a calibrated model (the majority of months were within this range for the practice building).

Level 1 is, as expected, considerably less accurate than the rest of the test stages. This suggests that for this building, an ideal air loads HVAC system cannot match the true performance of the building. The increase in energy consumption that more closely matches the actual building in the Level 2 model confirms this assumption.

Level 5 results show that for each month, the calculated energy consumption is the closest to the real building energy consumption. Although only one month, January, is within the acceptable tolerance for a calibrated model, the matching seasonal trend for the other months suggest that the loads of other electrical equipment (lighting or plug loads) assigned to the model are too low. This could be a result of an energy-intensive end-use, such as a server room, has not been accounted for in the data collection.

### **3. PART TWO: SENSITIVITY ANALYSIS**

When applying the data collected by the BEES monitoring team to an energy calculation model in order to calibrate it, the type of data that is used in the model has a significant impact on the model's performance. This is particularly apparent in buildings with more than one premise and/or multi-storey premises within a building. This study examined the likely influence of input parameters on the accuracy of the overall energy performance.

An example of how the processed data can differ is illustrated with the wall construction. Because detailed information is not collected, the actual construction layers of the walls for a building are unknown. Therefore, assumptions are made as to whether the wall construction includes insulation based on the age and construction of the building. Another issue arises from the generation of building average operational schedules and fresh air ventilation rates from the data that has been collected.

A sensitivity analysis of the collected data was conducted. Six scenarios were tested. Each scenario was compared to the other scenarios to identify how much of an influence each case has on the model's performance. The building's actual energy consumption was used to put the calculated results into perspective.

#### **3.1 Case Study Building**

The case study building that was selected for the sensitivity analysis was the BEES monitored building studied in the part one study. The building selected had two out of the nine storeys monitored; this included detailed data collected for both storeys.

Due to the setup of the monitoring and the data collected, the results of the sensitivity analysis are applicable to buildings with more than one set of monitoring. This includes both single storey multi-premise buildings, as well as multi-storey single-premise buildings.

##### **3.1.1 Modelling the Case Study Building**

To identify the influence that the different scenarios in the sensitivity analysis have on the case study building, three variations of the building were modelled. Each of the modelled variations has been developed in the part one study. Table 5 describes the three models used in the analysis.

The three model variations allowed for a comparison to be made that identified if one level of detail influenced the simulated performance more than another. The model variations were designed to test the effect of several scenarios on the model's energy consumption. This is essentially a measure of model reliability. If there is little difference in the performance then the scenario parameter has little effect, so for model reliability other parameters are more important. Conversely, if the scenario parameter has a large effect, then great care needs to be focused on obtaining the most accurate data possible.

**Table 5: Summary of the Models Used**

<b>Model Name</b>	<b>Description</b>
Template Geometry with Default HVAC	<p>Template geometry matches the floor area of the building using the CS (Cellular Strip) model.</p> <p>The HVAC equipment assigned to the model uses the EnergyPlus default values.</p>
Template Geometry with Detailed HVAC	Same as the template geometry with default HVAC however assigned HVAC uses efficiency and capacity values of the system installed in the building.
Podium and Tower with Detailed HVAC	<p>Detailed geometry that has a different floor areas for the podium and tower storeys.</p> <p>The assigned HVAC system contains parameters values for the real system.</p>

## 3.2 Scenarios

Six scenarios were tested in the sensitivity analysis to identify how much influence the individual changes have on the overall performance of a model. A combination of scenarios has not been tested.

Each scenario was selected because it was identified, from the BEES monitored data, to be an aspect that can be calculated differently and has a significant influence on how the models are constructed. An example of this is how the schedules of a single premise occupying multiple storeys of a building are applied to the modelled building.

### 3.2.1 Scenario 1: Occupancy Schedules

The two schedules tested in this scenario are:

- a) 100% of the occupants are present from 8am-5pm; 0% all other times
- b) Occupancy percentage matches lighting operational schedule measured on the two of the nine floors in the building

There are two types of schedules tested when modelling the occupancy. The first is a simple estimate that makes the assumption that all occupants are within the building between 8am and 5pm; no-one is in the building outside of these times. The second tested schedule is the same schedule used for the operation of the lighting. This schedule increases the occupancy step-by-step in mornings and decreases in the evenings.

### 3.2.2 Scenario 2: Operational Schedules

The two schedules tested in this scenario are:

- a) Average schedules for occupancy, lights and equipment
- b) Weighted schedules for occupancy, lights and equipment

Because data has been collected on two separate storeys of the building, the operational schedules for the occupancy, lighting and equipment can be applied in two ways. The first way is using a total of both storeys and averaging the results across the whole building floor area. The second method is to keep the data of the two storeys separate and averaging the data by the floor area of the individual storeys. The two individual schedule averages are then combined to provide a weighted building average. This method of producing a schedule is weighted due to the different floor areas of the monitored storeys.

The two average schedules are only applicable to the building models that are constructed with the standard geometry templates. This is because if the model is constructed using detailed geometry, the applied schedules are what had been monitored and average schedules are not required.

### 3.2.3 Scenario 3: Ventilation Rates using Measured CO<sub>2</sub> Levels

The fresh air ventilation rates, based on the measured indoor CO<sub>2</sub> levels in this scenario are:

- a) Maximum CO<sub>2</sub> level
- b) Average CO<sub>2</sub> levels
- c) NZS 4303:1990 recommended fresh air ventilation rate

Table 6 summarises the fresh air ventilation rates that are applied to the model; the table also contains the level of CO<sub>2</sub> that was used to calculate the ventilation rate. The maximum value is the calculated fresh air ventilation rate that would be needed to maintain the highest recorded CO<sub>2</sub> level within the building. The average values are the ventilation rates that would be needed to maintain the average recorded CO<sub>2</sub> level within the building.

For the model with template geometry, the building average ventilation rates were applied across the whole model. The detailed geometry had separate ventilation rates applied across the podium and tower zones. The ventilation rates stated are constant volumes being supplied to each building model zone via the HVAC system.

To put the ventilation rates into perspective, the recommended ventilation rate of 10 L/s/person was also compared in this scenario. The recommended ventilation rate is described in NZS 4303:1990, Ventilation for Acceptable Indoor Air Quality (Standards New Zealand, 1990). The 10 L/s/person ventilation rate is variable due to it being based on the number of occupants within each zone and as this number varies per zone a constant ventilation rate cannot be calculated and assigned to the whole building model; a per-person ventilation rate is used in the models.

Figure 5 displays the equation used to determine the outdoor fresh air rate as a function of the indoor CO<sub>2</sub> and outdoor CO<sub>2</sub> (Allard & Santamouris, 1998). The equation is rearranged from calculating the indoor CO<sub>2</sub> level to have the ventilation rate as the calculated variable.

The amount of outside air being delivered to the building can be calculated using the following equation for a general mass balance:

Formula:  $C_{in} = C_{out} + (R/V)$                       rearranged to:  $V = R / [C_{in} - C_{out}]$

Where:

- $C_{in}$  = indoor air CO<sub>2</sub> concentration, ppm
- $C_{out}$  = outdoor air CO<sub>2</sub> concentration, ppm
- $R$  = CO<sub>2</sub> release rate (0.005 L/s per person)
- $V$  = space ventilation rate (10 L/s per person recommended by NZS 4303)

**Figure 5: Outdoor Air as a Function of CO<sub>2</sub> (Allard & Santamouris, 1998)**

**Table 6: Fresh Air Ventilation Rates, Changing Inside CO<sub>2</sub> Levels**

	Maximum CO <sub>2</sub> measurement	Average CO <sub>2</sub> measurement	NZ Standard recommended*
<b>Template Geometry</b>	5.2 m <sup>3</sup> /s (787 ppm)	9.3 m <sup>3</sup> /s (661 ppm)	2.39 m <sup>3</sup> /s** (10 L/s/person)
<b>Podium</b>	12.5 m <sup>3</sup> /s (620 ppm)	34.09 m <sup>3</sup> /s (544 ppm)	1.78 m <sup>3</sup> /s** (10 L/s/person)
<b>Tower</b>	3.3 m <sup>3</sup> /s (954 ppm)	5.4 m <sup>3</sup> /s (778 ppm)	1.06 m <sup>3</sup> /s** (10 L/s/person)

\* NZS 4303:1990, *Ventilation for Acceptable Indoor Air Quality (Standards New Zealand, 1990)*.

\*\*Maximum ventilation, calculated from the maximum occupancy used in the models.

### 3.2.4 Scenario 4: Ventilation Rates using Outside CO<sub>2</sub> Levels

To calculate the ventilation expected within the building using CO<sub>2</sub> measurements, the same formula used in scenario 3 was used. The values that changed in this scenario are the outside levels of CO<sub>2</sub>. The three cases tested in this scenario are:

- a) City – 500 ppm
- b) Suburb – 450 ppm
- c) Rural – 400 ppm

By changing the outside CO<sub>2</sub> levels, new internal ventilation rates were calculated. With lower outside CO<sub>2</sub> levels, the ventilation rates also reduced.

The purpose of this scenario is to identify what influence the location of the building can have on the ventilation of the building. The three locations analysed are city, suburb and rural.

**Table 7: Fresh Air Ventilation Rates, Changing Outside CO<sub>2</sub> Levels**

	City (500 ppm)	Suburb (450 ppm)	Rural (400 ppm)
<b>Template Geometry</b>	9.3 m <sup>3</sup> /s	7.1 m <sup>3</sup> /s	5.7 m <sup>3</sup> /s
<b>Podium</b>	34.09 m <sup>3</sup> /s	15.96 m <sup>3</sup> /s	10.42 m <sup>3</sup> /s
<b>Tower</b>	5.4 m <sup>3</sup> /s	4.6 m <sup>3</sup> /s	4.0 m <sup>3</sup> /s

### 3.2.5 Scenario 5: Levels of Insulation

- a) No insulation, no cavity
- b) Cavity only
- c) Minimum insulation

When modelling the buildings using the collected information, all of the material layers within the construction of the walls, floor, roof and glazing are unknown. Based on the age of the building and the known façade construction material, the layers of the elements have to be estimated. Scenario 5 tests the influence that having insulation has in comparison to not having insulation, with and without a cavity. The

three cases tested within this scenario are the values that are most likely to be used when constructing future models.

To test the influence that having the minimum level of insulation has on the model's performance, the minimum R-values recommended in the New Zealand Standard NZS 4243.1.2007, Energy Efficiency in Large Buildings – Thermal Envelope were used (Standards New Zealand, 2007). The minimum insulation values are added as an additional insulation layer within the construction; the total element insulation value is therefore greater than the minimum values stated. Because glazing does not have a minimum requirement, the windows in the model remained as single glazed in aluminium frames for all tested models. Table 8 provides a summary of the construction element R-values that were used in the models to test the influence of including a minimum level of insulation.

**Table 8: Minimum Insulation Values ( $\text{m}^2 \text{ K/W}$ )**

	Roof	Wall	Floor	Glazing
<b>Minimum Insulation*</b>	R1.9	R1.2	R1.3	No requirement
<b>Total R with Insulation**</b>	R2.3	R1.5	R1.9	R0.15
<b>Total R without Insulation**</b>	R0.36	R0.27	R0.61	R0.15

\* All values are recommendations from New Zealand Standard NZS 4243.1.2007.

\*\* All values calculated with EnergyPlus.

### 3.2.6 Scenario 6: Server Room/Energy-Intensive Zones

To determine the influence of energy-intensive zones such as server rooms that are always operating, a scenario tested if the room should be modelled individually or have the load applied across the total floor area of the building. Four scenario cases were tested:

- High load servers across the floor area
- Low load servers across the floor area
- High load servers in an individually modelled room
- Low load servers in an individually modelled room

The server loads were calculated as high load and low load cases. The high loads represent three racks of eight servers (1920 Watts operational); the low loads represent one rack with only four servers (320 Watts operational). For the models with individual server rooms, the loads were scheduled to always be operational. Without separating the equipment loads when assigning them across the whole floor area, the loads in Case a) and Case b) used the standard operational schedules for office equipment.

The loads assigned to the podium and tower model were only assigned to the podium storeys as this is the location within the building that has the server room. The tower therefore remained unchanged.

When modelling the individual server room, a floor area of  $30 \text{ m}^2$  was used. This size is similar to the room size of the server room in the real building, as well as easily fitting within the template model geometry. Table 9 contains a summary of the server loads assigned in each modelling case.

**Table 9: Assigned Server Loads**

Load Distribution Method	High Load ( $\text{W/m}^2$ )	Low Load ( $\text{W/m}^2$ )
Template Model (Whole Building)	1.01	0.13
Podium Only	1.64	0.21
Server Room Only	64.0	10.6

### **3.3 Simulating the Scenario**

All six scenarios had annual simulations performed to calculate the total building energy consumption. To match the dates of the monitored data, the calculations were performed for the period between December 2010 and November 2011. These dates were selected as they are the most recent and therefore minimise the likelihood of changes to the building's operation and installed loads.

To ensure that the external environment is the same for the calculated model and what the building experienced, two custom weather files were created that contain the 2010 and 2011 weather data. The data used to create the weather files was sourced from the hourly recorded data collected by NIWA (National Institute of Water and Atmospheric Research).

## 4. RESULTS

### 4.1 Scenario 1: Occupancy Schedules

Results from Scenario 1 compare the annual energy consumption between the tested occupancy schedules. Both schedules have been applied to the three building models. Overall, the results have shown that the types of occupancy schedules applied to the models have a minimal influence on the annual energy consumption. The biggest difference is for the template geometry, default HVAC model; this model resulted in a 2% annual energy consumption difference. The other two models have a difference of less than 0.1%.

Using the lighting schedules for the occupancy schedules (i.e. assuming that when the lights are on in the monitored spaces the space is occupied) results in the template geometry models consuming greater energy annually; the opposite effect is seen with the podium and tower geometry model.

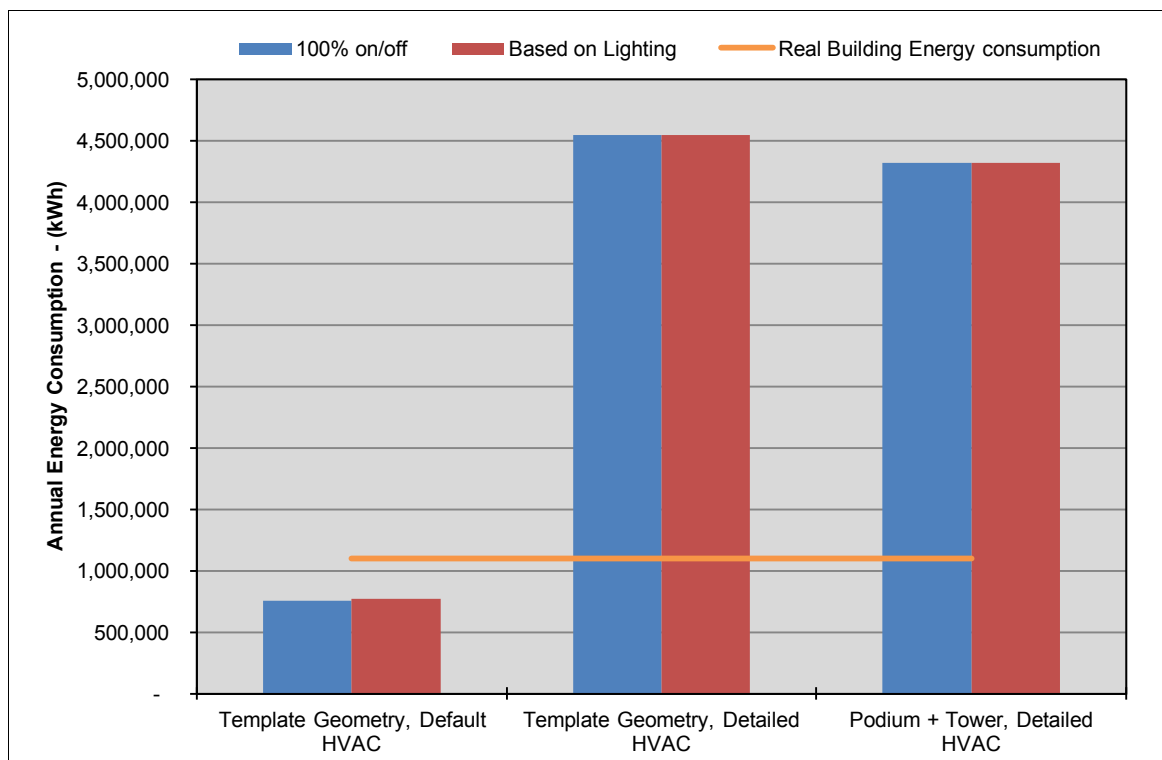


Figure 6: Scenario 1 Annual Energy Consumption Results

Further detail with a monthly total of each case in this scenario can be seen in Appendix F1. The monthly totals illustrate the seasonal trend that both the models and the real building experience. The differences between the occupancy based on the lighting schedule or 100% on/off scenarios are insignificant. Other aspects of the modelling, such as using default or detailed HVAC equipment values, are far more important.

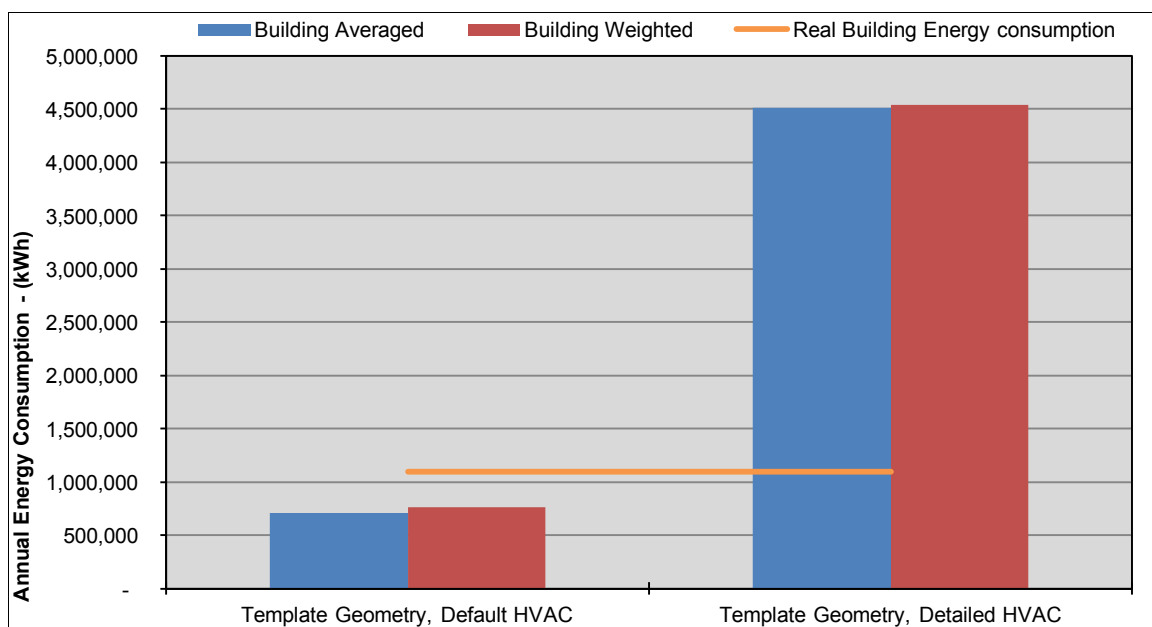
### 4.2 Scenario 2: Operational Schedules

The second set of schedules tested in the sensitivity analysis compared the influence of using averaged and weighted averages for the operational loads (Appendix E); these schedules are applied to all loads in the model. These schedules were compared using the template geometry models as a detailed model uses collected building operation schedules.



The outcome of comparing these schedules identified that the weighted averages result in the models consuming greater energy. For the model with only default values used for the HVAC equipment, a 6.1% (46,500 kWh) difference was calculated. When detailed HVAC equipment was used, the weighted schedules resulted in a 0.6% difference.

In terms of which model and schedule type provides results that are closest to the real building's energy consumption, it has been identified as the model with default value HVAC equipment and a weighted average schedule.



**Figure 7: Scenario 2 Annual Energy Consumption Results**

### 4.3 Scenario 3: Ventilation Rates Based on Indoor CO<sub>2</sub> Measurements

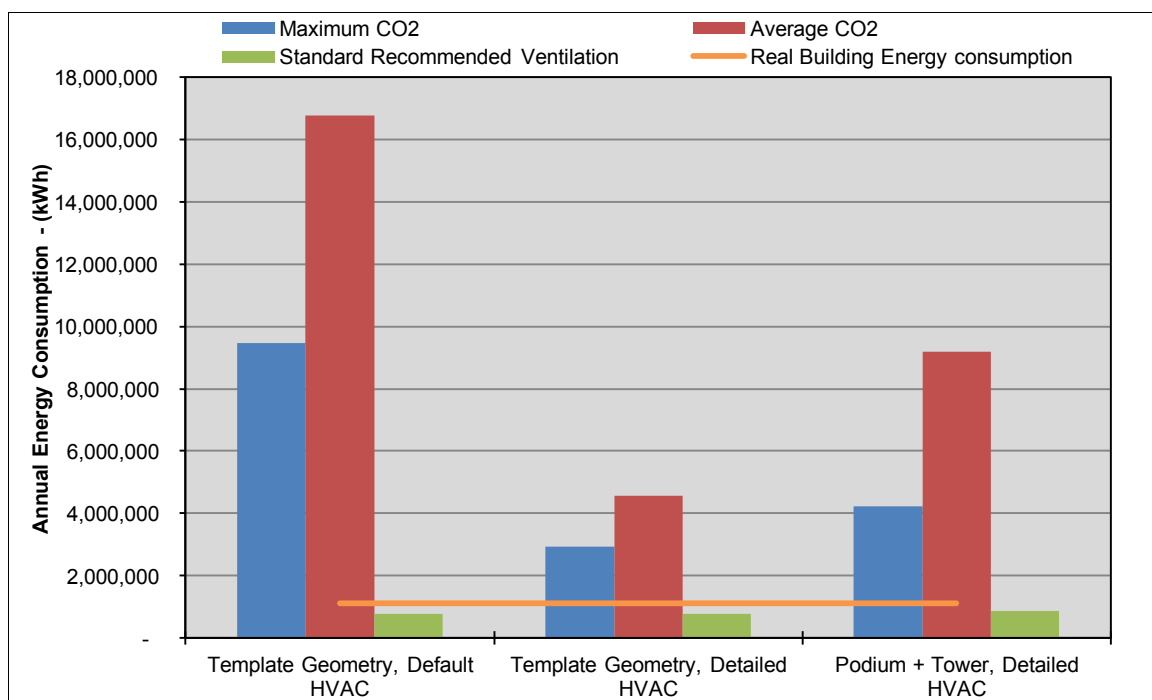
Scenario 3 tested the different fresh air rates that have been calculated based on the monitored inside CO<sub>2</sub> levels. The three ventilation rates calculated were based on an outside CO<sub>2</sub> level of 500 ppm.

The influence that different fresh air rates have on the models, illustrated in Figure 8, show a significant difference. For all three models, the average fresh air ventilation rate resulted in the greatest calculated annual energy consumption. When comparing the ventilation rate based on the average and maximum CO<sub>2</sub> levels recorded, there is between 35% and 55% difference in annual energy consumption. For all model types, using the maximum CO<sub>2</sub> value resulted in the calculated energy consumption to be closest to the real building consumption.

The least amount of energy consumed was calculated for the models that had the NZ Standard 4303:1990 recommended ventilation rate assigned. The results are also the closest to the actual building energy consumption. As this ventilation rate is calculated differently, based on a ventilation rate per person not a set ventilation rate per volume, the results are not directly comparable to the other results. It is likely that this is the reason why the energy consumption is significantly less.

Monthly results (Appendix F3) show how the recommended ventilation rates (based on NZS 4304:1990) for all of the models provide the closest values to the building's actual energy consumption. The seasonal trends identified in the monthly comparison also match between calculated and reality. It is far more important to note that the other scenarios are significantly different. It is clearly important to be sure that

the fresh air supply rates are calculated carefully in computer simulation. No conclusion can be made in this exercise whether the relatively close match between the scenario based upon “Standard Recommended Ventilation” rates is a result of accurate modelling of the real situation. Much more modelling and parametric evaluation would be needed.



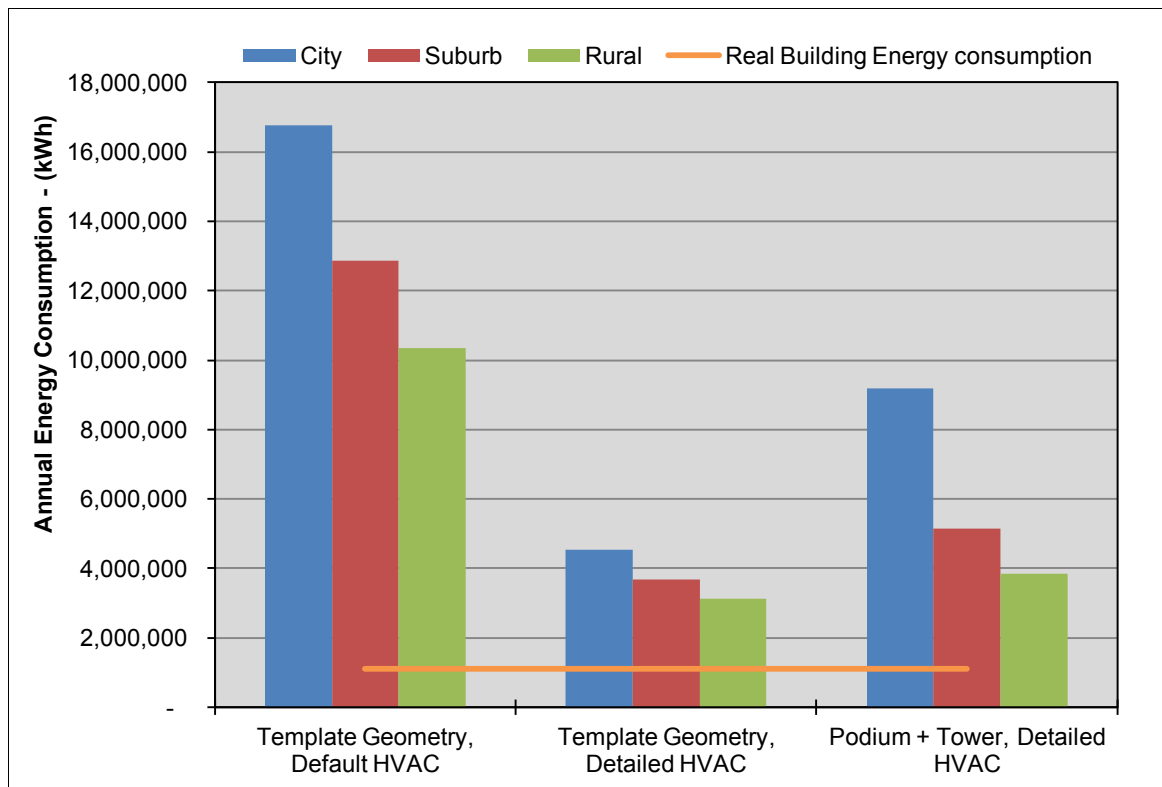
**Figure 8: Scenario 3 Annual Energy Consumption Results**

#### 4.4 Scenario 4: Location-based Ventilation Rates using CO<sub>2</sub>

A similar analysis as shown in Scenario 3, this scenario compares the influence of the location of the model in terms of expected ventilation rates based on the CO<sub>2</sub> levels outside.

The calculated results (Figure 9) identify that for all models, the greatest amount of energy is consumed when located in the city; in contrast, the least energy is consumed in a rural location. The difference in energy consumption between city and rural locations is up to 60%. Because of this large difference in annual energy consumption, it can be concluded that when calculating the ventilation rate using the inside and outside CO<sub>2</sub> levels, the correct outside location needs to be confirmed.

Out of the three models and the three scenarios tested, the template geometry with detailed HVAC equipment located in a rural location was identified to have the closest annual energy consumption to the real building. In the monthly comparisons, the seasonal trends matched for both the model and real building, however the calculated energy consumption is outside the acceptable calibration range. This is likely to be an influence of aspects other than just the ventilation rate modelled.



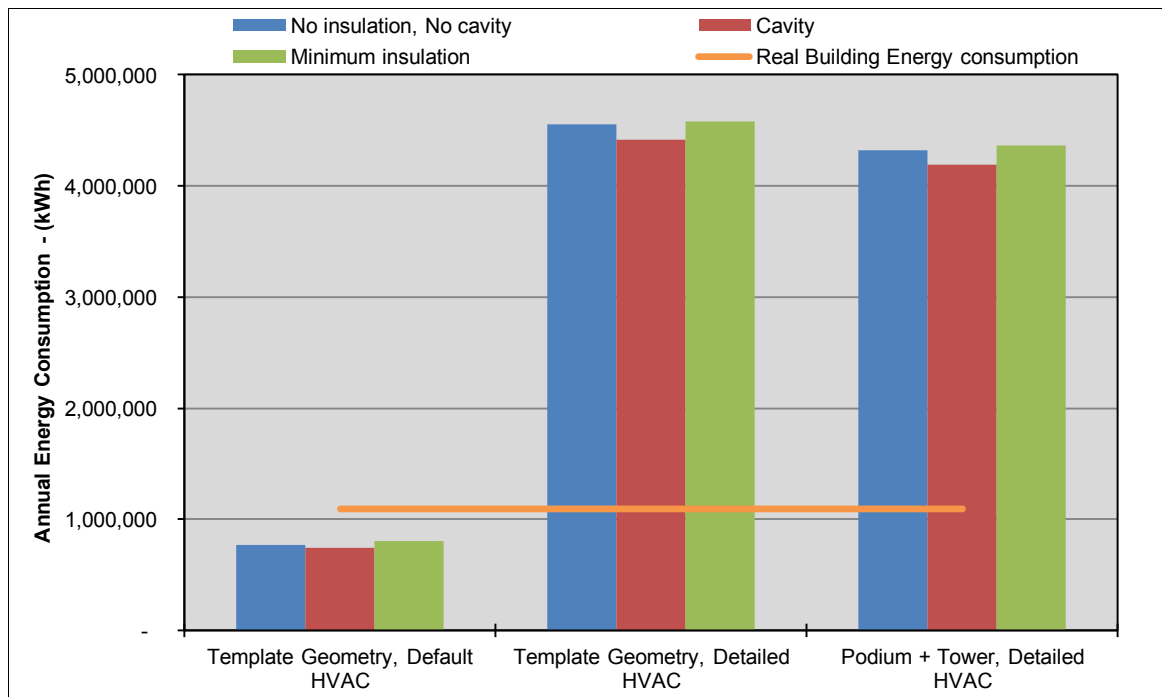
**Figure 9: Scenario 4 Annual Energy Consumption Results**

## 4.5 Scenario 5: Levels of Insulation

The performance differences between the three scenarios tested with the three types of models illustrate the impact that assumptions about the construction of building elements can have on overall energy performance. The scenarios cover the range of possible interpretations of the external appearance of a wall outlined in Section 3.2. The greatest difference calculated is 6.8% between a model with the minimum required level of insulation and the un-insulated cavity construction.

In all scenarios, the models with the minimum level of insulation and no insulation without a cavity consumed a similar amount of energy; within 1% difference when detailed HVAC equipment is assigned and 3.5% using default HVAC values. This suggests that the presence of a cavity and the presence of minimum levels of insulation may be relatively unimportant in a building thermal model for a commercial building. For models of existing buildings this is a sufficient conclusion. Further investigation would be needed to determine the influence of using levels of insulation greater than the minimum required.

Out of the three models, the template geometry with default HVAC values provided results that are closest to the real building's annual energy consumption. In the monthly energy comparison (Appendix F5), the three scenarios for this model type are predominantly within 15-20% of the real building. Less difference is found during the winter months; this suggests that the main differences are a result of the cooling energy during summer.



**Figure 10: Scenario 5 Annual Energy Consumption Results**

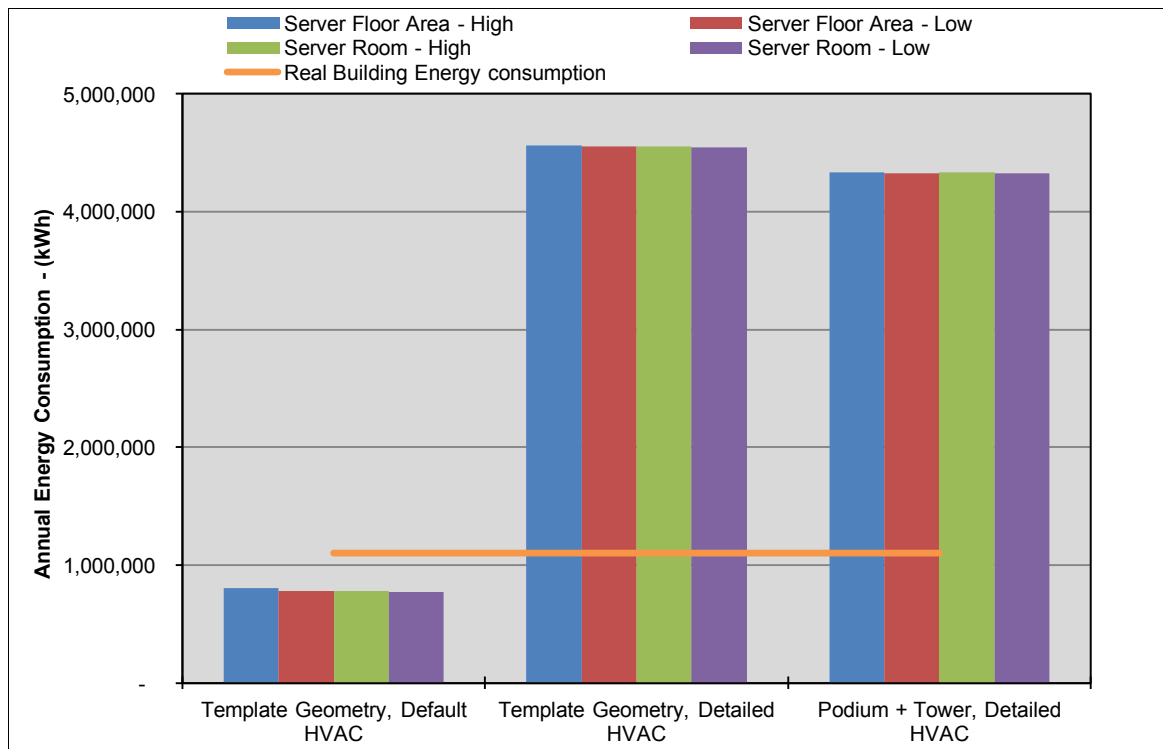
## 4.6 Scenario 6: Energy-Intensive Zones

Using the server room of the case study building, modelling methods were tested to identify the influence of the way in which energy-intensive zones within a building are modelled. The annual energy consumption results of the tested case scenarios can be seen in Figure 11.

The primary outcomes of the results have identified that there is little difference between modelling individual zones for energy-intensive rooms and applying the additional loads across the building floor area. Annual energy consumption difference between the models with high loads and the models with low loads assigned is less than 1%; except for the model with template geometry and default HVAC equipment, where the difference between the floor area assigned values resulted in a 3% annual difference.

Overall, the scenario that provided results closest to the real building annual energy consumption was the template geometry and default HVAC equipment with high server loads applied across the building's floor area. The monthly energy comparisons (Appendix F6) also confirm the similarities between the model and the building's actual energy consumption. However none of the calculated results are within the acceptable calibrated tolerance range.

The conclusion from this scenario is that for this building, an energy-intensive server room can be assigned across the total floor area of a building. An individual room does not need to be modelled due to the little influence it has on the annual energy consumption.



**Figure 11: Scenario 6 Annual Energy Consumption Results**

## **5. CONCLUSIONS: PART ONE AND PART TWO**

### **5.1 Part One: Level of Detail when Modelling HVAC Systems**

The results of modelling two buildings using five different levels of detail, showed that the more detail that is applied to the model, the closer the results match the actual building energy consumption. The overall conclusion for both buildings is that the Level 5 detail models provided the most reliable results as they most closely matched the actual building's energy consumption. Level 5 detail requires modelling of the exact geometry and zone layout of the building and a careful modelling of the as-built HVAC equipment.

Although Level 5 detail provided the most reliable results, Level 4 is almost as reliable, but requires far less effort in the modelling. This is because the use of default HVAC equipment values requires far less data than the detailed HVAC models. The reduction in reliability of the Level 4 model is approximately 10% less monthly in comparison to the Level 5 model.

To identify which level of modelling detail is recommended for future work, the personal assessment of modelling difficulty (including the time to model a building) is used in relation to the reliability of the results. This assessment highlights that the built form template geometry is recommended to be used; although not as reliable as using geometry that matches thermal zones in the building, the time difference in modelling is significantly less and easier to use. In addition to geometry templates, having complex HVAC systems are needed to provide the most reliable models. The HVAC templates which used the EnergyPlus default input parameters provided the quickest method for modelling complex HVAC systems within the models. Overall, Level 3 detail of modelling is recommended when considering the time and ease of modelling in combination with the reliability of the calculated outcomes. The level 3 detail of modelling includes the template geometry with detailed HVAC systems assigned within the templates.

Differences of the built form geometry between the practice building and the BEES building have highlighted that the OP5 built form can better match the building than the CS built form. This is concluded due to the better match of the OP5 results to the actual building's energy consumption. Although it has identified that matching the building geometry and selecting the correct built form template is important, further investigation will be needed to confirm if any built form geometry templates are more reliable than others.

It has been found that detailed geometry can improve a model's reliability by 5% to 15%; based on a comparison of template and detailed model results from Levels 2 and 4, and Levels 3 and 5 for both buildings.

### **5.2 Part Two: Outcomes of the Sensitivity Analysis**

The sensitivity analysis has identified the relative influence of six different model parameters thought likely to influence overall building performance.

Scenario 1 tested occupancy schedules. It was found that having all occupants within the building between 8am and 5pm made little difference in comparison to a stepped occupancy rate which mimicked the lighting schedule. The greatest difference between the models tested was 2%.

In Scenario 2, the weighted schedules have been found to have up to a 6% influence on the annual energy consumption in comparison to using a building average schedule. The building model that provided calculated results that are closest to the building's real energy consumption was the template geometry with default HVAC equipment assigned.

Ventilation rates in Scenarios 3 and 4 were based on the CO<sub>2</sub> measurements recorded within the building. The difference between using an average or maximum indoor-recorded CO<sub>2</sub> measurement to calculate the ventilation rates provide 35-55% difference in annual energy consumption. This is evident for all three model types tested. Modelling ventilation rates accurately is clearly critical to creating an accurate model. A standard per-person ventilation rate applied to the whole building provided results closest to the

building's actual energy consumption; this is purely coincidental as this value was not calculated using the BEES collected data; the ventilation rates were based on an outside airflow rate of 10 L/s per person.

When testing the influence of the location, and therefore the difference in outside CO<sub>2</sub> levels, to calculate the ventilation rates up to 60% difference in annual energy consumption was identified. This is the difference of being in a city or a rural location. If CO<sub>2</sub> calculations are used to provide a ventilation rate, it is recommended to use the maximum recorded inside CO<sub>2</sub> level and the correct location as these aspects have a large impact on the model's energy consumption.

Scenario 5 tested the insulation levels within the construction of the models. The biggest difference is between models with a cavity and with a minimum level of insulation or with no cavity; the minimum insulation and with no cavity provided similar results. Up to 7% less energy is consumed using a cavity within the construction layers. The surprising conclusion from this study is that the assumption from the external appearance of the wall as to what level of insulation might be in the wall is unlikely to have a large effect on the overall energy performance simulation.

Scenario 6 identified that if the energy-intensive server room had the loads applied evenly across the total building floor area, then the calculated annual energy consumption differed minimally, within 1%. This suggests that the way a server room or other energy intensive room is modelled has very little effect on the overall building energy performance. If the intensive zone loads are modelled as happening in one small room or as spread evenly across the whole floor area they make a minimal difference to the overall energy performance.

For four out of the six scenarios tested, the template geometry with default HVAC values provided annual energy consumption results that are closest to the real building's energy consumption. The other two scenarios identified that the template model with detailed HVAC equipment values provided the closest results. Although template geometry has been suggested as being a fast method of modelling while retaining reliability, the outcomes of the sensitivity analysis suggest that required input parameters can have a large impact on the overall energy performance. The unfortunate conclusion from this is that the parameters entered into a thermal simulation model must therefore be carefully determined as there is no clear evidence that the templates will consistently provide the same results as a detailed model. It seems likely that a hybrid modelling process will be sufficiently accurate: careful modelling of the HVAC system and manipulation of the template geometry to match the real geometry. . .

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# APPENDIX A – TEMPLATE AND DETAILED GEOMETRY FOR OPENSTUDIO

## A1 – Plan Image of Template Geometry - Practice Building

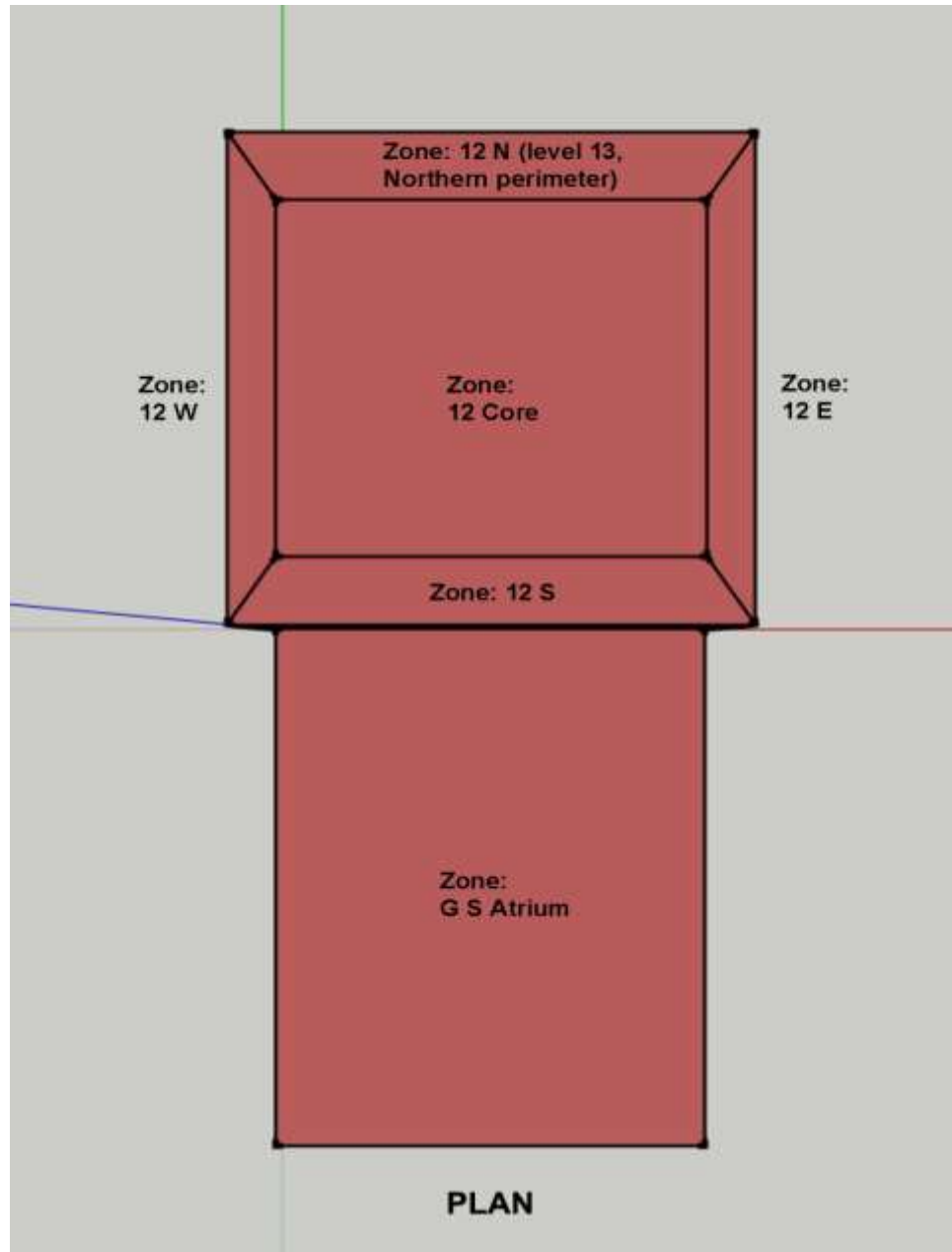


Figure 12: Template Geometry used for Levels 1, 2, and 3 of Practice Building

## A2 – Perspective Image of Template Geometry – Practice Building

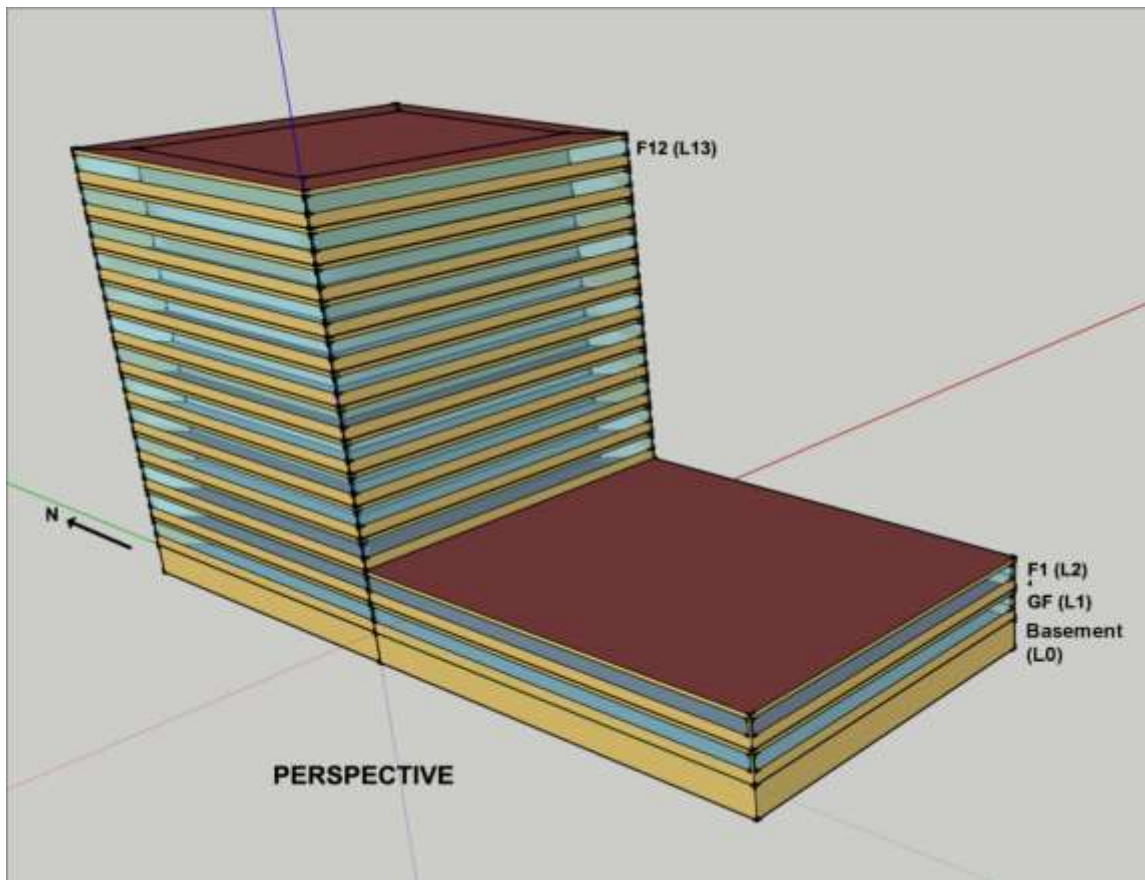


Figure 13: Template Geometry used of Levels 1, 2, and 3 of Practice Building

### A3 – Plan Image of Detailed Geometry

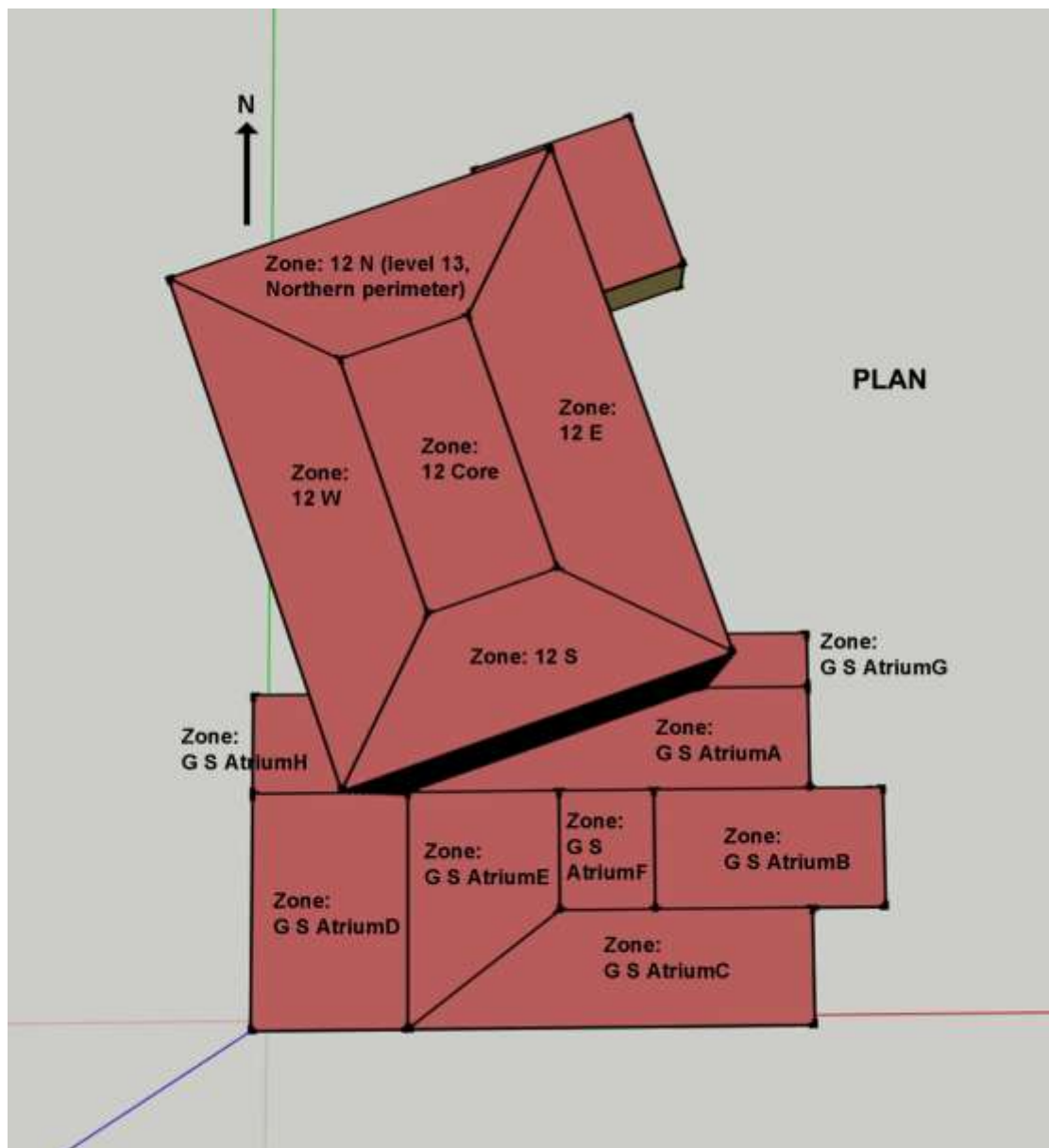


Figure 14: Detailed Geometry used for Levels 4 and 5 of Practice Building

#### A4 – Perspective Image of Detailed Geometry

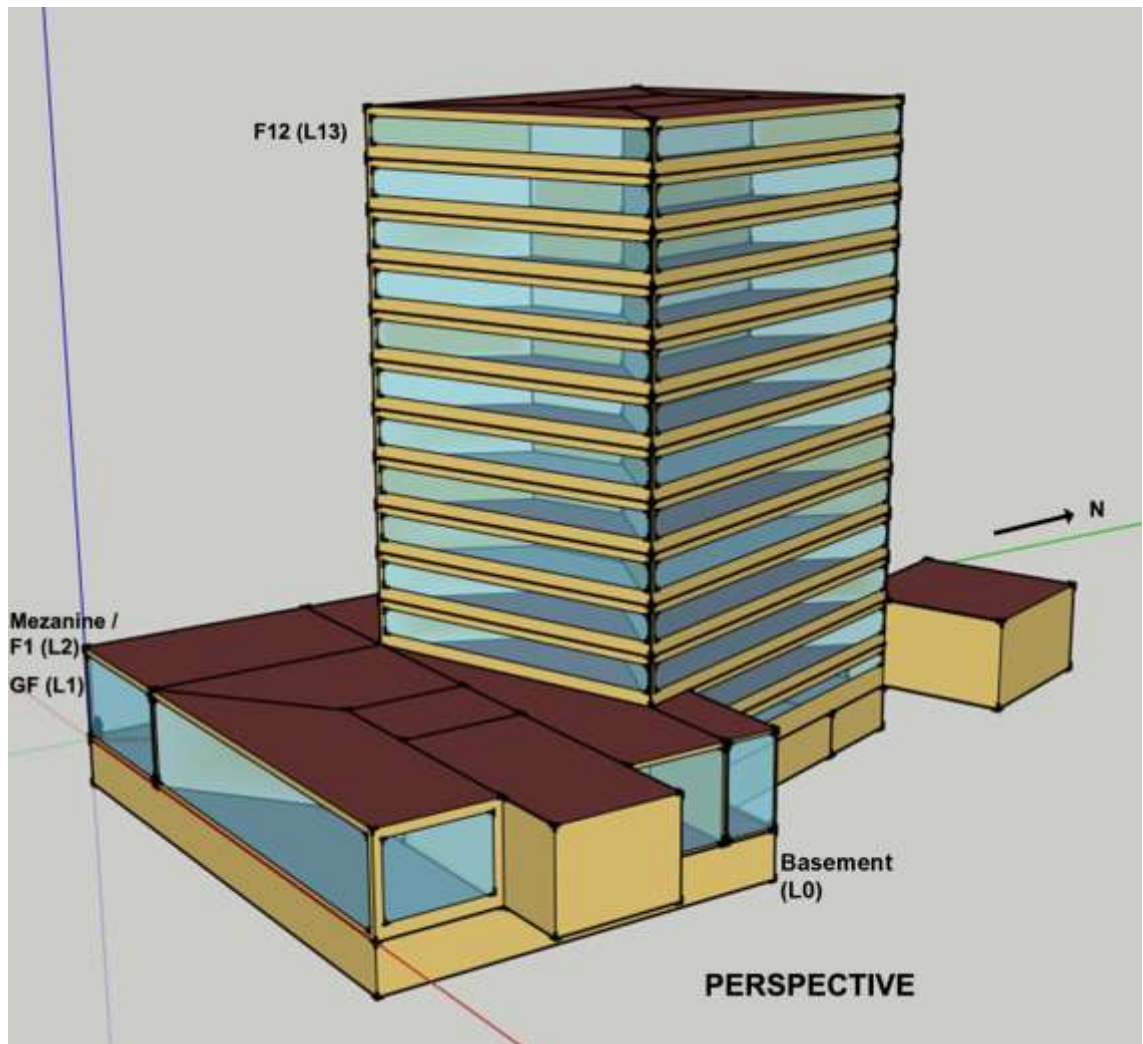


Figure 15: Detailed Geometry used for Levels 4 and 5 of Practice Building

# APPENDIX B - IDEAL LOADS, DEFAULT AND DETAILED HVAC INPUT LISTS FOR ENERGYPLUS

## B1 – EnergyPlus Inputs Required for Ideal HVAC Loads

[0001] ConvergenceLimits	
[0001] Site:Location	
[0002] SizingPeriod:DesignDay	
[0001] RunPeriod	
[0010] RunPeriodControl:SpecialDays	
[0001] RunPeriodControl:DaylightSavingTime	
[0001] Site:GroundTemperature:BuildingSurface	
[0001] Site:WaterMainsTemperature	
[0007] ScheduleTypeLimits	
[0008] Schedule:Compact	
[0015] Material	
[0018] Material:NoMass	
[0007] WindowMaterial:Glazing	
[0041] Construction	
[0001] GlobalGeometryRules	
[0070] Zone	
[0427] BuildingSurface:Detailed	
[0056] FenestrationSurface:Detailed	
[0070] People	
[0070] Lights	
[0070] ElectricEquipment	
[0070] ZoneInfiltration:DesignFlowRate	
[0001] HVACTemplate:Thermostat	
[0070] HVACTemplate:Zone:IdealLoadsAirSystem	

Explanation of Keyword

Zone thermostat control. Referenced schedules must be defined elsewhere in the idf. Thermostat control type is dual setpoint with deadband. It is not necessary to create a thermostat object for every zone, only for each unique set of setpoint schedules. For example, an office building may have two thermostat objects, one for "Office" and one for "Storage".

Field	Units	Obj1
Name		Thermostat
Heating Setpoint Schedule Name		
Constant Heating Setpoint	C	18
Cooling Setpoint Schedule Name		
Constant Cooling Setpoint	C	25

Figure 16: HVAC Template: Thermostat

[0001] ConvergenceLimits	
[0001] Site:Location	
[0002] SizingPeriod:DesignDay	
[0001] RunPeriod	
[0010] RunPeriodControl:SpecialDays	
[0001] RunPeriodControl:DaylightSavingTime	
[0001] Site:GroundTemperature:BuildingSurface	
[0001] Site:WaterMainsTemperature	
[0007] ScheduleTypeLimits	
[0008] Schedule:Compact	
[0015] Material	
[0018] Material:NoMass	
[0007] WindowMaterial:Glazing	
[0041] Construction	
[0001] GlobalGeometryRules	
[0070] Zone	
[0427] BuildingSurface:Detailed	
[0056] FenestrationSurface:Detailed	
[0070] People	
[0070] Lights	
[0070] ElectricEquipment	
[0070] ZoneInfiltration:DesignFlowRate	
[0001] HVACTemplate:Thermostat	
[0070] HVACTemplate:Zone:IdealLoadsAirSystem	
[0001] Output:VariableDictionary	
[0001] Output:Surfaces:List	
[0001] Output:Surfaces:Drawing	

Explanation of Keyword

Zone with ideal air system that meets heating or cooling loads  
Zone name must match a building zone name  
ID: A1  
Select from list of objects  
This field is required.

Field	Units	Obj1	Obj2	Obj3
Zone Name		B Core	Basement Carpark	B W
Template Thermostat Name		Thermostat	Thermostat	Thermostat

Figure 17: HVAC Template: Zone: Ideal Loads Air System

## B2 – EnergyPlus Inputs Required for HVAC Default

[0001] ConvergenceLimits [0001] Site:Location [0002] SizingPeriod:DesignDay [0001] RunPeriod [0010] RunPeriodControl:SpecialDays [0001] RunPeriodControl:DaylightSavingTime [0001] Site:GroundTemperature:BuildingSurface [0001] Site:WaterMainsTemperature [0007] ScheduleTypeLimits [0009] Schedule:Compact [0015] Material [0018] Material:NoMass [0007] WindowMaterial:Glazing [0041] Construction [0001] GlobalGeometryRules [0070] Zone [0427] BuildingSurface:Detailed [0056] FenestrationSurface:Detailed [0070] People	<p>Explanation of Keyword</p> <p>Zone thermostat control. Referenced schedules must be defined elsewhere in the idf. Thermostat control type is dual setpoint with deadband. It is not necessary to create a thermostat object for every zone, only for each unique set of setpoint schedules. For example, an office building may have two thermostat objects, one for "Office" and one for "Storage".</p>																		
	<table><tr><th>Field</th><th>Units</th><th>Obj1</th></tr><tr><td>Name</td><td></td><td>Thermostat</td></tr><tr><td>Heating Setpoint Schedule Name</td><td></td><td></td></tr><tr><td>Constant Heating Setpoint</td><td>C</td><td>18</td></tr><tr><td>Cooling Setpoint Schedule Name</td><td></td><td></td></tr><tr><td>Constant Cooling Setpoint</td><td>C</td><td>25</td></tr></table>	Field	Units	Obj1	Name		Thermostat	Heating Setpoint Schedule Name			Constant Heating Setpoint	C	18	Cooling Setpoint Schedule Name			Constant Cooling Setpoint	C	25
Field	Units	Obj1																	
Name		Thermostat																	
Heating Setpoint Schedule Name																			
Constant Heating Setpoint	C	18																	
Cooling Setpoint Schedule Name																			
Constant Cooling Setpoint	C	25																	

Figure 18: HVAC Template: Thermostat

[0001] ConvergenceLimits  
[0001] Site:Location  
[0002] SizingPeriod:DesignDay  
[0001] RunPeriod  
[0010] RunPeriodControl:SpecialDays  
[0001] RunPeriodControl:DaylightSavingTime  
[0001] Site:GroundTemperature:BuildingSurface  
[0001] Site:WaterMainsTemperature  
[0007] ScheduleTypeLimits  
[0009] Schedule:Compact  
[0015] Material  
[0018] Material:NoMass  
[0007] WindowMaterial:Glazing  
[0041] Construction  
[0001] GlobalGeometryRules  
[0070] Zone  
[0427] BuildingSurface:Detailed  
[0056] FenestrationSurface:Detailed  
[0070] People  
[0070] Lights  
[0070] ElectricEquipment  
[0070] ZoneInfiltration:DesignFlowRate  
[0001] HVACTemplate:Thermostat  
[0070] HVACTemplate:Zone:FanCoil  
[0001] HVACTemplate:Plant:ChilledWaterLoop  
[0001] HVACTemplate:Plant:Chiller  
[0001] HVACTemplate:Plant:HotWaterLoop  
[0001] HVACTemplate:Plant:Boiler  
[0001] Output:VariableDictionary  
[0001] Output:Surfaces:List  
[0001] Output:Surfaces:Drawing  
[0001] Output:Table:SummaryReports  
[0012] Output:Table:Monthly  
[0001] OutputControl:Table:Style  
[0009] Output:Variable  
[0003] Output:Meter  
[0001] Output:Diagnosis

Explanation of Keyword

4 pipe fan coil unit with optional outdoor air.  
Zone name must match a building zone name  
ID: A1  
Select from list of objects  
This field is required.

Field	Units	Obj1	Obj2	Obj3
Zone Name		G Core	G S Atrium	G E
Template Thermostat Name		Thermostat	Thermostat	Thermostat
Supply Air Maximum Flow Rate	m3/s	autosize	autosize	autosize
Zone Heating Sizing Factor				
Zone Cooling Sizing Factor				
Outdoor Air Method		Flow/Person	Flow/Person	Flow/Person
Outdoor Air Flow Rate per Person	m3/s	0.00944	0.00944	0.00944
Outdoor Air Flow Rate per Zone Floor Area	m3/s-m2			
Outdoor Air Flow Rate per Zone	m3/s			
System Availability Schedule Name		HVAC_Sch	HVAC_Sch	HVAC_Sch
Supply Fan Total Efficiency		0.7	0.7	0.7
Supply Fan Delta Pressure	Pa	75	75	75
Supply Fan Motor Efficiency		0.9	0.9	0.9
Supply Fan Motor in Air Stream Fraction		1	1	1
Cooling Coil Type		ChilledWater	ChilledWater	ChilledWater
Cooling Coil Availability Schedule Name				
Cooling Coil Design Setpoint	C	14	14	14
Heating Coil Type		HotWater	HotWater	HotWater
Heating Coil Availability Schedule Name				
Heating Coil Design Setpoint	C	50	50	50
Dedicated Outdoor Air System Name				

Figure 19: HVAC Template: Zone: Fan Coil

[0001] Site: Location	Explanation of Keyword
[0002] SizingPeriod: DesignDay	Plant and condenser loops to serve all HVAC template chilled water coils, chillers, and towers.
[0001] RunPeriod	
[0010] RunPeriodControl: SpecialDays	ID: A1 Enter a alphanumeric value
[0001] RunPeriodControl: DaylightSavingTime	
[0001] Site: GroundTemperature: BuildingSurface	Field
[0001] Site: WaterMains Temperature	
[0007] ScheduleTypeLimits	Units
[0009] Schedule: Compact	Obj1
[0015] Material	<a href="#">ChilledWaterLoop</a>
[0018] Material: NoMass	
[0007] WindowMaterial: Glazing	Pump Schedule Name
[0041] Construction	Pump Control Type
[0001] GlobalGeometryRules	Chiller Plant Operation Scheme Type
[0070] Zone	Chiller Plant Equipment Operation Schemes Name
[427] BuildingSurface: Detailed	Chilled Water Setpoint Schedule Name
[0056] FenestrationSurface: Detailed	Chilled Water Design Setpoint
[0070] People	C
[0070] Lights	7.22
[0070] ElectricEquipment	Chilled Water Pump Configuration
[0070] ZoneInfiltration: DesignFlowRate	Primary Chilled Water Pump Rated Head
[0001] HVAC template: Thermostat	Pa
[0070] HVAC template: Zone: FanCoil	Secondary Chilled Water Pump Rated Head
	Pa
	Condenser Plant Operation Scheme Type
	Default
<a href="#">HVAC template: Plant: ChilledWaterLoop</a>	Condenser Equipment Operation Schemes Name
[0001] HVAC template: Plant: Chiller	Condenser Water Temperature Control Type
[0001] HVAC template: Plant: HotWaterLoop	Condenser Water Setpoint Schedule Name
[0001] HVAC template: Plant: Boiler	Condenser Water Design Setpoint
[0001] Output: VariableDictionary	C
[0001] Output: Surfaces: List	29.4
[0001] Output: Surfaces: Drawing	Condenser Water Pump Rated Head
[0001] Output: Table: SummaryReports	Pa
[0012] Output: Table: Monthly	179352
[0001] Output: Control: Table: Style	Chilled Water Setpoint Reset Type
[0009] Output: Variable	None
[0003] Output: Meter	Chilled Water Setpoint at Outdoor Dry-Bulb Low
	C
	12.2
	Chilled Water Reset Outdoor Dry-Bulb Low
	C
	15.6
	Chilled Water Setpoint at Outdoor Dry-Bulb High
	C
	6.7
	Chilled Water Reset Outdoor Dry-Bulb High
	C
	26.7

[0018]	Material:NoMass	<p>Explanation of Keyword</p> <p>ID: A1</p> <p>Enter a alphanumeric value</p> <p>This field is required.</p> <table> <tr> <th>Field</th><th>Units</th><th>Obj1</th></tr> <tr> <td>Name</td><td></td><td>Chiller</td></tr> <tr> <td>Chiller Type</td><td></td><td>ElectricCentrifugalCI</td></tr> <tr> <td>Capacity</td><td>W</td><td>autosize</td></tr> <tr> <td>Nominal COP</td><td>W/W</td><td>3.2</td></tr> <tr> <td>Condenser Type</td><td></td><td>AirCooled</td></tr> <tr> <td>Priority</td><td></td><td></td></tr> <tr> <td>Sizing Factor</td><td></td><td>1</td></tr> </table>	Field	Units	Obj1	Name		Chiller	Chiller Type		ElectricCentrifugalCI	Capacity	W	autosize	Nominal COP	W/W	3.2	Condenser Type		AirCooled	Priority			Sizing Factor		1
Field	Units		Obj1																							
Name			Chiller																							
Chiller Type			ElectricCentrifugalCI																							
Capacity	W		autosize																							
Nominal COP	W/W		3.2																							
Condenser Type			AirCooled																							
Priority																										
Sizing Factor			1																							
[0007]	WindowMaterial:Glazing																									
[0041]	Construction																									
[0001]	GlobalGeometryRules																									
[0070]	Zone																									
[0427]	BuildingSurface:Detailed																									
[0056]	FenestrationSurface:Detailed																									
[0070]	People																									
[0070]	Lights																									
[0070]	ElectricEquipment																									
[0070]	ZoneInfiltration:DesignFlowRate																									
[0001]	HVAC template:Thermostat																									
[0070]	HVAC template:Zone:FanCoil																									
[0001]	HVAC template:Plant:ChilledWaterLoop																									
[0001]	HVAC template:Plant:Chiller																									
[0001]	HVAC template:Plant:HotWaterLoop																									
[0001]	HVAC template:Plant:Boiler																									
[0001]	Output:VariableDictionary																									

[UUU1] ConvergenceLimits		
[0001] Site:Location		
[0002] SizingPeriod:DesignDay		
[0001] RunPeriod		
[0010] RunPeriodControl:SpecialDays		
[0001] RunPeriodControl:DaylightSavingTime		
[0001] Site:GroundTemperature:BuildingSurface		
[0001] Site:WaterMainsTemperature		
[0007] ScheduleTypeLimits		
[0009] Schedule:Compact		
[0015] Material		
[0018] Material:NoMass		
[0007] WindowMaterial:Glazing		
[0041] Construction		
[0001] GlobalGeometryRules		
[0070] Zone		
[0427] BuildingSurface:Detailed		
[0056] FenestrationSurface:Detailed		
[0070] People		
[0070] Lights		
[0070] ElectricEquipment		
[0070] ZoneInfiltration:DesignFlowRate		
[0001] HVACTemplate:Thermostat		
[0070] HVACTemplate:Zone:FanCoil		
[0001] HVACTemplate:Plant:ChilledWaterLoop		
[0001] HVACTemplate:Plant:Chiller		
[0001] HVACTemplate:Plant:HotWaterLoop		
[0001] HVACTemplate:Plant:Boiler		

Explanation of Keyword

Plant loop to serve all HVACTemplate hot water coils and boilers.

ID: A1  
Enter a alphanumeric value

Field	Units	Obj1
Name		HotWaterLoop
Pump Schedule Name		
Pump Control Type		Intermittent
Hot Water Plant Operation Scheme Type		Default
Hot Water Plant Equipment Operation Schemes Name		
Hot Water Setpoint Schedule Name		
Hot Water Design Setpoint	C	82
Hot Water Pump Configuration		ConstantFlow
Hot Water Pump Rated Head	Pa	179352
Hot Water Setpoint Reset Type		None
Hot Water Setpoint at Outdoor Dry-Bulb Low	C	82.2
Hot Water Reset Outdoor Dry-Bulb Low	C	-6.7
Hot Water Setpoint at Outdoor Dry-Bulb High	C	65.6
Hot Water Reset Outdoor Dry-Bulb High	C	10

Figure 22: HVAC Template: Plant: Hot Water Loop

[UU15] Material		
[0018] Material:NoMass		
[0007] WindowMaterial:Glazing		
[0041] Construction		
[0001] GlobalGeometryRules		
[0070] Zone		
[0427] BuildingSurface:Detailed		
[0056] FenestrationSurface:Detailed		
[0070] People		
[0070] Lights		
[0070] ElectricEquipment		
[0070] ZoneInfiltration:DesignFlowRate		
[0001] HVACTemplate:Thermostat		
[0070] HVACTemplate:Zone:FanCoil		
[0001] HVACTemplate:Plant:ChilledWaterLoop		
[0001] HVACTemplate:Plant:Chiller		
[0001] HVACTemplate:Plant:HotWaterLoop		
[0001] HVACTemplate:Plant:Boiler		
[0001] Output:VariableDictionary		

Explanation of Keyword

ID: A1  
Enter a alphanumeric value  
This field is required.

Field	Units	Obj1
Name		Boiler
Boiler Type		HotWaterBoiler
Capacity	W	autosize
Efficiency		0.8
Fuel Type		NaturalGas
Priority		
Sizing Factor		1

Figure 23: HVAC Template: Plant: Boiler



## APPENDIX C – PRACTICE BUILDING RESULTS

### C1 – Electricity Consumption Comparison of Level 1-5 and Real Building

Table 10: Electricity Consumption (kWh/month)

Month	Real Building	Level 1	Level 2	Level 3	Level 4	Level 5
January	115,674	115,486	176,805	176,081	141,736	142,869
February	128,139	102,329	153,913	153,730	122,247	124,869
March	149,042	112,587	165,644	167,207	125,170	136,057
April	118,896	106,709	142,608	145,751	109,331	125,746
May	139,728	118,385	161,545	167,034	108,543	143,439
June	131,085	111,100	125,578	129,078	89,946	131,141
July	135,069	113,993	123,508	124,741	92,072	131,128
August	135,325	118,385	135,453	137,097	96,512	139,461
September	128,318	112,507	141,455	148,372	96,774	133,240
October	133,213	112,587	153,492	159,472	104,698	134,605
November	129,275	113,999	168,199	171,689	124,974	138,962
December	111,288	108,195	157,842	159,053	124,955	128,539

## C2 – Gas Consumption Comparison of Level 1-5 and Real Building

Table 11: Gas Consumption (kWh/month)

Month	Real Building	Level 1	Level 2	Level 3	Level 4	Level 5
January	0	0	0	0	569	10,164
February	42,505	0	0	387	703	9,358
March	129,089	0	391	1,737	2,114	13,416
April	96,694	0	3,270	6,796	6,643	16,998
May	158,911	0	3,655	8,205	7,041	20,443
June	158,911	0	14,808	21,601	23,112	31,657
July	189,610	0	27,692	29,376	39,468	43,723
August	214,309	0	28,986	32,400	40,279	42,986
September	161,294	0	10,954	15,567	17,603	24,568
October	132,769	0	5,101	8,390	9,360	18,787
November	132,769	0	755	2,242	3,137	14,109
December	93,472	0	101	540	1,034	9,384

## APPENDIX D – BEES BUILDING RESULTS

### D1 – Electricity Consumption Comparison of Level 1-5 and Real Building

Table 12: Electricity Consumption (kWh/month)

Month	Real Building	Level 1	Level 2	Level 3	Level 4	Level 5
January	73,317	45,757	62,250	64,115	65,694	72,785
February	76,955	40,643	55,460	57,067	58,094	64,298
March	89,720	44,969	59,809	60,850	62,797	68,081
April	89,098	42,477	55,239	57,758	57,958	64,518
May	97,196	46,544	61,943	64,764	66,581	72,991
June	102,507	44,052	59,785	64,684	65,363	74,538
July	102,815	44,969	61,766	67,576	67,514	78,133
August	113,146	46,544	63,951	69,748	70,744	81,394
September	102,482	44,052	58,757	62,893	63,684	72,008
October	87,997	44,969	59,021	62,452	62,940	70,188
November	87,117	44,840	59,489	60,180	63,301	67,578
December	75,660	43,395	56,863	58,017	59,444	65,556

# APPENDIX E - APPLIED OPERATIONAL SCHEDULES

Table 13: Operational Schedules Tested

	Averaged		Weighted	
	Weekday	Weekend	Weekday	Weekend
12:00:00 a.m.	0.02	0.18	0.03	0.28
1:00:00 a.m.	0.02	0.18	0.03	0.28
2:00:00 a.m.	0.02	0.18	0.03	0.28
3:00:00 a.m.	0.02	0.18	0.03	0.28
4:00:00 a.m.	0.02	0.18	0.03	0.28
5:00:00 a.m.	0.02	0.18	0.03	0.28
6:00:00 a.m.	0.08	0.18	0.12	0.27
7:00:00 a.m.	0.49	0.22	0.55	0.33
8:00:00 a.m.	0.76	0.39	0.78	0.45
9:00:00 a.m.	0.84	0.30	0.85	0.33
10:00:00 a.m.	0.84	0.23	0.85	0.27
11:00:00 a.m.	0.84	0.21	0.85	0.26
12:00:00 p.m.	0.83	0.19	0.85	0.26
1:00:00 p.m.	0.83	0.19	0.85	0.25
2:00:00 p.m.	0.83	0.24	0.86	0.30
3:00:00 p.m.	0.81	0.22	0.83	0.26
4:00:00 p.m.	0.79	0.15	0.80	0.17
5:00:00 p.m.	0.72	0.13	0.72	0.16
6:00:00 p.m.	0.65	0.13	0.67	0.17
7:00:00 p.m.	0.40	0.10	0.44	0.15
8:00:00 p.m.	0.24	0.09	0.26	0.13
9:00:00 p.m.	0.09	0.09	0.11	0.12
10:00:00 p.m.	0.07	0.08	0.10	0.11
11:00:00 p.m.	0.07	0.09	0.09	0.12
12:00:00 a.m.	0.02	0.18	0.03	0.28

# APPENDIX F - MONTHLY ENERGY COMPARISON

## F1 – Scenario 1

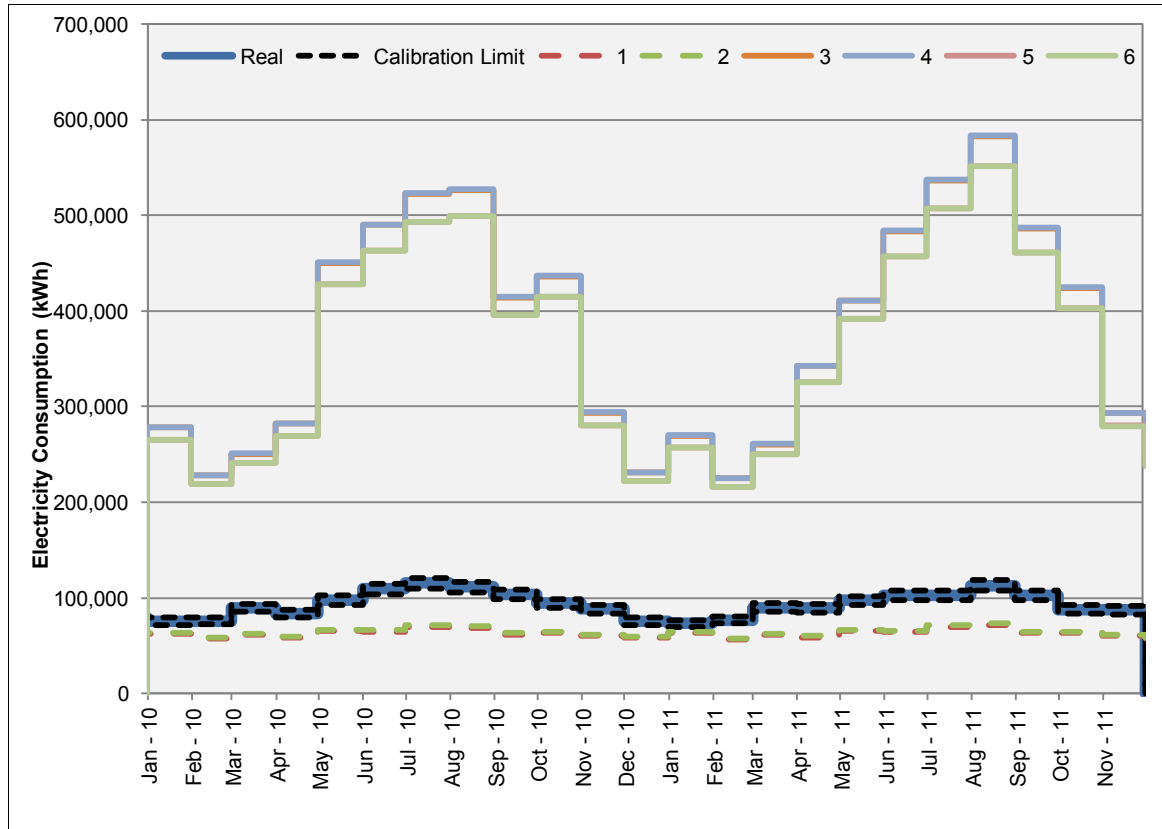


Figure 24: Scenario 1 Electricity Consumption Comparison

Table 14: Explanation of Numbers for Scenario 1

Explanation of Numbers		
1	100% occupancy, on/off	Template geometry, Default HVAC
2	Occupancy matches lighting schedules	
3	100% occupancy, on/off	Template Geometry, Detailed HVAC
4	Occupancy matches lighting schedules	
5	100% occupancy, on/off	Podium + Tower, Detailed HVAC
6	Occupancy matches lighting schedules	

## F2 – Scenario 2

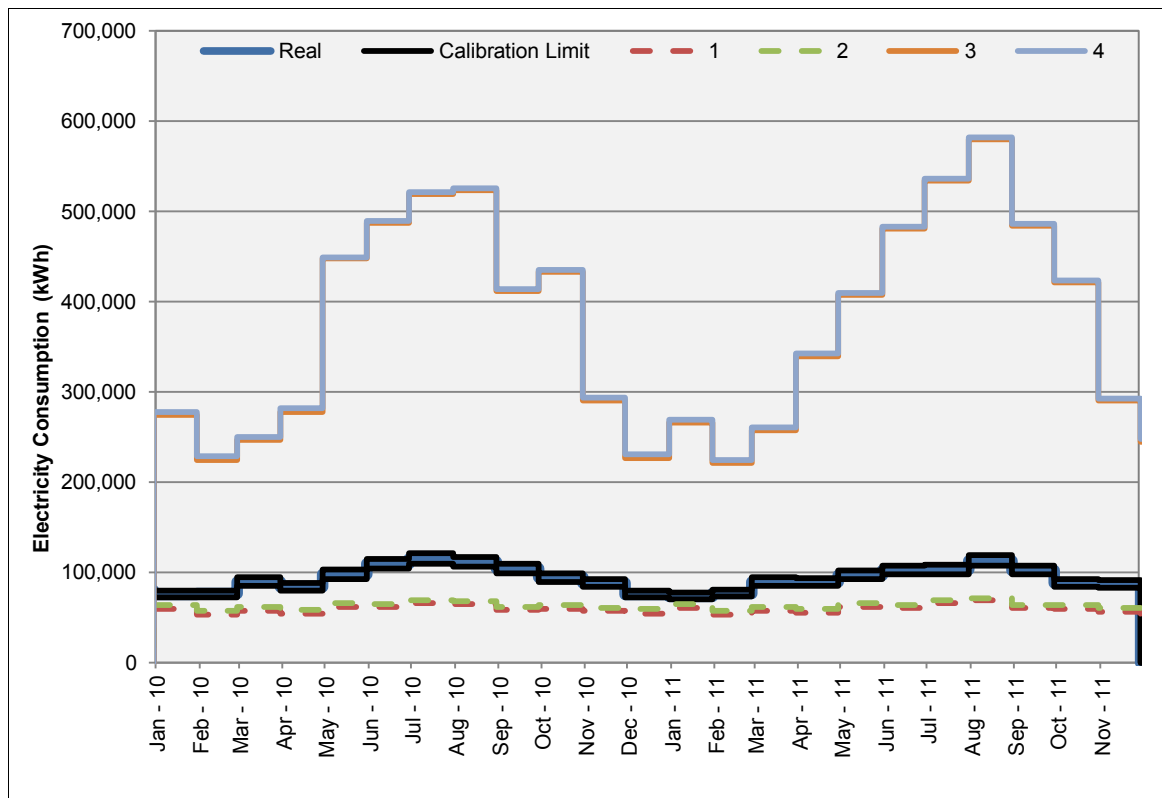


Figure 25: Scenario 2 Electricity Consumption Comparison

Table 15: Explanation of Numbers for Scenario 2

Explanation of Numbers		
1	Averaged Schedules	Template geometry, Default HVAC
2	Weighted average schedules	
3	Averaged Schedules	Template Geometry, Detailed HVAC
4	Weighted average schedules	

### F3 – Scenario 3

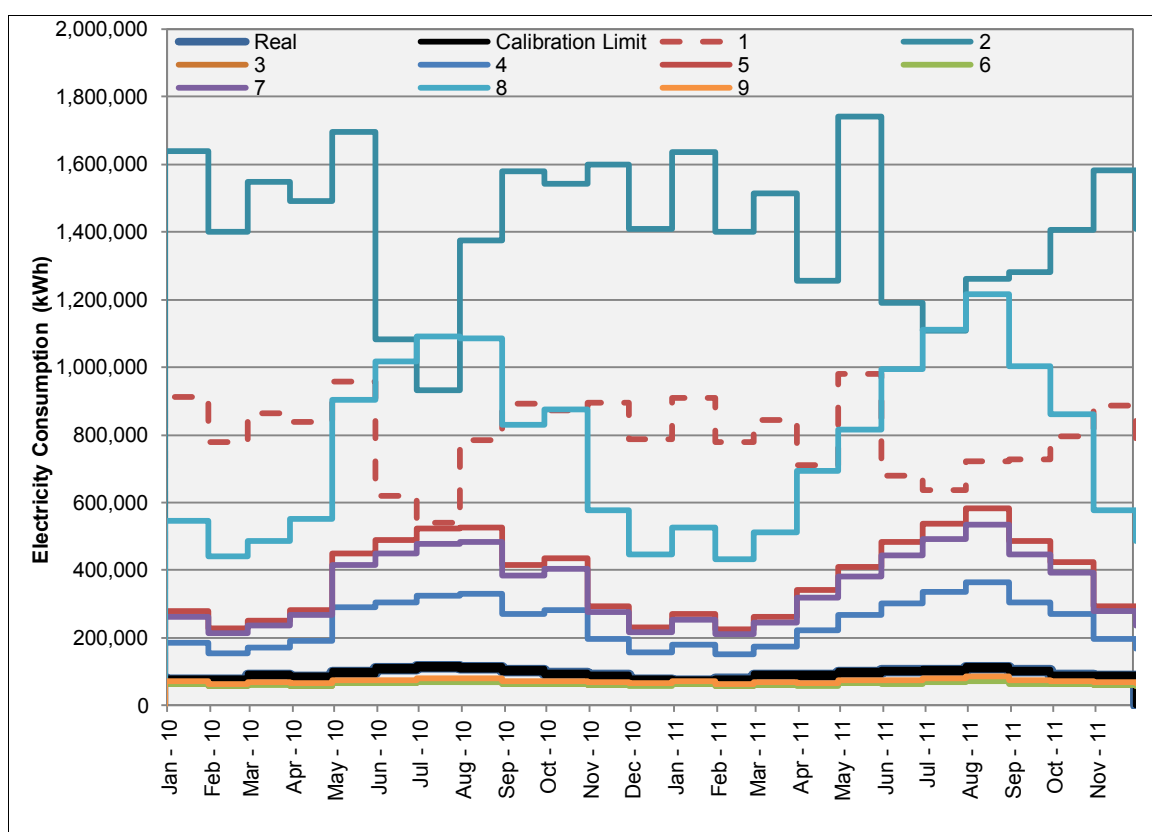


Figure 26: Scenario 3 Electricity Consumption Comparison

Table 16: Explanation of Numbers for Scenario 3

Explanation of Numbers		
1	Maximum CO <sub>2</sub> measurement	Template geometry, Default HVAC
2	Average CO <sub>2</sub> measurement	
3	NZ Standard recommended	
4	Maximum CO <sub>2</sub> measurement	Template Geometry, Detailed HVAC
5	Average CO <sub>2</sub> measurement	
6	NZ Standard recommended	
7	Maximum CO <sub>2</sub> measurement	Podium + Tower, Detailed HVAC
8	Average CO <sub>2</sub> measurement	
9	NZ Standard recommended	

## F4 – Scenario 4

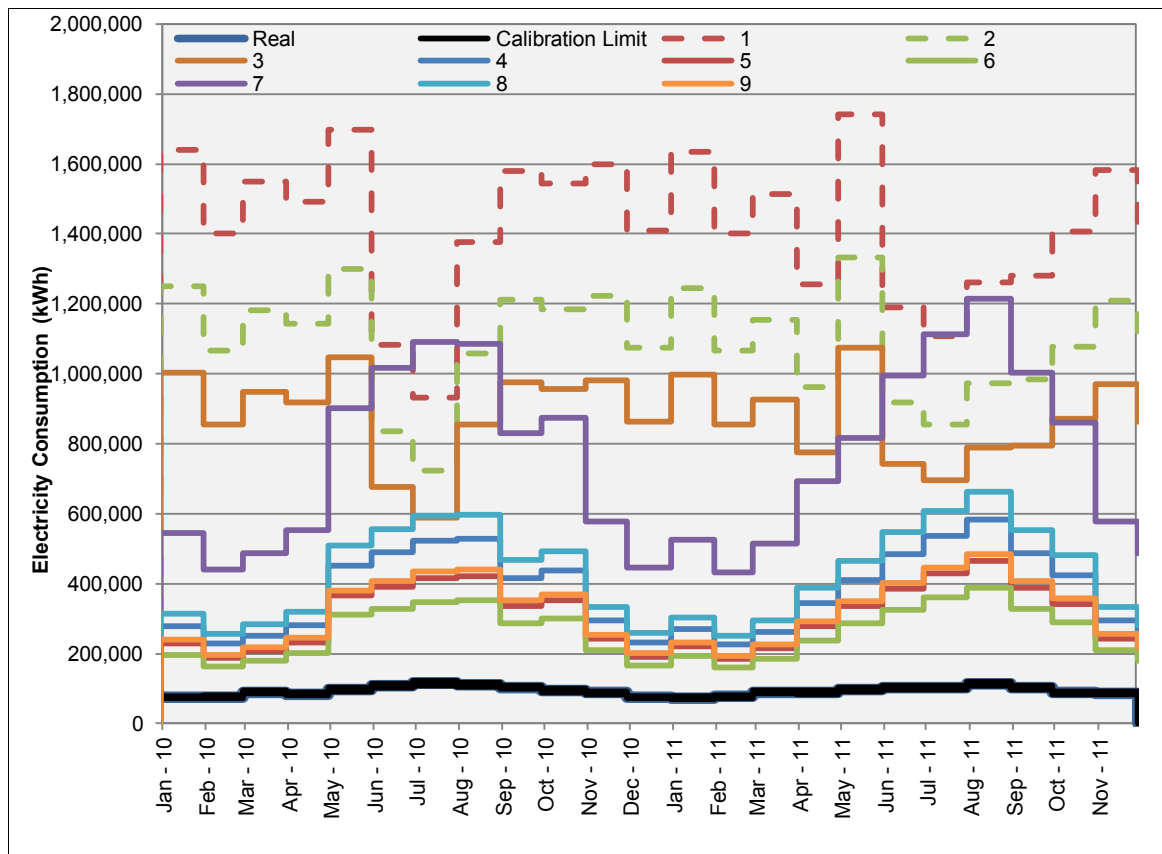


Figure 27: Scenario 4 Electricity Consumption Comparison

Table 17: Explanation of Numbers for Scenario 4

Explanation of Numbers		
1	City - 500 ppm	Template geometry, Default HVAC
2	Suburb - 450 ppm	
3	Rural - 400 ppm	
4	City - 500 ppm	Template Geometry, Detailed HVAC
5	Suburb - 450 ppm	
6	Rural - 400 ppm	
7	City - 500 ppm	Podium + Tower, Detailed HVAC
8	Suburb - 450 ppm	
9	Rural - 400 ppm	



## F5 – Scenario 5

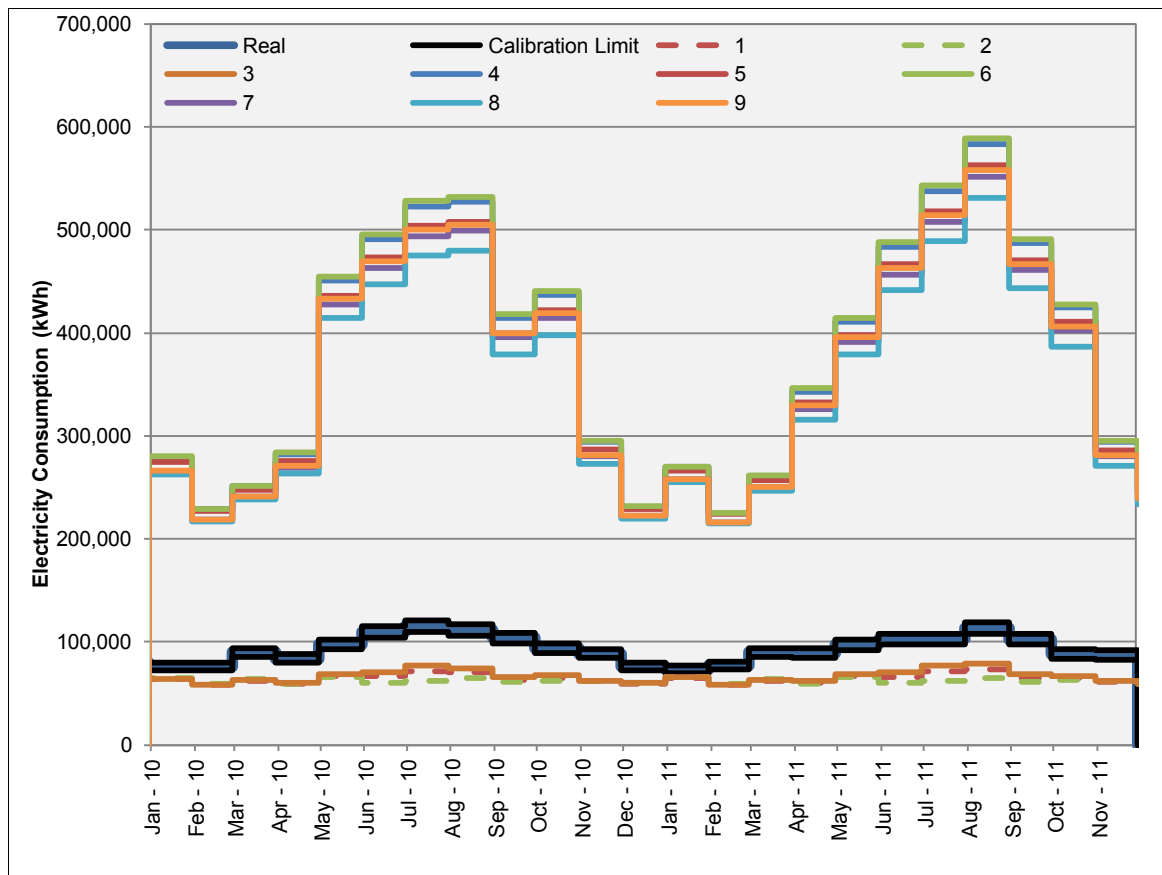


Figure 28: Scenario 5 Electricity Consumption Comparison

Table 18: Explanation of Numbers for Scenario 5

Explanation of Numbers		
1	No insulation, no cavity	Template geometry, Default HVAC
2	Cavity only	
3	Minimum insulation	
4	No insulation, no cavity	Template Geometry, Detailed HVAC
5	Cavity only	
6	Minimum insulation	
7	No insulation, no cavity	Podium + Tower, Detailed HVAC
8	Cavity only	
9	Minimum insulation	

## F6 – Scenario 6

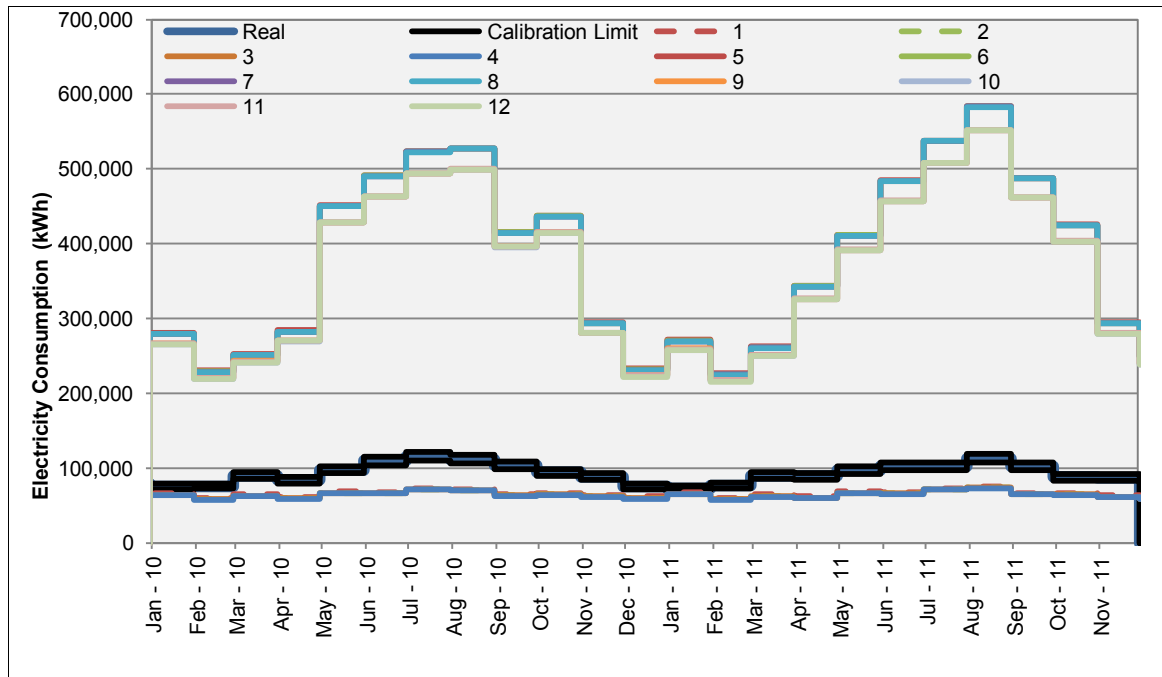


Figure 29: Scenario 6 Electricity Consumption Comparison

Table 19: Explanation of Numbers for Scenario 6

Explanation of Numbers		
1	High load servers across the floor area	Template geometry, Default HVAC
2	Low load servers across the floor area	
3	High load servers, individual room	
4	Low load servers, individual room	
5	High load servers across the floor area	Template Geometry, Detailed HVAC
6	Low load servers across the floor area	
7	High load servers, individual room	
8	Low load servers, individual room	
9	High load servers across the floor area	Podium + Tower, Detailed HVAC
10	Low load servers across the floor area	
11	High load servers, individual room	
12	Low load servers, individual room	