TOWARDS THE REMOVAL OF UNCERTAINTY IN SUSTAINABLE BUILDING DESIGN THROUGH FULL SCALE OPTIMIZATION

By

Stuart Carlisle Fix

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Abstract

The lack of whole-building design optimization resources available to building designers has led to uncertainty in design decisions involved with building highly sustainable or 'Green' buildings. This uncertainty can be removed using Full Scale Optimization: the process of conducting a massive number of building energy simulations, and combining this predicted operational data with life cycle analysis metrics to optimize building design. This method has been executed over the scope of 1 080 000 single detached home designs under Toronto climate conditions by automating EnergyPlus simulations within Amazon's Elastic Compute Cloud. A lifetime energy consumption analysis was performed using data from Athena's Impact Estimator. Example analysis shows parameters such as total building size, sub-grade floor area, window U-value, and air infiltration level have the greatest effect on total lifetime energy consumption. Future research is to include more rigorous database analysis and the inclusion of other relevant optimization metrics.

Acknowledgements

I would like to thank Matt Mercer for his invaluable knowledge of computer science and information technologies. I would also like to thank Matthew Bowick of the Athena Institute for his advice and data on life cycle analysis. I extend my gratitude to Professor Russell Richman, Davis Marques, and the rest of the Ryerson community for their support through this endeavor.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1 - Introduction

1.1 - Motivation

As humanity strives to better understand and mitigate its negative impact on the earth, it is of crucial importance that the building sector does its part. The building sector currently consumes energy, emits carbon dioxide, produces landfill waste, and releases harmful chemicals into the environment. Shown in Figure 1, the Canadian building sector consumes more energy than any other.

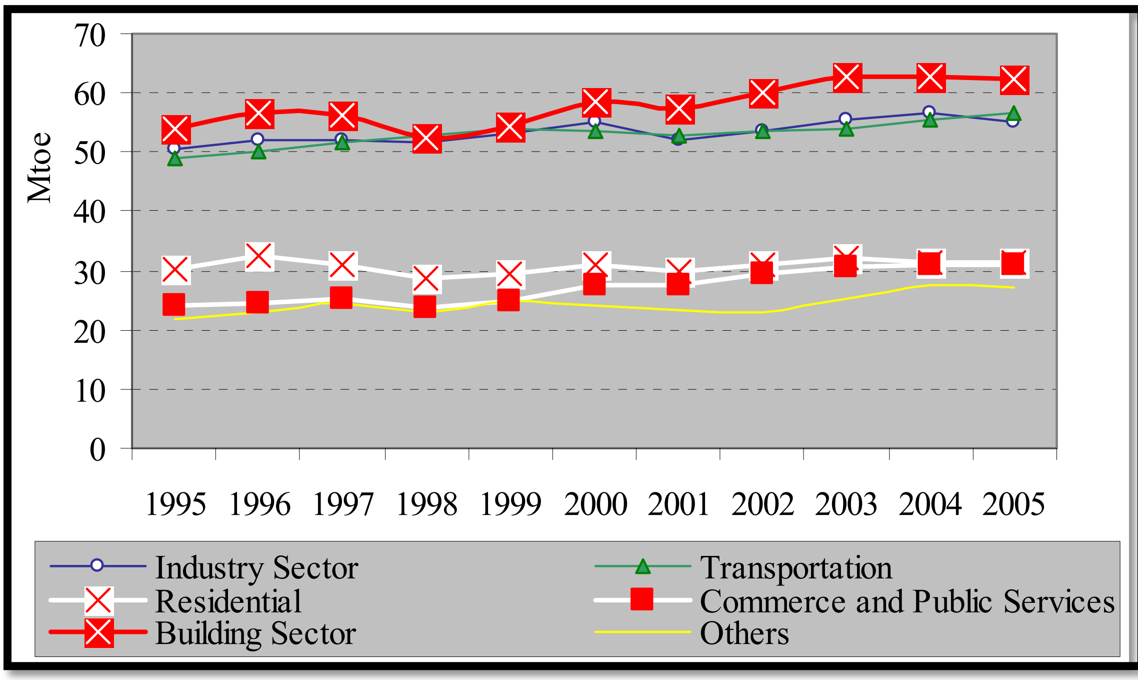

Figure 1 - Energy Consumption by Sector in Canada, 1990-2005. Energy consumption in this figure refers to final energy use, which includes consumption of renewable and waste energy; the sector "Others" includes agriculture, forestry, fishing, and non-specified and non-energy use. Chart compiled by(Pacific Northwest National Laboratory, 2009) based upon International Energy Agency Data: Energy Balances of OECD Countries (1997-2007 editions).

This revelation is perhaps shocking, as many sources cite Industry or Transportation to consume the most energy. Data from Natural Resources Canada, shown in Figure 2 below, reflects this common belief on first glance. It is important to note that the residential and commercial sector's energy consumption are almost entirely building related. Also, a portion of the Industrial sector's energy consumption comes from buildings. When the commercial and residential sectors are added together, the total is greater than transportation energy usage. Unfortunately, the percentage of Industrial energy usage from buildings is not easily obtainable from Natural Resources Canada. Regardless of information source and data categorization technique, the energy consumption of the building sector is large in magnitude and should be a prime target in Canada's national strategy to lower environmental impacts.

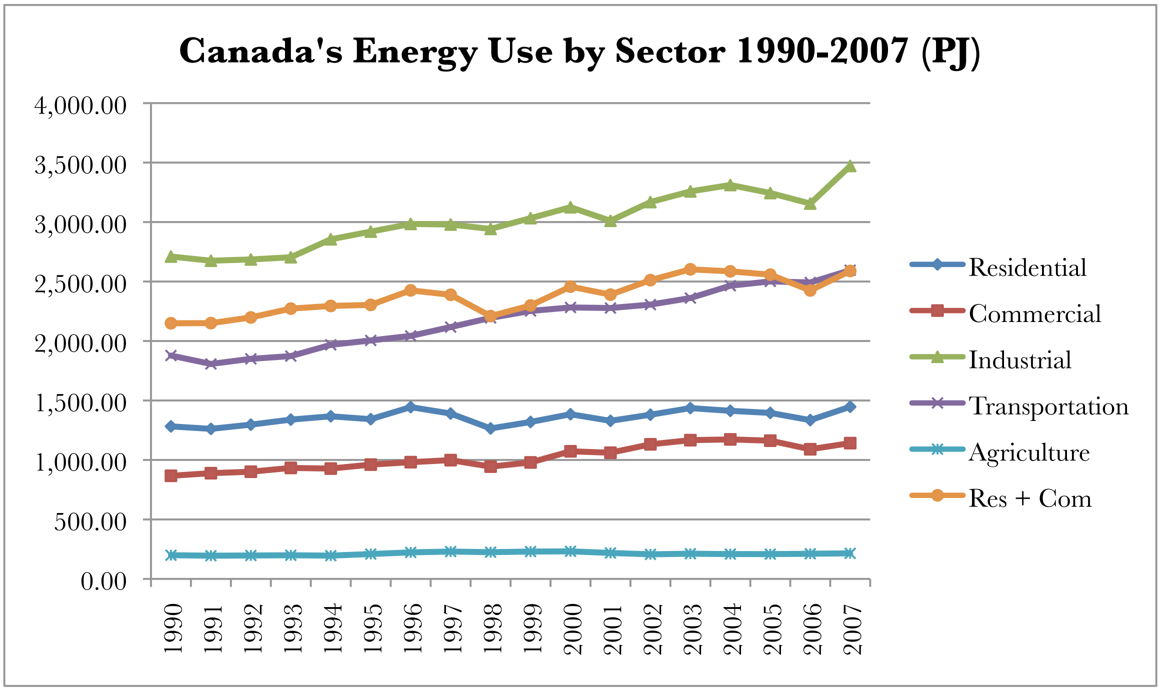

Figure 2 - Canada's Energy Use by Sector, 1990-2007. 'Res + Com' represents the addition of the Residential and Commercial energy usage data points. (Natural Resources Canada, 2009)

Traditionally, negative environmental effects have largely been ignored, and building design has been dictated by economics. In recent years, awareness of these negative environmental impacts has increased, and the push to design 'Green' buildings has emerged. 'Green' buildings are loosely defined as those buildings that lessen and ultimately aim to completely remove negative impacts on the environment. The building design profession has become flooded with often-conflicting anecdotal & theoretical advice on the technologies and techniques that produce the 'Greenest' buildings. This flux of new information has created confusion and even built mistrust between building professionals, building component suppliers, building owners, and the public. Seemingly simple questions like, "how much and what type of insulation should a home have to minimize environmental impact?" and more complex questions like "what is the ecologically optimal building configuration for this climate?" currently have no distinct answers. The lack of whole-building design optimization resources available to building designers has led to great uncertainty in design decisions involved with 'Green' buildings. This thesis proposes a method that combines massive scale building simulation with life cycle analysis data, which can be used to answer to many of these questions. This method is called Full Scale Optimization.

1.2 - Objectives

The underlying motivation for this thesis is to present a method that can be used to remove uncertainty from 'Green' building design. To do this, the method must be applicable on a broad scale, to a broad range of optimization metrics, and provide justified, transparent results. Uncertainty exists because design relationships are complex, and highly interrelated. Uncertainty is removed when designers are empowered by informed choices that leave no questions unanswered. The objectives of this thesis are as follows:

1) Develop the Full Scale Optimization method into a repeatable, open source optimization methodology

2) Prove the relevance of the Full Scale Optimization method as an effective tool for removing uncertainty from sustainable building design decisions through the execution of the Toronto Pilot

3) Produce an example of transparent and justified research that can be used to inform design decisions through the simple analysis of the Toronto Pilot results

1.3 - Conceptual Method

In general, the Full Scale Optimization method requires the selection of one or more optimization criteria, such as energy consumption or greenhouse gas production, along with the range of building types in interest. One then calculates the quantity of the chosen metric(s) produced during each building permutation's operational lifetime and the quantity embodied within the built components. This sum of the operational and embodied environmental metric represents each building's total ecological impact (within that metric), and thus the design(s) that have the lowest impact are optimal. Where there are multiple objectives, the relative value of each objective must be determined and applied. This technique can be used on a broad scale, from the optimization of a single building design with 1000's of design permutations, to optimization on a national level, encompassing trillions of design permutations.

1.4 - Toronto Residential Pilot

To prove that this method can be applied on a large scale within a reasonable budget, and using readily available computing power, a demonstration pilot was developed and conducted encompassing 1 080 000 home design permutations in Toronto, ON. For each permutation, the overall operational energy consumption was calculated using EnergyPlus V4, and the embodied energy of specific variables was calculated using data from Athena's Environmental Impact Estimator V4.1. The resulting data was put in database format, from which lifetime energy consumption was developed.

1.5 - Further Study

The results database constructed from the Toronto Pilot contains a massive amount of information, which should be rigorously analyzed for trends and relationships between design parameters. The goal is to determine which parameters have the greatest influence on lifetime energy consumption. From this information a design priority order can be developed to aid designers make design decisions by order of impact. It is hoped that this analysis may also yield user-friendly equations or 'rules of thumb' that may help simplify smaller-scale design optimization decisions in the future. This rigorous analysis has been left for future study, as it exceeds the scope of this thesis.

In addition, the scope of the Toronto Pilot should be expanded to include additional optimization metrics. Example results show that lifetime energy consumption energy analysis alone can only be used to compare the performance of designs, but does not lead to any discretely optimal design conclusions. One must look at the motivation for energy conservation, describe this motivation as an optimization metric (such as greenhouse gas emission), and then combine this metric with the lifetime energy consumption results, to determine what magnitude of energy consumption is 'optimal'.

Finally, with additional funding and support, the Full Scale Optimization method could be expanded in scope to include additional design parameters, additional parameter range, and additional operationally independent parameters. There are few limits to the scope that the Full Scale Optimization method can be applied upon.

1.6 - Organization of This Paper

This paper is organized into the following six chapters. Chapter 2 presents a review of the existing research on building design optimization, and a comparison of methods similar to Full Scale Optimization. Chapter 3 summarizes the Toronto Pilot intent, scope, and the tools used to implement the method. Chapter 4 presents a detailed explanation of the code written to generate and database the Toronto Pilot Data. Chapter 5 presents some example results generated using graphical and simple statistical analysis. Finally, Chapter 6 presents the paper's conclusions and lessons learned.

Chapter 2 - Literature Review

2.1 - Early Optimization Techniques

The idea of optimizing a building's design is relatively new. Historically, building design was simply based upon aesthetic values, regional climate stresses, and the availability of construction materials and capital. Thermal insulation, which was not widely used in North American buildings until the 1930's (Oviatt, 1975), was the only commonly optimized building element until the 2000's. One might assume that most homebuilders in the 1930's knew of the relationship between the amount of insulation, energy consumption, and construction costs, but the low energy prices at the time did little to motivate change. Shown in Figure 3 below, the cost of heating gas was low until the energy crisis of the 1980's.

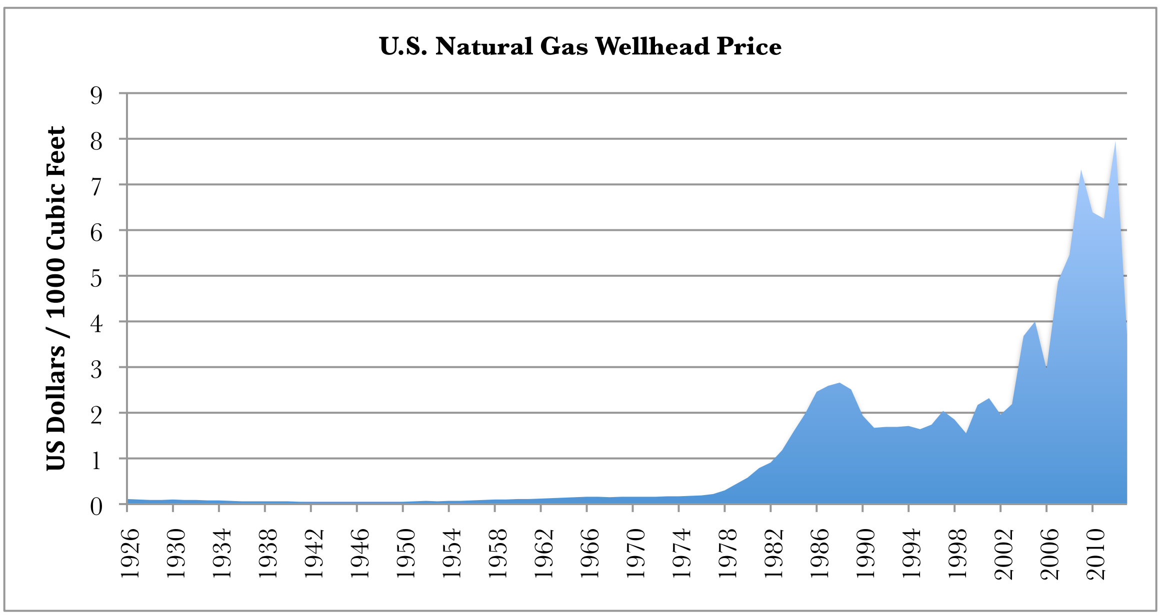

Figure 3 - Annual wellhead price of Natural Gas in the United States over the past 90 years. (U.S. Department of Energy, 2010)

A lifetime optimized insulation design methodology was proposed by both Oviatt and Stephenson in the mid-1970's, with the intent of shielding the public from rapidly rising energy prices (Oviatt, 1975, Stephenson, 1976). In Stephenson's method, it was assumed that "societal concerns about pollution and depletion of nonrenewable resources would enter into consideration via the price of fuel" (Stephenson, 1976). Since then, similar cost-optimization methods have been applied to building codes in cold and hot climates to regulate minimum insulation thickness (Hasan, 1999)(Al-Saadi, 2006)(Yu, 2009). The result of Stephenson's cost-optimization in 1976 suggested that "an R=20 [RSI=3.52] wall would be appropriate for most parts of Canada." (Stephenson, 1976). The simple methodology of cost-optimization is explained in Figure 4, below.

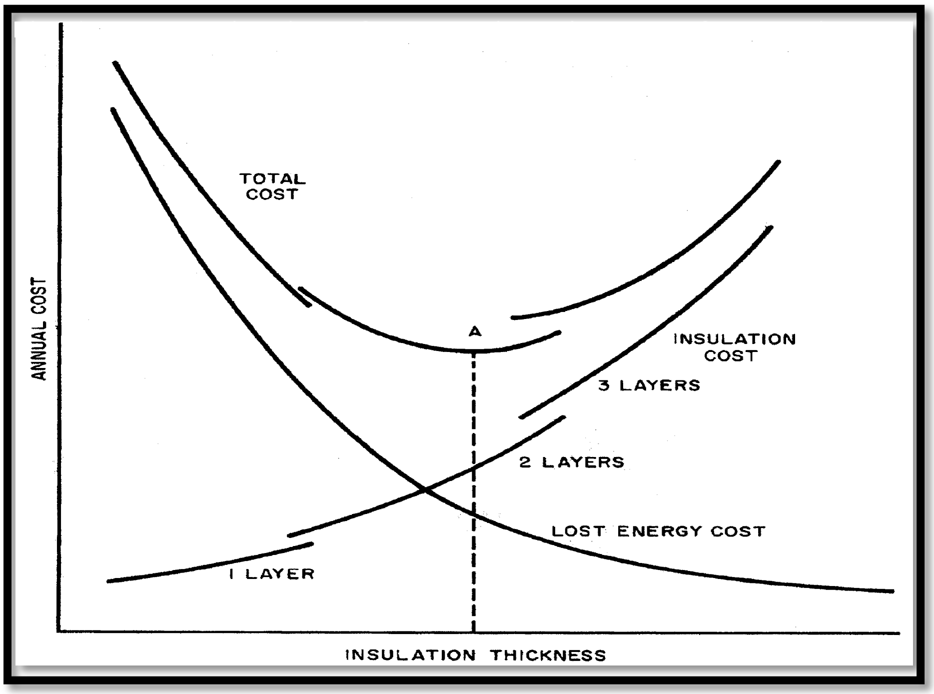

Figure 4 - ASHRAE Handbook: Determination of Economic Thickness of Insulation (ASHRAE, 2005).

Since the 1970's, however, social pressure has proved ineffective in regulating pollution through the manipulation of energy prices, contrary to Stephenson's prediction. Nonrenewable resources, such as natural gas, oil, and coal, are being depleted at ever accelerating rates (National Energy Board of Canada, 2010). Environmental pollution, such as carbon dioxide, also continues unhindered by energy prices, as the current global warming phenomenon exposes (IPCC Working Group I, 1997). Both the price and consumption of heating gas have only increased since Stephenson made his predictions, and there is increasing uncertainty in the future supply of these heat sources (National Energy Board of Canada, 2010).

The National Building Code of Canada was first developed in 1941 to set minimum standards of building construction in Canada. Since its inception, the code has only required that enough insulation be included to mitigate condensation on interior wall surfaces (National Building Code of Canada, 1965-1995). Since Stephenson's work in the 1970's, the 1990 Ontario Building Code (OBC) was the first code to present prescriptive requirements for thermal insulation in buildings. The OBC has been updated in 1997 and 2006, and the Model National Energy Code was released in 1997 on a federal level. Table 1, shown below, summarizes the progression of prescriptive insulation requirements under these codes.

Table 1 - Summary of prescribed insulation levels [rsi] for historic Ontario Building Codes (OBC) and Model National Energy Code (MNEC).

Location	Stephenson 1976	OBC 1990	OBC 1997	MNEC 1997	OBC 2006
Ceiling Below Attic		5.4	5.4	5.00	7
Roof w/o Attic	3.52	3.52	3.52	4.35	4.93
Exposed Wall		2.11	3	1.82	3.34
Exposed Floor		4.4	4.4	4.55*	4.4
Foundation Wall		2.11	1.41	0.77	2.11
Slab w/ Pipes		1.76	1.75	0.93	1.76
Slab w/o Pipes		1.41	1.41	0.00	1.41

[* denotes parallel-chord trusses and joist-type construction. (Ontario Ministry of Municipal Affairs and Housing-Building and Development Branch, 2008)(National Research Council Canada, 1997)(Ontario Ministry of Municipal Affairs and House - Building and Development Branch, 1997)(Ontario Ministry of Housing - Buildings Branch, 1989)(Stephenson, 1976)]

While the background calculations that go into these codes are not publically available, it would appear that both the 1990 and 1997 OBC levels are based on some sort of cost optimization, as the wall levels match Stephenson's. In the 1997 MNEC and 2006 OBC the levels begin to increase above Stephenson's, possibly reflecting either higher fuel prices or an effort to reduce the environmental impacts of Canadian buildings, to some level. Regardless, these codes present prescriptive values to be followed, but don't offer justification nor motivation.

The problem with cost-optimization methods is that they fail to reflect the full environmental impacts of design and become inaccurate as soon as the price of fuel or materials change. Canada has not successfully met any of its climate change treaty obligations under the Framework Convention on Climate Change (1992), nor the Kyoto Protocol (1997); in fact, Canada's carbon emissions have grown by 27% since the Kyoto Protocol was signed (The Globe And Mail, 2009). Since buildings consume one of the largest shares of energy in Canada (Natural Resources Canada, 2009), our building designs seem only governed by cost-optimized codes to date, and society hasn't been successful in reducing pollution nor consumption of nonrenewable resources, it appears that cost-optimization alone is not an effective method of making building design choices that will lessen the environmental impact of our buildings.

2.2 - Multi Parameter Optimization

Expanding design optimization methods beyond the simple life cycle cost analysis of insulation levels is challenging, as the additional parameters one might include are generally interrelated. For example, one might include the life cycle cost analysis of varying window performance levels. The operational energy component of a home with varying insulation levels is affected by the performance of the windows present. Additionally, one could include the life cycle energy analysis of both the insulation and window levels. Now the model has four interrelated parameters and two interrelated objectives; lowest lifecycle cost and lowest life cycle energy consumption. This multi-parameter, multi-objective optimization is too calculation intensive to complete by hand, and thus the idea wasn't seriously approached until computer processing became more affordable and efficient. In 1981, Byrne presented a simple example of the cost optimization of 5 different envelope thermal performance parameters (Byrne, 1981). At the time, computer-processing power was still weak and expensive, and the method didn't catch mainstream attention. For example, the optimization of 5 parameters, each with a range of discrete 5 values, requires the simulation of over 3000 permutations, which would have been an expensive and monumental task with 1980's processing power. Further developments in building simulation software, computer science, and statistics over the past 30 years have made it possible to optimize massive interrelated models and push the field beyond single parameter optimization. Recent examples of massive design optimization projects combine simulation with artificial intelligence models such as Artificial Neural Networks and Genetic Algorithms to improve the efficiency of results generation. The method chosen for the Toronto Pilot, Full Scale Optimization, has not yet been applied on a large scale, to the author's knowledge. The explanation, advantages, and disadvantages of each method are discussed in sections 2.2.1-2.2.3.

In all cases, the large amount of data produced with massive scale, multi-parameter, multi-objective optimization projects can be used to develop interactive design tools. A designer can steer a building design towards optimal performance through the use of such tools. The applicability of the following optimization models to public design tools is also discussed in sections 2.2.1-2.2.3.

2.2.1 - Artificial Neural Network Models

In basic terms, an Artificial Neural Network (ANN) is an attempt to replicate the intelligence and learning ability of the human brain. There is no equivalent of a Central Processing Unit (CPU) in the human brain; rather a massive network of simple processing units, known as neurons, carries out information processing. Neural networks learn by example, under the stimulus of 'training' data. If humans had a CPU, like a computer, it would have to be programmed to know the proper reaction to literally every possible action encountered. Instead, our brains learn constantly, and our behavior is a reflection of our lifetime of learned lessons. When applied to the field of building design optimization, an ANN can be trained to replace the role of a building simulation program, resulting is vastly faster results generation.

William O'Brien, a current PhD student at Concordia University, has trained an ANN to produce nearly instantaneous computational results in a Solar House Design Tool. O'Brien's model includes 26 continuous design parameters that describe a home's geometry, orientation, thermal envelope, glazing and shading, ventilation, internal gains, thermal mass, and HVAC settings (O'Brien, 2008). O'Brien randomly selected 10 000 combinations of the 11 most significant design parameters, and simulated the whole-year performance of each using ESP-r, which represents about 10 days processing power on a standard desktop computer. These 10 000 results formed the training set for a feed-forward, back propagation, 30-node, artificial neural network. When the trained ANN was compared with the known simulations, the predicted performance was within a mean error of 4.1% (O'Brien, 2008). By using non-discrete parameter ranges as the training set for his ANN, O'Brien's design tool is now capable of handling input combinations unforeseen by the developer, in real time, with nearly instantaneous results. The economical efficiency of each parameter is also included in O'Brien's model, on the basis that the cheapest efficiency-improvement measures should always be pursued first. The author questions this method, as it requires that 1kWh of energy saved by insulation or passive design is equivalent to 1kWh generated by renewable technologies. Renewable energy technologies require high-tech maintenance, have a limited operational lifetime, can be affected by changing weather patterns, and are impacted by changes to the surrounding physical environment (solar/wind right-of-way, etc). Thermal insulation and passive design features are typically free of these long-term weaknesses.

Artificial Neural Networks are advantageous because they can handle non-linear functions, learn from data relationships that are not otherwise known, can generalize to unseen situations, and are extremely computationally efficient once trained. However, they are disadvantageous because they offer limited understanding of the process of the phenomenon being modeled, are subjective in design, and their testing and validation are often inadequate from a statistical perspective (Stergiou, 1997). In addition to O'Brien's work, Magnier is also working on ANN type optimization models (Magnier, 2010). While efficient, neural networks lack the transparency of data generation that Full Scale Optimization can produce, and hence this method was not selected for the Toronto Pilot.

2.2.2 - Genetic Algorithm Models

As artificial neural networks mimic the brain's function, Genetic Algorithms (GA) mathematically mimic genetic evolution. Unlike ANNs, GAs cannot replace a simulation program, however they allow for optimal solution hunting. First, one defines 'optimal' within the scope of the project; it may be lowest life cycle cost, lowest life cycle energy consumption, etc. Starting with a sample population, similar to the neural network's training sample, GA code randomly samples a multitude of pairs from the population, and 'mates' them, by combining 'genes' (parameter values) of each 'parent' sample. The single offspring of this 'mating' is then given a fitness score, defined as how optimal it has performed. This pattern repeats, but now new mate selection pairs are continually selected based upon the weighted fitness of each new offspring. This results in a mathematical representation of survival of the fittest, as the more successful a design is, the greater its frequency of 'mating'. When applied to the field of building design optimization, GA's improve optimization efficiency, by lowering the total amount of simulations required to find the most optimal. Hypothetically, one could start with a scope encompassing 1 billion design scenarios, but then hunt down the most optimal scenarios with just 1 million simulations, using GAs to direct the search (these numbers may not meet statistical reliability requirements). There are many examples of researchers using GAs to aid optimization research.

Griet Verbeeck and Hugo Hens, of Belgium, seek to create a "global methodology to develop and evaluate on a scientific basis residential buildings that are globally optimized from the viewpoint of energy use, ecological impacts, and costs." (Verbeeck, 2007). Their effort is a multi-objective optimization that combines a Genetic Algorithm with the Pareto concept, which includes various building types and configurations from the Belgian building practice (Verbeeck, 2007). Many others have developed work in this area of building optimization, including Wang (Wang, 2005), Radford and Gero (Radford, 1987), Hauglustaine and Azar (Hauglustaine, 2001), Wright et al (Wright J. L., 2002), Xu (Xu, 2007), and Znouda et al (Znouda, 2007).

While optimization using Genetic Algorithms is very powerful, and can reliably produce high quality results, it is inherently inflexible as a finished product. The results are only validly 'optimal' under the strict definition of 'fitness' within the project. If things change and this definition of fitness is no longer relevant, or accepted, the whole project becomes obsolete. Also, one cannot build a fully functional design tool around GA optimization results, because only the more optimal designs are present. An optimization run generated using GAs cannot predict how much better performing the optimal design is from the least-optimal design, which makes the results less-transparent.

2.2.3 - Toronto Pilot: Full Scale Optimization

The Full Scale Optimization model involves simulating the full scope of design permutations, which are combined with embodied metrics over a selected lifetime to generate a database of relative lifetime building performance within the selected scope. Optimal designs and design trends can then be pulled from this database. If applied on a large enough scope, this database could be used to develop a justified and transparent scientific basis for a National Building Code that leads designers to create optimal designs. Purposefully, there are no efficiency improving techniques like Artificial Neural Networks or Genetic Algorithms involved. By doing so, full results transparency and reliability are achieved. The Full Scale Optimization database that can be implemented into a design tool, and analyzed using any and all desirable optimization criteria, now and in the future; a full scale database doesn't become obsolete. Because of this, Full Scale Optimization is inherently politically friendly. Since multi-objective optimization inherently requires the subjective valuing of economic and environmental factors, the 'optimal' design is likely to change with the political party in power as with the sentiment of the nation's population. If one is seeking funding for a massive optimization project that would form the scientific basis of a national building code, then the method with the highest transparency, reliability, and long-term relevance is highly desirable. If such a project were to include ANN, the results' reliability and transparency would be highly suspect, and if the results were to include GA fitness hunting, then the whole project would become obsolete if the current political party in power modifies the definition of 'optimal' (an easy sabotage strategy).

The main drawback of the Full Scale Optimization method is that it requires massive computer processing power. A province-wide optimization project would likely require around 1 billion design permutations. On a single desktop computer-processing core, this translates into roughly 32 years of simulation time, depending on the simulation software and complexity of model. Realistically, this method requires a supercomputer to process results, which has historically been very expensive and only available to an elite few. Until recently, this drawback was enough to steer interested researchers away and onto short-cut methods like ANN and GA. With recent advancements in cheap, on-demand, online cloud processing power, Full Scale Optimization is now a relevant method. Cloud processing is the act of linking a multitude of computer processors into a remotely accessible supercomputer cluster.

For the Toronto Pilot, a scope of 1 080 000 design permutations were simulated using EnergyPlus V4, in under a month, for under $2500 CAD, using Amazon Web Service's EC2 cloud processing power. Expanding this model, one could create a nation-wide optimization library that includes virtually all possible home designs, under all national climates, with 1 trillion design permutations, for 850 million dollars, and less than a year's processing time (Amazon Web Services, 2010). While this is a considerable amount of money, it is within a reasonable magnitude of federal government operations; it's less than the 1 billion dollar security cost of a recent international summit (CTV News, 2010). The statement that 'all possible home designs' could be included is a strong one, but the author believes that all envelope, geometry, internal construction, and loading patterns can be described using the combination of the simulated operational metric and calculated embodied metric.

Chapter 3: Pilot Methodology Summary

3.1 - Toronto Pilot Intent

The primary motivation of this thesis is to develop a method that removes the uncertainty in 'Green' building design choices by providing transparent and reliable optimization information to the designer. The intent of the Toronto Pilot is to prove the relevance of the Full Scale Method, by the execution of an example, in generating an optimization database that can be used to better inform 'Green' building design decisions.

3.2 - Toronto Pilot Scope

Since historic optimization research has been heavily influenced by economic payback, and this method has been found ineffective in reducing humanity's impacts on the environment, the Toronto Pilot's primary focus is on lifetime energy analysis, where the optimal design is defined as that which causes minimal lifetime energy consumption. Lifetime energy consumption is a logical starting point as its lifetime operational component uses the primary results of energy simulation, which can then be combined with embodied energy data to find the lifetime total consumption. Additional metrics such as environmental impact factors and cost are also important in reality. Because of the transparency and full-scope of the Full Scale method, the Toronto Pilot Database can simply be amended in the future to include any other optimization metrics, or combination of metrics, as the operational component of these environmental impact factors and cost can generally be calculated from the operational energy consumption data, and thus don't require re-simulation.

To describe the scope of an optimization project, one must break down a building into design parameters that can be used to describe the complete lifetime performance of under the selected optimization metrics. As the Toronto Pilot focuses on lifetime energy consumption, the two necessary calculations are lifetime operational energy consumption and embodied energy of construction, for each design permutation. It follows then that a building's design components can be separated into two groups: 1) those elements that greatly influence heating, ventilation, and cooling (HVAC) operational energy consumption, such as thermal insulation, window size, window orientation, window IGU design, air barrier system, thermal massing, and internal energy loading; and 2) those elements which do not greatly influence HVAC operational energy consumption such as structure, interior design, furniture, etc. From a lifetime energy consumption perspective, the optimal design of a building component with little influence on operational energy consumption can be simply found by minimizing its embodied energy. For a component with great effect on HVAC operational energy consumption, this optimal design must be determined through simulation, as most operational energy dependent parameters are interrelated. For the Toronto Pilot, the building design parameters with little effect on operational energy consumption have been left out of the analysis, to help fit the project into a reasonable time frame.

The Author's intent for the Full Scale Optimization methodology is that every conceivable building design parameter, with an inclusive range of values, could be included to generate a result database that predicts the lifetime performance of every possible building design, under all metrics. Such an undertaking would require billions if not trillions of operational energy simulations, which is simply not possible without large amounts of time and money. Also, it would also be imprudent to undertake such a large scope with an unproven method. Thus, for this master level thesis, the Toronto Pilot focuses on a scope of 1 080 000 design scenarios, incorporating the range of parameters and parameter values described in sections 3.4 and 3.6. Five major tools were integral to the Toronto Pilot process: the Python programming language (version 3), the EnergyPlus building energy simulation software (version 4), Amazon's Elastic Compute Cloud (EC2), the Athena Impact Estimator for Buildings (version 4), and the FileMaker Pro database software (version 11). The role of these tools is discussed in sections 3.3-3.7.

3.3 - Python Programming Language

The Full Scale Optimization methodology involves the generation and manipulation of massive amounts of data. To handle these demands, all thesis work has been written in the Python programming language. Python is a dynamic object-oriented programming language that can be used for many types of software development and is distributed on an OSI-approved open source license that makes it free to use for all projects, on all platforms (www.python.org). Python has strong mathematic, file manipulation, and web development modules that were especially helpful in developing this thesis. Python was used to generate the 1 080 000 different .IDF EnergyPlus input files, to parallelize and control twenty-four EnergyPlus simulation streams, and to manipulate the results data into the required input format for a database. By using a coded structure, the optimization methodology is easily scalable for larger or smaller projects, and is highly repeatable. Python is also quite easy to learn and user friendly.

3.4 - EnergyPlus

EnergyPlus is a building energy simulation program based on DOE-2 and BLAST, with numerous added capabilities. First released in April 2001, EnergyPlus was developed jointly by Lawrence Berkeley National Laboratory, the University of Illinois, the U.S. Army Construction Engineering Research laboratory, GARD Analytics Inc., Oklahoma State University, and others, with the support of the U.S. Department of Energy (EnergyPlus, 2010). EnergyPlus was used to simulate the operational energy performance of each design permutation. This software was selected for its text-based input capability, its strong simulation accuracy (Crawley, 2005), and its support within the Ryerson Building Science faculty.

The definition of specific input parameters is dependent on the format required by the energy simulation program in use. To limit the scope to the desired range, one must separate all input parameters into those to be held constant and those to be manipulated, for all simulations. The specific definition of the constant and manipulated parameter values used in the Toronto Pilot follows in sections 3.4.1-3.4.2. The selection of simulation parameters for the Toronto Pilot represented a difficult balance of scope inclusion and a reasonable total number of permutations. Although some may disagree with the author's selections and assumptions, this work is preliminary and exploratory and the parameters were selected according to the author's goals and desired scope. The author welcomes and encourages the repetition of this method using different parameter selections.

3.4.1 - Constant Simulation Parameters (CSP)

CSP #1: Building Occupancy

While occupancy patterns can have great effect on building energy use, they were deemed too complex to manipulate in the Toronto Pilot. In EnergyPlus, occupancy can be defined in three ways: 1) Number of People, 2) People per zone area, and 3) Area per person. Originally, the author developed the average occupancy in Canada of 0.02 people/m^2 floor area, based upon the average family size in Canada of 3 people (Statistics Canada, 2007), and the average home size in Canada of 141m^2 (National Resources Canada, 2008). This value would keep the effect of occupancy constant over all building floor areas under investigation. However, it was later concluded that this assumption produces unrealistic occupancy in larger homes. For example, a 464.5m2 home would have 9 occupants, which is not typical, as only 10% of Canadian households have 5 or more occupants (Statistics Canada, 2006). Thus the number of occupants was held at a constant 3 people for each simulation, to attempt to reflect typical Canadian households.

The second method to control occupancy internal gains in EnergyPlus is through an Occupants Schedule, which dictates when these loads are applied. The Occupancy schedule used in all Toronto Pilot simulations is shown in Figure 5. For simplicity, the schedule is defined such that all occupants are always present in the home, except for holiday days. It was assumed that 'work efficiency' of occupants is 0%, and thus all energy expended is released as heat into the building. While this schedule does not reflect reality, where home occupants constantly come and go, it is an attempt to set a baseline from which variable occupancy patterns can be compared. Indeed, for higher accuracy, future expansions could include both multiple occupancy levels and multiple occupancy schedules to give a wider range of investigation.

```
! Schedule: Occupants
Schedule:Compact,
    2234,                     !- Name
    Fraction,                 !- Schedule Type Limits Name
    Through: 31 Dec,          !- Field 1
    For: Weekdays SummerDesignDay WinterDesignDay, !- Field 2
    Until: 18:00,1,           !- Field 3
    Until: 22:00,1,           !- Field 5
    Until: 23:00,1,           !- Field 7
    Until: 24:00,1,           !- Field 9
    For: Weekends,            !- Field 11
    Until: 10:00,1,           !- Field 12
    Until: 17:00,1,           !- Field 14
    Until: 18:00,1,           !- Field 16
    Until: 23:00,1,           !- Field 18
    Until: 24:00,1,           !- Field 20
    For: Holidays,            !- Field 22
    Until: 24:00,0,           !- Field 23
    For:  AllOtherDays,       !- Field 25
    Until: 24:00,0;           !- Field 26
```

Figure 5 - Sample EnergyPlus Code - Occupancy schedule held constant in all Toronto Pilot simulations. (Line 242 - Create.IDF, see appendix)

CSP #2: Internal Lighting

Unlike occupancy, it is more accurate to assume that lighting energy consumption is linearly related to building size, as most home areas have lighting. In 2006, Canadian single detached homes, having a total floor area of 1 076 000 000m^2, consumed 52.7PJ electric lighting energy (Natural Resources Canada, 2009), which averages out to 1.55 W/m^2. This average consumption was applied to all simulations, using appropriate wattage/zone floor area in EnergyPlus. Similar to occupancy, a lighting use schedule must also be defined in EnergyPlus; for the Toronto Pilot, an 'always on' schedule was defined, as shown in Figure 6 below. The lighting radiant fraction was defined at 42%, the EnergyPlus default, meaning that 42% of lighting energy is converted into a heat load within the home. Lighting is only included in the simulations for its affect on space conditioning energy usage. For greater accuracy and depth of scope, future expansions should include multiple lighting intensity levels, radiant fractions, and multiple lighting schedules.

```
! Schedule: Lighting
Schedule:Compact,
    2235,                    !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 Dec,         !- Field 1
    For: Weekdays SummerDesignDay WinterDesignDay, !- Field 2
    Until: 08:00,1,          !- Field 3
    Until: 18:00,1,          !- Field 5
    Until: 24:00,1,          !- Field 7
    For: Weekends,           !- Field 9
    Until: 10:00,1,          !- Field 10
    Until: 24:00,1,          !- Field 12
    For: Holidays,           !- Field 14
    Until: 24:00,1,          !- Field 15
    For: AllOtherDays,       !- Field 17
    Until: 24:00,1;          !- Field 18
```

Figure 6 - Sample EnergyPlus Code - Lighting schedule held constant in all Toronto Pilot simulations. (Line 263 - Create.IDF, see appendix)

CSP #3: Appliance Energy

Appliance internal gains have been defined in a similar manner to lighting. In 2006, Canadian single detached homes having 1 076 000 000m^2 total floor area used 126.2 PJ in electrical appliance energy (Natural Resources Canada, 2009). This averages to 3.73 W/m^2 energy consumption, which was held constant in each simulation. The appliance radiant fraction was assumed at 20%, again an EnergyPlus default, meaning that 20% of this 3.73 W/m^2 is converted to heat in the home. The appliance energy schedule was also defined as 'always on', as shown below in Figure 7, removing the dynamic effect of variable appliance energy consumption from the simulations.

```
! Schedule: Equipment
Schedule:Compact,
    2236,                    !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 Dec,         !- Field 1
    For: Weekdays SummerDesignDay WinterDesignDay, !- Field 2
    Until: 18:00,1,          !- Field 3
    Until: 23:00,1,          !- Field 5
    Until: 24:00,1,          !- Field 7
    For: Weekends,           !- Field 9
    Until: 10:00,1,          !- Field 10
    Until: 24:00,1,          !- Field 12
    For: Holidays,           !- Field 14
    Until: 24:00,1,          !- Field 15
    For:  AllOtherDays,      !- Field 17
    Until: 24:00,1;          !- Field 18
```

Figure 7 - Sample EnergyPlus Code - Appliance schedule held constant in all Toronto Pilot simulations. (Line 280 - Create.IDF, see appendix)

Again, future scope expansion should include variable appliance energy consumption and consumption scheduling to predict their affect on overall lifecycle energy consumption.

CSP #4: Domestic Hot Water Use

The domestic hot water usage was held constant for each simulation, using a value of 3.04e-6 m^3/s, as defined below. EnergyPlus only requires an input of 'peak flow rate', which is then applied to a fractional usage schedule. Since occupancy is fixed at the average family size of 3 people, it follows that the DHW usage should be fixed at the average household consumption rate. For the Toronto Pilot, this average rate is linked to the occupancy rate, which is an 'always on' schedule, as discussed above.

1) Assume hot water is on average heated from approximately 10˚C to 60˚C

2) In 2006, the total Canadian domestic hot water energy consumption was 152.9 PJ, spread over a total of 1 076 000 000 m^2 home area (Natural Resources Canada, 2009).

3) The average home size in Canada being 141m^2 (National Resources Canada, 2008)

Using: $Q = mC\Delta T$, where: Q = heat energy applied

m = mass heated

C = heat capacity of mass

ΔT = temperature change

Thus: $m = (152.9\text{PJ/yr})(141\text{m}^2)/[(4181.3\text{J/kg˚C})(50˚\text{C})(1\ 076\ 000\ 000\text{m}^2)]$

$=(95.84\ \text{tonnes/yr})/[(365\text{day/yr})(24\text{hr/day})(60\text{min/hr})(\text{s/min})]$

$= 3.04e^{-}6\ \text{m}^3/\text{s}$

CSP #5: Zone Density

There is little research available on the precise effects of manipulating the zone layout of a building energy simulation. Trial simulations, by the author, show that the number of zones within a single storey home does not dramatically affect simulation results. The results of these trial simulations are shown in Figure 8 below. The largest deviation from average was 3% in heating load, and 23% in cooling load. Simple zoning minimizes simulation processing time and allows a larger scope within a certain budget. Though the test trial is not rigorous, and 23% variance is not trivial, this trial convinced the author that selecting a single zone model for all simulations would not present any serious flaw in accuracy, especially considering the complexity of multiple zone modeling.

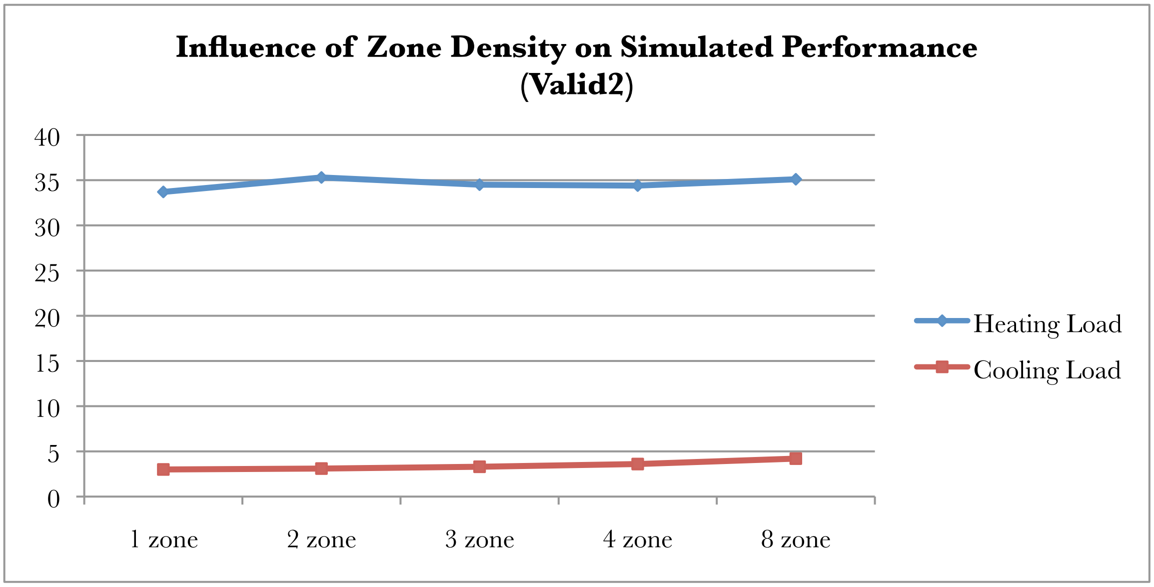

Figure 8 - Influence of Zone Density on Simulated Performance. Trial modeled with Designbuider software, by varying only the internal zoning of the single story residential building.

CSP #5: Ventilation Requirements

The fresh air supply rate for each simulation was held constant at 0.126 litres/s/m^2 fresh air. This value was calculated using the following ASHRAE 62.2 ventilation equation (ASHRAE, 2003), assuming the average sized Canadian home:

```
Required CFM = [ 0.01(area) + 7.5 (num bedrooms+1) ] / 141m2
             = [ (0.01)(1500ft2) + 7.5(3) ] / 141m2
             = 37.5 cfm / 141m2
             = 0.126 l/s/m2
```

Use of this value over all home sizes requires the assumption that each home has the required ratio of floor area to number of bathrooms. For greater accuracy, variable ventilation rates could be included in future studies.

CSP #6: Door Thermal Performance

For simplicity, external doors were not included in the Toronto Pilot simulations. Test simulations that compared two identical homes supported this decision: one with a highly insulated door, and one with negligibly insulated doors (Valid4). Results showed that there was no measurable difference in performance. Coupled with the fact that the ‘always on’ occupant settings would require any doors included in the simulation to remain closed at all times, doors were omitted from all Toronto Pilot simulations.

CSP #7: Location/Weather Data

To limit the scope of this pilot project, all simulations were computed under a Toronto climate. While some performance parameters are interrelated, climate location independent. The Toronto Pilot could easily repeated in every climate location in Canada, simply by calling a different EnergyPlus weather file with each simulation. This parameter was purposefully limited to a single location for the test pilot, to minimize the required number of simulations.

CSP #8 Insulation Material

The assumption was tested that simulated performance is only influenced by the RSI value of the insulation, and not the type/thickness of insulation used. Since the lifetime energy consumption analysis focuses on the effect of insulation type used in construction, it greatly simplifies the simulation process if a single insulation type can be used for all. Two simulations were compared: one that used expanded polystyrene insulation and one that used loose fill wool insulation of the same overall RSI value. The result showed negligible difference in overall yearly heating and cooling load (Valid5). While this test is by no means rigorous, it was enough to convince the author that using RSI-value instead of insulation type/thickness in the simulations would not cause a major flaw in accuracy, while it allows for a major reduction in the total number of simulations. The simulated RSI value can be used to calculate the required volume of each insulation type in any scenario.

CSP #9: HVAC System

All Toronto Pilot simulations used an idealized HVAC model in EnergyPlus, called an 'Ideal Loads Air System'. This system is not modeled with any connections to a central air system or ducting. Instead, the Ideal Loads Air System object simply supplies cooling or heating air to a zone in sufficient quantity to meet the zone load. This selection works well with the single zone model, as both minimize simulation time.

CSP #10: Building Orientation

Building orientation is another design parameter that is not interrelated with other parameters, though in reality, it has a large impact on building energy performance. For simplicity, and to minimize the number of simulations, all Toronto Pilot buildings have a true north/south orientation. Future expansion to this project should add multiple orientations to investigate their affect on simulated building performance.

CSP #11: Shading

All glazing in the Toronto Pilot has external shading that is controlled by cooling demand. While it would be informative to include various shade locations, shading control mechanisms, and shading types in the simulation, the simplicity of the Toronto Pilot dictated that these be left for future studies. Since it has been shown that automatic external shading saves operational energy (Tzempelikos, 2007), the default for all simulations was to include shading.

CSP #12: Sheltering

Each Toronto Pilot simulation is modeled as a single detached home, with no external shelter present. This model was chosen for its simplicity, but in the future, the sheltering effects of adjacent buildings and foliage could be added to better simulate building performance in an urban setting.

CSP #13: North Window to Wall Ratio

North windows were assumed to always be net energy losers throughout the heating season, and thus were left at a constant 10% wall area. This assumption may not always be valid, and could be validated through future applications of the Full Scope method.

3.4.2 - Manipulated Simulation Parameters (MSP)

A summary of the manipulated simulation parameters can be found in Table 2, below. The detailed explanation and validation of the selected parameter values follows.

Table 2 - A Summary of the Manipulated Simulation Parameters within the Toronto Pilot. For MSP#1, 'w/ B' denotes with basement, and 'w/o B' denotes without basement.

MSP #1: Number of Stories					
Number of Permutations	Possible Values:				
6	1 w/ B	2 w/ B	3 w/ B		
	1 w/o B	2 w/o B	3 w/o B		
MSP #2: Total Floor Area (including basement)					
Number of Permutations	Possible Values:				
5	1000ft^2 (93m^2)	1500ft^2 (139m^2)	2000ft^2 (186m^2)	3500ft^2 (325m^2)	5000ft^2 (465m^2)
MSP #3: Shape Ratio W:L					
Number of Permutations	Possible Values:				
3	0.75	1	1.25		
MSP #4: East/West Window to Wall Ratio					
Number of Permutations	Possible Values:				
3	10%	30%	50%		
MSP #5: South Window to Wall Ratio					
Number of Permutations	Possible Values:				
4	10%	30%	40%	60%	
MSP #6: Window Performance Level					
Number of Permutations	Possible Values:				
5	101	102	103	104	105
MSP #7: Thermal Insulation Level [RSI]					
Number of Permutations	Possible Values:				
10	2.5	5	7.5	10	12.5
	15	17.5	20	22.5	25
MSP #8: Air Tightness [ACH@50Pa]					
Number of Permutations	Possible Values:				
5	10	5	2.5	1	0.25
MSP #9: Thermal Mass [mm concrete]					
Number of Permutations	Possible Values:				
4	0.01	50	150	300	
Total Number of Design Permutations					
1080000					

MSP #1: Number of Stories

The selection of 1-3 stories, with and without basement is based upon the common existence of these single detached home configurations in Toronto. Any design involving a 4th floor requires 'Part 6' design and engineer sealing, by the 2006 Ontario Building Code, and thus it is less common to build a 4th floor (Ontario Ministry of Municipal Affairs and Housing-Building and Development Branch, 2008).

MSP #2: Total Floor Area

The five floor area sizes were based around the average single detached home size in Canada being 141m^2 (National Resources Canada, 2008). From this average, one smaller and two larger home sizes were included, to focus more on the effect that having a much larger than average home has on lifetime energy consumption. Total floor area is strictly define in the Toronto Pilot using the following relationship:

```
Single Floor Area = Total Floor Area / (Num Stories + Basement)
```

This inclusion of the basement in the Total Floor Area is important to keep in mind.

MSP #3: Building Shape Ratio

The selection of three shape ratios, or width:length ratios, is a balance between minimizing the total number of simulations, while still capturing the effect of variable exposure to the south. For the Toronto Pilot, width is measured in the East to West direction, meaning that a design with a shape ratio of 0.75, has an East-West dimension equal to:

```
Width = sqrt[total area/(# floors + # basement)]*(0.75)
```

While the resulting length, or North-South dimension equals:

```
Length = sqrt[total area/(# floors + # basement)]/(0.75)
```

MSP #4 and 5: Window:Wall Ratios

The Window to Wall ratio of Toronto Pilot simulations presented the most difficult compromise between increased model inclusion with a larger scope and minimizing the total number of simulations. There is little research on the conclusive effects of varied window size, on each exposure, on overall lifetime energy consumption. Just looking at the operational energy component, there exist situations where a window on any exposure can be a net energy loss or a net energy gain over a yearly simulations, depending on the climate, the window size, the window performance, the orientation and shading of the house, etc (Passive House Planning Package, 2007). The ideal data range to investigate this phenomenon would be to include 5 values, 10%, 30%, 50%, 70%, and

90%, independently for each exposure. But this results in a permutation multiplier of 625, which drastically increases the total number of project simulations. As a result, the values selected for the Toronto Pilot represent a heavy compromise, based upon an educated guess that gives weight to the window exposures and window sizes that would have the largest effect on the lifetime energy consumption. It was assumed that East and West windows could be most accurately coupled in size, the North has the least effect and is generally a net-loser of operational energy, and finally, that the South windows have the strongest effect. Expanding the scope to include a full range of window sizes could validate these assumptions, or provide insight into a better parameter definition.

MSP #6: Window Performance Level

The Toronto Pilot includes 5 different glazing constructions, defined in Table 3:

Table 3 - Summary of Glazing construction types for Toronto Pilot.

Construction	U-Value [W/m2K]	Glazing Construction (inside -> outside)
101	5.4	Single glazed, clear glass
102	3.15	Double glazed, clear glass, air filled
103	1.803	Double glazed, interior pane LowE, Krypton gas filled
104	0.995	Triple glazed, interior pane LowE, Krypton gas filled
105	0.447	Quadruple glazed, interior pane LowE, Krypton gas filled

These window constructions have been selected based upon the following assumptions: 1) single glaze windows are the worst available, but still exist in some old buildings; 2) double glazed windows have become the industry norm (National Resources Canada, 2003); 3) as the simulation parameters include extremely high insulation levels, up to RSI 25, the best windows possible must also be included; 4) RSI 2.2 is approximately the highest performance glazing that's currently available in Europe (Passive House Planning Package, 2007). Window frames were omitted from the Toronto Pilot for simplicity, and to keep the window RSI value uniform over the entire rough opening area. Multiple frame performance values should be included in future expansions to the type of optimization project.

MSP #7: Thermal Insulation Level

The Toronto Pilot project focuses on the impact of extremely high levels of thermal insulation, and thus includes the most insulation performance values of any parameter. To simplify the process, and reduce the total number of simulations, the ratio of insulation level between slab, sub-grade walls, above-grade walls, and exposed ceiling was held constant, based on the ratio found in the 2006 Ontario building code. This ratio is explained in Table 4, below. If the project were expanded in the future, it would be interesting to remove this fixed insulation ratio, and calculate the influence of various ratios, or even independent thicknesses, on the overall lifetime performance of buildings.

Table 4 - Summary of Thermal Insulation Ratio between insulation locations on Toronto Pilot. (Ontario Ministry of Municipal Affairs and Housing-Building and Development Branch, 2008)

Location	2006 OBC Ratio	Normalized OBC	Simulation RSI=25
Slab	1.76	0.25	6.29
Foundation Wall	2.11	0.30	7.54
Exposed Wall	3.34	0.48	11.93
Exposed Ceiling	7	1.00	25.00

MSP #8: Air Infiltration

In selecting the range of building air tightness, it is useful to refer to the various 'Green' building standards. The German standard, PassivHaus requires less than 0.6 ACH@50Pa, while the Canadian R-2000 standard requires less than 1.5 ACH@50Pa, and LEED Homes requires less than 2 ACH@50Pa (PHIUS, 2010)(Natural Resources Canada, 2005)(USGBC, 2008). With these levels in mind, and also including worse performance numbers to represent existing buildings, the selected range includes 10, 5, 2.5, 1, and 0.25 [ACH@50Pa]. Since EnergyPlus requires infiltration levels to be inputted at 1Pa pressure difference, Sherman's approximate relationship can be used to convert from results measured at 50Pa pressure difference:

```
ACH@1Pa = ACH@50Pa/15                    (Sherman, 1987)
```

Thus the range of infiltration at 1Pa pressure difference is 0.667, 0.334, 0.167, 0.067, and 0.017, converted into EnergyPlus's required format.

MSP #9: Thermal Mass

Within a building envelope, thermal mass can have a mitigating effect on extreme temperature swings, by storing energy during heating periods, and releasing energy during cold periods that follow (Childs, 1983). The range of thermal mass in Canadian building stock varies, from light-weight wood frame homes, to wood frame homes with brick veneer, to the older structural brick buildings common in Toronto, to massive homes built with renewed interest in Rammed Earth construction, on Salt Spring Island

(SIREWALL, 2010). An easy method of including thermal mass within an EnergyPlus simulation envelope is to add a layer of concrete to all exterior surfaces. To emulate the four scenarios described above, the Toronto Pilot simulations include a range of uniform concrete thermal mass layers of 4 thicknesses: 0.01mm, 50mm, 150mm, and 300mm. Energyplus cannot handle materials of zero thickness, so the 0.01mm value is used to approximate a very low thermal mass scenario.

3.5 - Amazon EC2 Processing Cloud

The Full Scale Optimization method is only now feasible for low-budget projects because of recent developments in online cloud processing power by Amazon Web Services. Working from a personal computer, one can create and instantaneously control virtual supercomputer clusters, from any Internet connection, that work dynamically to meet the user's needs, all at a low price. In the context of building optimization, a sample project might include 10 design parameters each with 10 discrete values. This translates into 10^10, or 10 000 000, total design permutations. Since an EnergyPlus simulation takes approximately 30s-1min to run on a single 2.5GHz processor (author's testing), this equates to approximately 14 years of single core computational time. This 14 year single core time could be reduced to a month if 168 virtual cores were rented from Amazon, for a total processing cost of approximately $10 300 (Amazon Web Services, 2010).

For the Toronto Pilot, with 1 080 000 design permutations, the processing power of three Amazon '`High-CPU On-Demand Instances`' was harnessed, which is the combined power of 24 virtual processing cores, each with 2.5 'compute units', or 2.5 times the processing power of a 1.0-1.2 GHz 2007 Opteron processor (Amazon Web Services, 2010). Each of these instances can be rented for $0.68/hour on a LINUX platform, or $1.16/hour on a Windows platform. To save costs and to better interact with the author's Apple laptop, the LINUX platform was used for the pilot, which required the author to learn basic UNIX navigation and file manipulation scripts. The total 1 080 000 simulations were randomly broken down into twenty-four 45 000 simulation subsets to parallelize the simulation process over the twenty-four Amazon virtual cores. The specific EC2 methodology is laid out in detail in Section 4.2.

3.6 - Athena Impact Estimator for Buildings

The Athena Institute is a non-profit organization seeking to improve the sustainability of the built environment by meeting the building community's needs for better information and tools (The Athena Institute, 2010). The Athena Institute has developed the Impact Estimator for Buildings, which is the only tool in North America for the life cycle assessment of whole buildings and assemblies (The Athena Institute, 2010). The Impact Estimator was the source of the embodied data for the Toronto Pilot. This data, detailed in section 3.6.1, was used to calculate the embodied energy of the 'operational energy dependent' materials present in each of the Toronto Pilot's design permutations.

3.6.1 - Embodied Parameters (EP)

This section presents the scope of Embodied Energy sources included in the Toronto Pilot. As discussed previously, only those parameters affecting operational energy consumption are included in the analysis.

EP #1: Insulation Type

A summary of the six different insulation types, and performance data, included in the Toronto Pilot is shown below in Table 5.

Table 5 - Summary of embodied energy data for Toronto Pilot Insulation types (ASHRAE, 2005)(Athena Impact Estimator for Buildings, 2010).

Insulation Type	RSI/100mm	Embodied Energy [kWh/ m^3]
Loose Fill Cellulose	2.38	26.00
Fiberglass Batt	2.50	186.82
Rockwool Batt	2.56	316.68
Expanded Polystyrene	2.70	446.82
Polyisocyanurate	5.00	720.65
Extruded Polystyrene	3.45	893.02

As discussed previously, RSI-value alone was manipulated in Toronto Pilot simulations. The RSI value can then be converted to an equivalent thickness of each insulation type and corresponding magnitude of embodied energy, using the above data.

EP #2: Building Lifetime

The estimated building lifetime has a profound influence on any Life Cycle Analysis, as it directly sets the balance between operational and embodied contributions.

Lifetime is also easy to manipulate within an LCA calculation, at any time, as shown in the equation below:

```
Lifetime Consumption = Lifetime*Operational + Embodied
```

The example results analysis for the Toronto Pilot investigates the effect of a 50-year and 100 year building lifetime. While these lifetimes are longer than Canadian homes tend to last, as only 12.5% of the existing single detached housing stock in Canada is older than 60 years (Natural Resources Canada, 2007), our known ability to build long-lasting buildings (Gonzalez, 1999) and environmental due diligence suggest that buildings should be designed to last longer than they currently are. Future analysis of the Toronto Pilot should include a more in-depth look at the effects of building lifetime on lifetime energy consumption.

EP #3: Window Glazing

Since window frames were not included in the Toronto Pilot simulation set, the embodied energy of each construction is simply that of the glazing. Using the Athena Impact Estimator, the area-based embodied energy of each glazing type was calculated, the summary of this is shown in Table 6, below.

Table 6 - Summary of window glazing embodied energy for Toronto Pilot (Athena Impact Estimator, 2010)

Window Type	Construction Summary	Embodied Energy [kWh/m2]
101	Single glaze, plain	28.81
102	Double glaze, plain	57.62
103	Double glaze, lowE, krypton	57.75
104	Triple glaze, lowE, krypton	86.63
105	Quad glaze, lowE, krypton	115.50

EP #4: Thermal Mass

In the Toronto Pilot, thermal mass is modeled as a skin of 20 MPa concrete, with varied thickness, on the interior side of the insulation on all exposed surfaces. The embodied energy of this concrete layer can be found by multiplying the total volume of concrete in each design by the unit embodied energy, 482.8 kWh/m^3, for the Toronto local (Athena Impact Estimator, 2010).

EP #5: Fuel Type

The site operational energy usage estimated by simulation does not include in the energy and material usage consumed to deliver this energy to site. The Athena Institute has calculated the total lifetime energy consumption, or primary energy, of electricity and natural gas consumed in Ontario. For every kWh of electricity used on site, 2.03 kWh of primary energy are consumed (Athena Impact Estimator, 2010). Similarly, every kWh of natural gas that is burned in Ontario actually consumes 1.08 kWh of primary energy (Athena Impact Estimator, 2010). Both of these scenarios are included in the Toronto Pilot database, to represent two of the available heating options in Toronto.

3.7 - FileMaker Pro Database

The Python coding language and UNIX terminal interface were highly useful tools for generating and manipulating the millions of files and data involved with the Full Scale optimization method, but neither is highly effective at generating visual representation or results analysis of massive data sets. All relevant input and results parameters were written into a tab-delimited text file, which was fed into FileMaker Pro to create a database. This database is a massive, dynamic spreadsheet, with columns for each important parameter, and 1 080 000 rows that contain the full definition and calculated performance of each design scenario.

An initial database was built to include the input parameters and operational performance results from simulation. Additional columns were added to include the selected embodied energy factors and to calculate the total lifetime energy consumption of each unique situation. FileMaker Pro was used to generate the graphical results presented in Chapter 5.

Chapter 4 - Detailed Pilot Methodology

This chapter presents a step-by-step overview of a pilot execution of the Full Scale design optimization method. The specific scope of optimization parameters was discussed in Chapter 3; this chapter explains the mechanics of the method so that it may be repeated or expanded upon in the future. All developmental work was completed on the author's 2008 Macbook Pro, outfitted with a dual core 2.4GHz processor, and 4Gb memory. The fundamental UNIX platform that the Macs are built on made interacting with Amazon's LINUX platform very smooth. The Mac's Terminal UNIX interface was also highly useful for manipulating the millions of text files involved with the method; one cannot 'drag and drop' or visually scroll through directories with this scope. For future work, the continued usage of a Macintosh platform is highly recommended over a Windows environment for these reasons.

4.1 - Python Driven EnergyPlus

4.1.1 - Learning Python

At the onset, the author had minimal computer coding experience, having only learned the basics of the C++ and Matlab languages during mechanical engineering coursework in undergraduate studies. As mentioned in Chapter 3, Python, version 3, was selected for this thesis work as it provides a full scope of technical code modules and is freely available. The author learned the Python basics by working through various online material and tutorials, but the best sources were the 'Dive Into Python 3' and the main Python website (Pilgrim, 2010)(Python Software Foundation, 2010). The language is very powerful, highly object oriented, based upon tabbed hierarchy, and thus quite user-friendly compared to older languages.

4.1.2 - Generating Permutations

After attaining basic function skills in Python, the first step was to develop conceptual code that could take a set of parameters, each with a number of discrete values, and reliably generate every possible combination of these parameters. After a number of revisions, the Python file `permutationsR2.py` achieved this goal. Shown below in Figure 9, the first section of `permutationsR2.py` defines 5 hypothetical design parameters and a range of discrete values for each.

```
#def permutations():

time = (0,1,2, 3, 4)
location = ('toronto', 'edmonton', 'calgary', 'los angelos')
insulation = (10,20,30,40,50,60,70,80)
climate = ('arid', 'temperate', 'moderate', 'wet', 'saucy')
insulationtype = ('xps', 'eps', 'wool', 'cellulose', 'batt', 'rockwool', 'sprayfoam', 'cotton')

mm = (time,location,insulation,climate,insulationtype)
n = 0
numperm = 1
```

Figure 9 - Python code excerpt #1 from `permutationsR2.py`, the definition of a hypothetical list of parameters and parameter values.

Next, the array, `mm`, is populated with the full scope of parameters and values. The specific parameter names and discrete values can be returned from `mm`, by calling `mm[parameter#][value#]`. The values `n` and `numperm` are then defined, and will be used as indexing parameters in the code that follows. Figure 10 below, shows code that calculates the total number of unique permutations that can be generated from the input parameters/values, and then prints this number for visual verification.

```
# Figure out how many permutations there are?

counter = list(range(len(mm)))

for i in counter:
    counter[i] = len(mm[i])

for s in counter:
    numperm = numperm*s

print("number of permutations = {0}".format(numperm))
```

Figure 10 - Python code excerpt #2 from `permutationsR2.py`, showing calculation of total number of permutations possible from master array `mm`, defined in Figure 9.

Finally, a set of nested 'for' loops runs through each parameter's value list, and populates the `permutation` array with the permutation number, followed by the unique combination of input values. This code portion is shown in Figure 11, below.

```
# Generate permutations

permutation = list(range(numperm))

for elem in list(range(len(mm[0]))):
    for part in list(range(len(mm[1]))):
        for chunk in list(range(len(mm[2]))):
            for piece in list(range(len(mm[3]))):
                for sliver in list(range(len(mm[4]))):
                    permutation[n] = (n,mm[0][elem],mm[1][part],mm[2][chunk],mm[3][piece],mm[4][sliver])
                    n = n+1

#for s in permutation: print(s)
print(permutation)
```

Figure 11 - Python code excerpt #3 from `permutationsR2.py`, showing the generation of permutations from list of parameters and values in Figure 9.

The `permutation` array produced by this code becomes the master list, and can be used to write virtually any information about the combination of design parameters. It was important to test this code on a small scale, so that the results could be validated first by hand calculating the number of permutations, and then visually certifying that each permutation was indeed present and error-free. Once this process is scaled up, the volume of data become too great to manually validate in any way. This was an important lesson, that operations with the Full Scale method require automated validation and inspection techniques.

4.1.3 - Automating EnergyPlus

4.1.3.1 - EnergyPlus Execution from Python

After creating the permutation generation code, the next step was to determine how to control an EnergyPlus execution from a Python file, as the vast number of simulations required in the Full Scale method cannot be run manually. Shown in Figure 12 below, the `Popen` module in Python presented the solution. The actual EnergyPlus executable is `runenergyplus`, which can be found in the `bin` folder of the installation. This code requires the EnergyPlus input file name as an argument, in the format `/filelocation/name.IDF`, which is embedded below in the `currentIDF` variable. The weather file must be defined in a similar fashion, `/filelocation/weathername.EPW`. The Toronto weather file did not come with the default EnergyPlus V4 installation, and was downloaded from the main EnergyPlus website (US. Department of Energy, 2010). Finally, the simulation results are generated in an `output` folder in the same location as the input `.IDF`.

```
from subprocess import Popen
Popen( "/usr/local/bin/runenergyplus        '/thesis/run1/{0}' '{1}' "
<B>.format(currentIDF, weatherfile,) , shell=True).wait()
```

Figure 12 - Python code required to execute EnergyPlus, <B> denotes a line broken to aid in visualization, and must be unbroken for execution.

4.1.3.2 - EnergyPlus .IDF Generation

Once it was proven possible to generate permutations and execute EnergyPlus from Python code, the next step was to define a basic simulation `.IDF` to be the constant for all Toronto Pilot simulations, and then embed the manipulated simulation parameters within this `.IDF` file. Without prior experience with EnergyPlus, the author began by generating a sample `.IDF` file using the DesignBuilder, a graphical user interface for EnergyPlus. Using a basic text editor, the author dissected this `.IDF` file's code using EnergyPlus' Engineering Reference. The EnergyPlus code language was slowly understood as each section of the foundation `.IDF` was rewritten to suit the Toronto Pilot project. Once the basic `.IDF` layout was complete, it was dropped into Python code as one large character string. This Python code file is named `CreateIDF.py`, and is the main `.IDF` generation executable for the Toronto Pilot. From this point, the manipulated parameters were defined in Python code, shown in Figure 13 below, modeled after the method shown in Figure 9.

```
# Building Parameter Definition and Range:

NumStories = [1,2,3]
Basement = [0,1]                                        # 1 = basement, 0 = no basement
TotalArea = [92.9,139.4,185.8,325.2,464.5]              # Square Meters
ShapeRatio = [0.75,1,1.25]                              # South Facade Width = ShapeRatio*squareDim
SouthWinWallRatio = [0.1,0.3,0.5,0.6]                   # %area window to wall
EastWinWallRatio = [0.1,0.3,0.5]                        # %area window to wall
NorthWinWallRatio = [0.1]                               # %area window to wall
WindowPerform = [101,102,103,104,105]                   # Construction names in IDF
Infiltration = [0.667,0.334,0.167,0.067,0.01667]        # Levels at 1Pa pressure drop (10,5,2.5,1,0.25 @ 50Pa)
ThermalMass = [0.00001,0.05,0.15,0.3]                   # Thickness of concrete in [m]

RSIvalue = [2.5,5,7.5,10,12.5,15,17.5,20,22.5,25]       # [Km2/W]
ThermConductivity = 0.035                               # [W/mK]
InsulThickness = [i*ThermConductivity for i in RSIvalue] # Insulation thickness in [m], for dense polystyrene
```

Figure 13 - Python code excerpt #1 from `Create.IDF`. Toronto Pilot manipulated simulation parameter definition.

Those manipulated simulation parameters that were value-based, such as thickness of insulation, were quite simple to embed using Python's string manipulation tools. Those parameters that affected the building's geometry were more difficult, as each value requires the manipulation of a whole block of EnergyPlus code, which itself has embedded values. To remedy this, the EnergyPlus geometry definition was separated into another Python executable, named `SubFunction.py`, that houses all of the unique geometry code blocks required and embeds the various values that must be fed into each block. This `SubFunction.py` is slave to by the master `CreateIDF.py` executable, called when geometry code is required.

EnergyPlus defines building geometry as a construction of surfaces. A box shape is defined by six, edge-mated surfaces, and each surface is defined via 4 vertices. Windows or doors are defined as sub-surfaces within a main surface, again via a 4 vertex input. Thus to dynamically modify building size, shape, and number of stories, the definition of these surfaces for each simulation was complex. The `SubFunction.py` file contains three main sections: a calculation section, a basement geometry section and an aboveground building geometry section. The initial calculation section is shown below in Figure 14.

```
def GeometryFunction(NumStories, Basement, TotalArea, ShapeRatio, SouthWinWallRatio,
                     <B> EastWinWallRatio, NorthWinWallRatio, WindowPerform):
    """This function generates the geometry dependent Zone information for your IDF"""

    import math

    FloorArea = 1

    if Basement == 1:

        FloorArea = TotalArea/(NumStories + 1)

    if Basement == 0:

        FloorArea = TotalArea/NumStories

    SquareDim = math.sqrt(FloorArea)
    Width = SquareDim*ShapeRatio
    Length = SquareDim/ShapeRatio
    OverHang = 0.75
    OverWidth = Width + OverHang
    OverLength = Length + OverHang
    HalfWidth = Width/2
    HalfLength = Length/2
    Height = 3                    #only number defined in this function
    SecondHeight = 2*Height
    ThirdHeight = 3*Height

    if NumStories == 1:
        PeakHeight = Height + 4.5
        RoofHeight = Height + 0.350

    if NumStories == 2:
        PeakHeight = SecondHeight + 4.5
        RoofHeight = SecondHeight + 0.350

    if NumStories == 3:
        PeakHeight = ThirdHeight + 4.5
        RoofHeight = ThirdHeight + 0.350

    WinHeight = 0.75*Height
    WinVertOffset = 0.125*Height

    FirstFlrShortDim = WinVertOffset
    FirstFlrTallDim = FirstFlrShortDim + WinHeight
    SecondFlrShortDim = Height + WinVertOffset
    SecondFlrTallDim = WinHeight + SecondFlrShortDim
    ThirdFlrShortDim = 2*Height + WinVertOffset
    ThirdFlrTallDim = WinHeight + ThirdFlrShortDim

    SouthWinArea = SouthWinWallRatio*Width*Height
    SouthWinWidth = SouthWinArea/WinHeight
    SouthWinShortDim = (Width-SouthWinWidth)/2
    SouthWinLongDim = SouthWinShortDim + SouthWinWidth

    EastWinArea = EastWinWallRatio*Length*Height
    EastWinLength = EastWinArea/WinHeight
    EastWinShortDim = (Length-EastWinLength)/2
    EastWinLongDim = EastWinShortDim + EastWinLength

    NorthWinArea = NorthWinWallRatio*Width*Height
    NorthWinWidth = NorthWinArea/WinHeight
    NorthWinShortDim = (Width-NorthWinWidth)/2
    NorthWinLongDim = NorthWinShortDim + NorthWinWidth
```

Figure 14 - Python Code excerpt #1 from 'SubFunction.py', showing the definition of geometry parameters from input values, which are used to dynamically generate EnergyPlus geometry code. All numbers have units of [m], and <B> denotes a line broken for ease of visualization.

This calculation section takes the input values fed into the function and calculates general geometry parameters such as: 1), storey height, length, and width; 2), each exposure's window height and length; and 3), roof peak height, eave shading overhang, and pitch. Through these parameters, the surfaces of every building configuration can be dynamically defined, via a few input values.

Recall that the Toronto Pilot includes 1, 2, and 3 storey options, all with and without a basement. In the basement code section of `SubFunction.py`, `if-else` statements define two separate blocks of basement code. One block is for the scenario of no basement, containing only a floor-on-grade surface definition that mates with the walls of the first floor. The second block defines the 5 surfaces of the basement: a below-grade floor and four foundation walls. Similarly, `if-else` statements define three separate aboveground geometries, one for each number of possible stories. The roof is included in the aboveground geometry, with surfaces mated to the appropriate storey's ceiling. Thus when `CreateIDF.py` calls `SubFunction.py`, the current permutation values are fed into `SubFunction.py`, and the appropriate Energyplus geometry code is returned as text. A sample of the basement geometry generation logic is shown on the following page, in Figure 15. In this figure, the input parameters `Width`, `Length`, and `Height` are embedded within the text using Python's string format function which embeds the value of `Width` everywhere it finds `{0}` within the preceding text, `Length` for `{1}`, and `Height` for `{2}`. All values were dynamically embedded within the EnergyPlus code using this string format technique. During the development of this technique, the author had a frustrating moment of realization that EnergyPlus .IDF files are riddled with units denoted as `{m}`, `{l/s}`, etc. Thus to use Python's string formatting to embed values, the .IDF files must be rid of extraneous curly `{}` brackets. The author replaced them with square `[]` brackets using an extensive search and replace operation.

```
if Basement == 1:

    BasementIDF = """   ! Basement, Basement, Ground floor

BuildingSurface:Detailed, S_208_0_0_0,         !- Surface name

   Floor, 1,                                   !- Class and Construction Name
   208,                                        !- Zone Name
   Ground, ,                                   !- Outside Face Environment
   NoSun,                                      !- Sun Exposure
   NoWind,                                     !- Wind Exposure
   1,                                          !- View Factor to Ground
   4,                                          !- Number vertices
    {0},0,-{2},               !- Vertex 1
    0,0,-{2},                 !- Vertex 2
    0,{1},-{2},               !- Vertex 3
    {0},{1},-{2};             !- Vertex 4


! Basement, Basement, East Wall

BuildingSurface:Detailed, W_208_2_0_0,         !- Surface name

   Wall, 2,                                    !- Class and Construction Name
   208,                                        !- Zone Name
   Ground, ,                                   !- Outside Face Environment
   NoSun,                                      !- Sun Exposure
   NoWind,                                     !- Wind Exposure
   .5,                                         !- View Factor to Ground
   4,                                          !- Number vertices
    {0},0,-{2},               !- Vertex 1
    {0},{1},-{2},             !- Vertex 2
    {0},{1},0,                !- Vertex 3
    {0},0,0;                  !- Vertex 4

! Basement, Basement, North Wall

BuildingSurface:Detailed, W_208_3_0_0,         !- Surface name
```

```
   Wall, 2,                                    !- Class and Construction Name
   208,                                        !- Zone Name
   Ground, ,                                   !- Outside Face Environment
   NoSun,                                      !- Sun Exposure
   NoWind,                                     !- Wind Exposure
   .5,                                         !- View Factor to Ground
   4,                                          !- Number vertices
    0,0,-{2},                 !- Vertex 1
    {0},0,-{2},               !- Vertex 2
    {0},0,0,                  !- Vertex 3
    0,0,0;                    !- Vertex 4""".format(Width, Length, Height)
```

Figure 15 - Python code excerpts #2 and #3 from `SubFunction.py`, showing logical definition of basement geometry code. Python's string formatting function is set to embed the value of the variable `Width` wherever there is a `{0}` within the preceding text, and similarly the value of `Length` for `{1}`, and `Height` for `{2}`. Thus the vertices of building surfaces can be defined dynamically.

In Figure 16 below, Python code defines the scenario of 'no basement', where the input parameter, `Basement`, does not equal `1`. In either case, with or without a basement, the string definition of the EnergyPlus basement geometry code is stored in the variable, `BasementIDF`.

```
 else: BasementIDF = """    ! 1st Floor, 1st Floor, Ground floor

BuildingSurface:Detailed, S_208_0_0_0,          !- Surface name

   Floor, 1,                                    !- Class and Construction Name
   208,                                         !- Zone Name
   Ground, ,                                    !- Outside Face Environment
   NoSun,                                       !- Sun Exposure
   NoWind,                                      !- Wind Exposure
   1,                                           !- View Factor to Ground
   4,                                           !- Number vertices
    {0},0,0,                  !- Vertex 1
    0,0,0,                    !- Vertex 2
    0,{1},0,                  !- Vertex 3
    {0},{1},0;                !- Vertex 4""".format(Width, Length, Height)
```

Figure 16 - Python code excerpt #4 from `SubFunction.py`, showing the EnergyPlus geometry code generation for the scenario where there is no basement, and only a ground floor surface must be defined.

In a similar but more complex fashion, the string definition of the aboveground geometry is stored in the variable, `UpperIDF`. A shortened example of this is shown below in Figure 18, on the following page. Within `SubFunction.py`, all six possible geometry blocks are defined. The final code line of `SubFunction.py`, shown below in Figure 17, returns both the basement geometry code and the aboveground geometry code, separated by 3 blank lines. By defining the EnergyPlus geometry code in this fashion, the user can feed any set of input parameter values into `SubFunction.py`, and simply receive the required geometry text. To expand this method beyond 3 stories, with and without a basement, additional blocks of code must be written within the `SubFunction.py` file.

```
return "{0} \n\n\n {1}".format(BasementIDF, UpperIDF)
```

Figure 17 - Python code excerpt #7 from `SubFunction.py`, showing the final return of basement and aboveground geometry text.

```
 if NumStories == 3:

     UpperIDF = """! 1st Floor, 1st Floor, East Wall
BuildingSurface:Detailed, W_220_2_0_0,              !- Surface name
   Wall, 3,                                         !- Class and Construction Name
   208,                                             !- Zone Name
   Outdoors, ,                                      !- Outside Face Environment
   SunExposed,                                      !- Sun Exposure
   WindExposed,                                     !- Wind Exposure
   .5,                                              !- View Factor to Ground
   4,                                               !- Number vertices
    {0},0,0,                  !- Vertex 1
    {0},{1},0,                !- Vertex 2
    {0},{1},{2},              !- Vertex 3
    {0},0,{2};                !- Vertex 4

   ! East Window
   FenestrationSurface:Detailed, W_220_2_0_0_0_0_Win,  !- Window name
      Window,                                       !- Class
      {3},                                          !- Construction Name
      W_220_2_0_0,                                  !- Base surface
      ,                                             !- corresponding other window subsurface
      .5,                                           !- View Factor to Ground
      1111,                                         !- Window shading control
      ,                                             !- Frame divider name
      1,                                            !- Multiplier
      4,                                            !- Number vertices
       {0},{6},{10},              !- Vertex 1
       {0},{7},{10},              !- Vertex 2
       {0},{7},{11},              !- Vertex 3
       {0},{6},{11};              !- Vertex 4

! 1st Floor, 1st Floor, North Wall
BuildingSurface:Detailed, W_220_3_0_0,              !- Surface name
```

```
  ! Roof 1, Roof, South External roof
  BuildingSurface:Detailed, R_265_6_0_0,            !- Surface name
     Roof, 6,                                       !- Class and Construction Name
     265,                                           !- Zone Name
     Outdoors, ,                                    !- Outside Face Environment
     SunExposed,                                    !- Sun Exposure
     WindExposed,                                   !- Wind Exposure
     .067,                                          !- View Factor to Ground
     3,                                             !- Number vertices
      0,0,{21},                  !- Vertex 1
      {0},0,{21},                !- Vertex 2
      {23},{24},{22};            !- Vertex 3

  ! Roof 1, Roof, West External roof
  BuildingSurface:Detailed, R_265_7_0_0,            !- Surface name
     Roof, 6,                                       !- Class and Construction Name
     265,                                           !- Zone Name
     Outdoors, ,                                    !- Outside Face Environment
     SunExposed,                                    !- Sun Exposure
     WindExposed,                                   !- Wind Exposure
     .067,                                          !- View Factor to Ground
     3,                                             !- Number vertices
      0,{1},{21},                !- Vertex 1
      0,0,{21},                  !- Vertex 2
      {23},{24},{22};            !- Vertex 3""".format(Width, Length, Height,
<B>WindowPerform, SouthWinShortDim, SouthWinLongDim, EastWinShortDim, EastWinLongDim,
<B>NorthWinShortDim, NorthWinLongDim, FirstFlrShortDim, FirstFlrTallDim, SecondFlrShortDim,
<B>SecondFlrTallDim, ThirdFlrShortDim, ThirdFlrTallDim, SecondHeight, ThirdHeight, OverHang,
<B>OverWidth, OverLength, RoofHeight, PeakHeight, HalfWidth, HalfLength)
```

Figure 18 - Python code excerpts #5 and #6 from `SubFunction.py`, showing a sample of the more complex logical definition of aboveground floor geometry. Here, in the three-storey example, 25 input parameters are embedded within the text, so that their value may be dynamically changed.

With the dynamic geometry issue solved, all of the manipulated simulation parameters were embedded within the main `CreateIDF.py` execution file, by combining all of the methods discussed in this section to this point. A broken sample of this method follows, in Figure 19.

```
    # Generate permutations

    permutation = list(range(numperm))
    permtext = list(range(numperm))

    for a in list(range(len(mm[0]))):
        for b in list(range(len(mm[1]))):
            for c in list(range(len(mm[2]))):
                for d in list(range(len(mm[3]))):
                    for e in list(range(len(mm[4]))):
                        for f in list(range(len(mm[5]))):
                            for g in list(range(len(mm[6]))):
                                for h in list(range(len(mm[7]))):
                                    for i in list(range(len(mm[8]))):
                                        for j in list(range(len(mm[9]))):
                                            for k in list(range(len(mm[10]))):

                                                InsulationSlab = mm[9][j]*0.251
                                                #0.251:0.301:0.477:1 normalized OBC2006 slab:found:expwall:expceil
                                                InsulationFound = mm[9][j]*0.301
                                                InsulationWall = mm[9][j]*0.477
                                                InsulationCeiling = mm[9][j]

                                                permutation[n] = [str(n).zfill(7),mm[0][a],mm[1][b],mm[2][c],
                                                <B>mm[3][d],mm[4][e],mm[5][f],mm[6][g],mm[7][h],mm[8][i],InsulationSlab,
                                                <B>InsulationFound,InsulationWall,InsulationCeiling,mm[10][k]]

                                                Geometry = GeometryFunction(mm[0][a],mm[1][b],mm[2][c],mm[3][d],mm[4][e],
                                                <B>mm[5][f],mm[6][g],mm[7][h])

                                                #Create IDF's
                                                IDFText = """! File originally generated by DesignBuilder - 2.0.4.002

!- Thesis Simulation Trial #: {0}

Version,4.0;

RunPeriod,
    ,                                   !- Name
    1,                                  !- Begin Month
    1,                                  !- Begin Day of Month
    12,                                 !- End Month
    31,                                 !- End Day of Month
    UseWeatherFile,                     !- Day of Week for Start Day
    No,                                 !- Use Weather File Holidays and Special Days
    No,                                 !- Use Weather File Daylight Saving Period
    Yes,                                !- Apply Weekend Holiday Rule
```

```
    40,                                 !- Maximum Outdoor Temperature [C]
    ,                                   !- Maximum Outdoor Temperature Schedule Name
    40;                                 !- Maximum Wind Speed [m/s]


    {7}


! - Basement Surfaces Output
Output:Variable, S_208_0_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_208_2_0_0, Opaque Surface Inside Face Conduction, monthly;
```

```
    Until: 17:00,1,                     !- Field 17
    Until: 24:00,1,                     !- Field 19
    Through: 31 December,               !- Field 21
    For: AllDays,                       !- Field 22
    Until: 05:00,0,                     !- Field 23
    Until: 09:00,0,                     !- Field 25
    Until: 17:00,0,                     !- Field 27
    Until: 24:00,0;                     !- Field 29 """.format(permutation[n],permutation[n][9],permutation[n][10],
                                                <B>permutation[n][11],permutation[n][12],permutation[n][13],
                                                <B>permutation[n][14],Geometry,permutation[n][8])

                                                print('making IDF #{0}'.format(n))
                                                #Create new IDF file
                                                currentIDF = '{0}_{1}_{2}_{3:.1f}_{4:.2f}_{5:.1f}_{6:.1f}_{7:.1f}'
                                                <B>'_{8}_{9:.5f}_{10:.3f}_{11:.3f}_{12:.3f}_{13:.3f}_{14:.5f}.idf'
                                                <B>.format(permutation[n][0],permutation[n][1],permutation[n][2],
                                                <B>permutation[n][3],permutation[n][4],permutation[n][5],permutation[n][6],
                                                <B>permutation[n][7],permutation[n][8],permutation[n][9],permutation[n][10],
                                                <B>permutation[n][11],permutation[n][12],permutation[n][13],permutation[n][14],)

                                                permtext[n] = currentIDF
                                                notf = open('/thesis/runsR1/{0}'.format(currentIDF), 'w')
                                                notf.write(IDFText)
                                                notf.close()
                                                n = n + 1
```

Figure 19 - Python code excerpts #2,3,4 from `CreateIDF.py`, giving an overview of the permutation generation method used in the Toronto Pilot. <B> denotes a broken line, which must be repaired before code is executable.

The Python code presented in Figure 19 can be explained as a basic flow of logic:

"Index through the master array, once for each combination of parameter and value. At each step, take this block of IDF text, and embed this step's parameter values, including the geometry text from `SubFunction.py`. *Open a new file with the name of the current permutation and write the IDF text to it. Close this file, and proceed to the next step. Repeat until all possible permutations are covered, and each has generated a unique IDF file."*

All code files are located in Appendix C and can be reviewed for more detailed process information. All EnergyPlus input files are available electronically, but require 100GB of storage space.

4.1.3.3 - Parallel Processing

Without access to a traditional, single-processor supercomputer, large-scale optimization projects inherently rely on the separation of computer processing over multiple processors. For the Toronto Pilot, which utilized 24 virtual processing cores from Amazon, the simulation calculations had to be split into 24 parallel processes. While complex methods exist to split a single calculation onto multiple processors, the simplest way to parallelize EnergyPlus simulations is to simply split the total workload into groups, and feed each group into a dedicated processor. Thus, the 1 080 000 simulations were broken down into 24, 45 000 simulation groups.

Because of the large range of input parameters in the Toronto Pilot, and especially the variable building geometry, the simulation run time varies significantly between permutations. For example, the average single storey home simulation takes about 30s, while a three storey home with basement takes about 90s to simulate, on the author's laptop. While this may seem irrelevant, if during the parallelization grouping an unbalanced percentage of slower simulations ended up together, the resulting time for this 45 000 group to simulate could double that of a balanced group. Since the Amazon Web Services instances were rented hourly, and with 8 subgroups on each of the 3 instances, one subgroup running longer would cause a whole instance, to continue running, underutilized, at great cost, after the others had finished. Thus, prior to the generation of subgroups, the master permutation array was randomized. Thus when the subgroups were sequentially drawn from this randomized master array during the execution process, each 45 000 grouping ended with a random selection of input files. This method ensured a balanced simulation time between the 24 groups, since the probability of an unbalanced random grouping of 45 000 out of 1080000 is low. This randomization was successful, and accomplished with code shown in Figure 20, which exists near the end of `CreateIDF.py`.

```
#Randomize the complete permutation array (for balanced
#processing time groups) and write it out to a globally available file
import random
random.shuffle(permtext, None, int)
count = list(range(numperm))

a = open('/thesis/run1/randarray', 'w')
for elem in count:
    a.write('{0} '.format(permtext[elem]))
a.close()
print('done rand 1')
```

Figure 20 - Python code excerpt #5 from `CreateIDF.py`, showing the randomization of the master permutation array for the purpose of generating subgroups with balanced simulation time.

Initially, 24 separate Python executables were written to concurrently pull out `.IDF` files from the same folder, simulate them, and write the output files into the same directory. Quickly this proved impossible, as EnergyPlus creates temporary files during simulation, which conflict when multiple EnergyPlus executions run concurrently from the same directory. To solve this, each EnergyPlus execution had to have its own 'silo' to work within. The second portion of code in Figure 20 shows the creation of a text file that contains a line-by-line list of the randomized permutation names. This file was copied into each of the 24 EnergyPlus processing silos, as a master dictionary of all the input file names.

An example of one of the 24 Python execution files used to control the Toronto Pilot's simulation processes is shown in Figure 21, on the following page.

```
#!/usr/local/bin/python3.1

def IDFexecutor():
    """This function executes a subset of randomized IDF files with EnergyPlus.
    <B>Req's SubFunction.py"""

    numperm = 1080000
    randarray = list(range(numperm))

    import sys
    import shutil
    import re
    from subprocess import Popen

    #Open up the randomized permutation array and read in the data
    f = open('/thesis/run1/randarray','r')
    pulldata = f.read()
    randarray = re.split(' ',pulldata)
    f.close()

    #Split permutations into 1 of 8 randomized groupings, and execute independently
    count = list(range(numperm))
    weatherfile = 'CAN_ON_Toronto_CWEC'

    count1 = count[360000:405000]
    for elem in count1:

        currentIDF = randarray[elem]

        try:
            shutil.move('/thesis/runs/{0}'.format(currentIDF), '/thesis/run1/')

            Popen( "/usr/local/bin/runenergyplus        '/thesis/run1/{0}' '{1}' "
            <B>.format(currentIDF, weatherfile,) , shell=True).wait()

        except (IOError):
            print('{0} doesnt exist'.format(currentIDF))

        except (shutil.Error):
            print('{0} is done already'.format(currentIDF))

IDFexecutor()
```

Figure 21 - Python Code from `Run1.py`, complete. This file is one of 24 run files that execute a 45 000 subset of EnergyPlus simulations in a parallel manner. This code is executing the range of 360 000 to 405 000, out of the total 1 080 000 simulations.

The code can be explained as a process of logic:

"Initialize `randarray` *as a list of length 1080000. Open the master dictionary of randomized file names and populate* `randarray` *with this list of permutation file names. Within the context of there being 1 080 000 names in* `randarray`*, index through the range of 360 000 to 405 000, step by step. For each of these steps, define the* `currentIDF` *name, physically move this* `.IDF` *file from the master directory to the local, silo directory, and simulate this* `.IDF` *using EnergyPlus. If this file doesn't exist in the master directory, or if it already exists in the silo directory, print a message saying so, and then proceed to the next step."*

4.2 - Amazon EC2 and UNIX

4.2.1 - Developing an AMI

Amazon EC2 stands for 'Elastic Cloud Computing'. This service offers virtual computing services of various performance levels for various prices, that can all be completely designed and controlled remotely through a web connection. A user creates virtual computers, called instances, by either designing their own or using an available Amazon Machine Image (AMI) to define the basic setup. An AMI varies by its instance type, operating system, and by the software and data that has been installed on it. For supercomputing applications like the Toronto Pilot, three identical instances of type `c1.xlarge`, were created using a basic 64bit LINUX-based AMI that's freely available from Amazon. The `c1.xlarge` instance type is designed for high-processing requirements and provides the user with 8 virtual cores, each capable of 2.5 'compute units' processing speed. Recall that each compute unit is the equivalent of 1.0-1.2 GHz 2007 Opteron processor (Amazon Web Services, 2010). In addition to this processing power, the `c1.xlarge` instance comes with 7GB ram, and 1690GB storage space (Amazon Web Services, 2010). Other instance types exist for different applications, such as those with higher memory to processing power ratios, or those with lesser performance for lower demand projects. For the Toronto Pilot, a single instance was first developed into the desired configuration, a new AMI was generated from this configuration, and was then two more identical instances were cloned from this AMI. Each instance required two storage volumes, a 10GB volume for the operating system and run files, and a 1TB volume to store the simulation results as they were calculated.

Interacting with a LINUX-based Amazon instance is mostly a text-based endeavor, as few graphic interfaces exist. Firefox, an open source web browser, has a highly useful and free add-on called ElasticFox, which provides a basic graphical interface for managing Amazon Instances, AMI's, and Elastic Block Storage (EBS) volumes (Amazon Web Services, 2010). Once connected to a LINUX instance, the interaction is solely through a terminal window connection, which requires knowledge of the UNIX command language. This terminal interface has a bit of a learning curve, but is quite logical and highly efficient in manipulating large processes and data volumes.

To begin the process, one can connect to a newly created Amazon EC2 instance using encrypted `ssh` connection types, after generating security key pairs through a guided Amazon process. This can be achieved using the following Terminal command, where `stufix.pem` is a security key and the IP address is that of the Amazon instance you with to connect with:

```
ssh -i /Users/stufix/AmazonEC2/MyCreds/stufixkey.pem root@174.129.77.90
```

Once connected for the first time, the basic AMI will be empty, except for a foundation of useful UNIX modules, RUBY modules, and Python modules, depending on the AMI selected. For the Toronto Pilot, two main software packages were required on the Amazon instance, EnergyPlus V4, and Python V3. Downloading software from a terminal interface is a simple as:

```
wget www.software.com/thefiletodownload
```

Once downloaded, most LINUX installation packages come as g-zipped tar files, or `filename.tar.gz`. To install, ensure that the file permissions allow for execution and then execute the file with the following command:

```
chmod +x python-3.1.2.tgz
tar -zxvf python-3.1.2.tgz
```

The installation process will begin, and the user will be prompted for inputs to control how the install proceeds. For safe install, issue the four commands in sequence, once the previous operation has completed:

```
1) configure
2) make
3) make test
4) sudo make install
```

The `configure` command sets up the process, the `make` command compiles the code into an install-ready format, the `make test` command verifies the code compilation, and finally `sudo make install` executes the installation as a "super user do" command. The EnergyPlus installation process is slightly different, as it requires a password, and is more automated.

Once Python and EnergyPlus were installed on the first instance, the next step was to upload the Toronto Pilot execution files from the author's laptop. This can be accomplished using the following UNIX command:

```
scp -i /Users/stufix/…/stufixkey.pem filename.txt root@75.101.207.28:/root
```

This command is a secure copy, using `ssh` protocols, requiring the same security key generated with Amazon. `Filename.txt` represents the file on the local machine to be uploaded, with full directory path, `root@75.101.207.28` represents the instance IP address and login name, and `:/root` is the directory location for the file to be uploaded to. After the Toronto Pilot Files were uploaded, the proper file directories had to be set up. The following UNIX commands are useful for this type of work:

```
cd      -  'current directory', type 'cd /directory/etc' to navigate
mkdir   -  'make directory', type 'mkdir /directorypath/foldertomake
cp      - 'copy', type 'cp /original/file /new/file/and/path
rm      - 'remove', type 'rm /filename' or 'rm -r /directory'
ls      - 'list objects present', type 'ls -l' for detailed listing
mv      - 'move', type 'mv /presentfilelocation&name /movedfilelocation&name
```

When using the `cp` and `mv` commands, it is imperative that the directory path and file names are carefully inputted, as the destination file can be named different than the source. During the Toronto Pilot development, the author misnamed a single copy command within a sequence, which went unnoticed until full-scale simulations were well underway. The result of the copy error was that the `Run5.py` and `Run6.py` execution files both had the contents of `Run5.py`, though they were named correctly. When simulations began, both executables tried to feed the same range of input `.IDF files` into simulation, concurrently. The two processes managed to run through about 25 000 `.IDF` files before crashing, at which point the author became aware of the problem. Even after the processes were restarted, this simple copy mistake caused a cascading chain of garbage files and clutter throughout the rest of the process, until the final database was built.

In addition, the 1000GB EBS volume created separately from the instance AMI, had to be attached and then mounted to the AMI. Elasticfox quite easily allows for the generation and attachment of new storage volumes within its graphic interface. To mount the volume once it's attached, the following UNIX commands can be used:

```
mkfs.ext3 /dev/sda2
mkdir /thesis
mount /dev/sda2 /thesis
```

The first command applies the `ext3` files system to the volume, which is located at `/dev/sda2`. Secondly, create the directory that the volume will be mounted to, `/thesis` in the case of the Toronto Pilot project. Finally, mount this volume to the designated directory. Once this is completed, the 1000GB volume acts as though it is part of the original 10GB AMI volume, accessible through the `/thesis` directory. At this point, the original generic AMI has been fully customized and can saved as a new personal AMI, and then used to clone new identical instances.

4.2.2 - Simulating within the Cloud

Throughout the process of managing multiple instances, it can be cumbersome to transfer large amounts of data between local machine and the Amazon instance. A possible solution to this is to transfer information between Amazon instances, using Amazon's S3 storage as an intermediate transfer point. S3 stands for 'Simple Storage Solution', and is a service that allows for the storage of large amounts of data within an online cloud that can be accessed via the web. The difference between an Amazon Elastic Block Storage (EBS) volume and an S3 bucket is the speed of accessibility; an EBS volume is designed to act as a hard drive connected to Amazon instances, while a S3 bucket is meant for cheap, reliable, long term storage of data. To interact with S3 from an Amazon instance, a RUBY package named `sc3sync` has been developed and is freely available (Amazon Web Services, 2007). This package can be downloaded and installed using the `tar` package instructions explained above. Once installed, this module can be used to connect to an S3 bucket, from an Amazon instance, using the following commands:

```
AWS_ACCESS_KEY_ID=AKIAI........HXIVT7RA          (broken for author's security)
export AWS_ACCESS_KEY_ID
AWS_SECRET_ACCESS_KEY=jC5dXksc........2b/+QF9hCpw (broken for author's security)
export AWS_SECRET_ACCESS_KEY
```

```
./s3sync/s3cmd.rb listbuckets
./s3sync/s3cmd.rb list stustorage
./s3sync/s3cmd.rb get stustorage:/FileonS3 /InstanceDirectory/ToCopyTo
./s3sync/s3cmd.rb put stustorage:/FileonS3 /InstanceFileToPutOntoS3
./s3sync/s3sync.rb -r /InstanceDirectory stustorage:/S3directory
```

The first four lines of code on previous page are the required commands to authenticate with Amazon from within an instance. Once this is completed, the user can access the S3 buckets they own. The `listbuckets` command line will list the S3 storage buckets that the user has permission to access. The next line, containing `list stustorage`, will list the contents of the `stustorage` S3 bucket. The `put` and `get` commands will transfer data to and from, respectively, the S3 storage bucket designated. Finally, the `s3sync.rb` command will synchronize the contents of a S3 directory with an EC2 instance directory.

When working locally within a Terminal command line, one can only execute a single process at a time, without opening multiple Terminal windows. When working through a secure remote Terminal connection with an Amazon Instance there is typically only a single window to work from. Thus to control multiple EnergyPlus processes in real time requires a modified Terminal interaction. The program, `screen`, has been developed to allow multiple Terminal windows to be created, all within a single connection (Robbins, 2006). Once installed, the program can be used with the following commands:

```
screen        - starts the program
ctrl-a c      - creates a new window, within the existing Terminal connection
ctrl-a p      - navigates to the previous window
ctrl-a n      - navigates to the next window
```

Finally, once all three `c1.xlarge` Amazon Instances were fully developed, the 1080000 input `.IDF files` were generated on each instance, the identical randomized master `.IDF` name file was loaded into each simulation silo, and all of the Python execution files were fully refined and tested for accuracy through small-scale trial and error, the massive-scale simulation process was ready to begin. Within each Instance, the start-up sequence followed these UNIX commands:

```
screen        - start 'Screen' program

./Run1.py     - execute python code, drives simulations 0-45000

ctrl-a c      - create new window within the Terminal connection

./Run2.py     - execute python code, drives simulations 45000-90000

ctrl-a c

./Run3.py     - execute python code, drives simulations 90000-135000
ctrl-a c

./Run4.py     - execute python code, drives simulations 135000-180000

ctrl-a c

./Run5.py     - execute python code, drives simulations 180000-225000

ctrl-a c

./Run6.py     - execute python code, drives simulations 225000-270000

ctrl-a c

./Run7.py     - execute python code, drives simulations 270000-315000

ctrl-a c

./Run8.py     - execute python code, drives simulations 315000-360000

TOP           - Displays the active process list in real time
```

Once these commands were executed, the `TOP` command provided visual verification that the 8 EnergyPlus processes were running successfully, as shown in Figure 22 on the following page.

Once 8 processes were running on all three Amazon Instances, the author would periodically log into each instance and verify that all 24 processes continued to run. To check the overall progress of each process, the following commands can be used:

```
df -h                         - display disk fullness

cat /proc/partitions          - list disk partitions and size

du -s /FileorFolder           - list file or folder size


find /targetdirectory -maxdepth 1 -type f | wc -l

                              - this command returns the number of files in a
                              directory, to a single level of directory depth
```

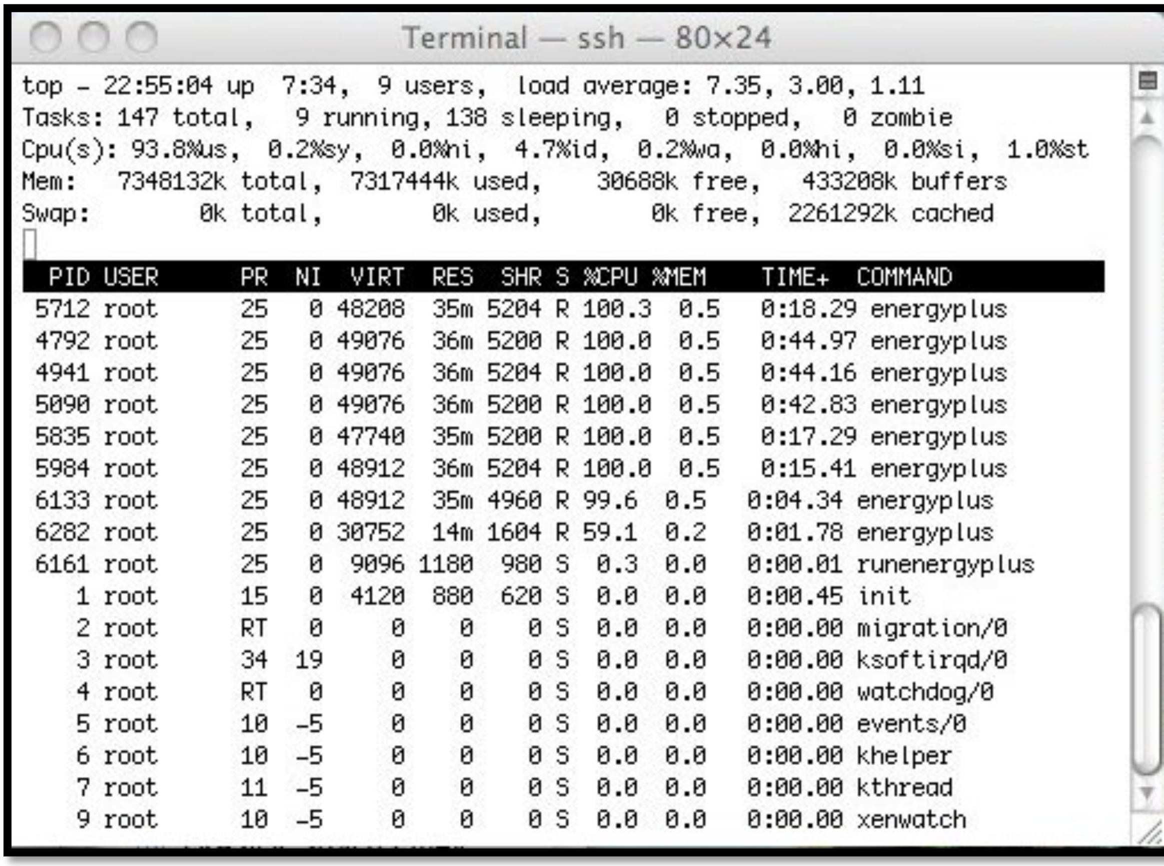

Figure 22 - Screenshot of 8 concurrent EnergyPlus processes running on 1 of 3 Amazon EC2 Instances, used to simulate 1 080 000 design scenarios for the Toronto Pilot project.

The final simulation process took just under a month to complete and resulted in approximately 700GB of data. To retrieve this data from Amazon, the following UNIX command was useful:

```
rsync -avz -e "ssh -i /users/stufix/AmazonEC2/mycreds/stufixkey.pem"
                      <single space>root@204.236.253.246:/thesis /Volumes/DigLib1/stu
```

This `rsync` process uses `ssh` protocols, and synchronizes the contents of a remote directory to a local directory. The process has real-time internal compression, so the total 700GB of data was reduced to 120GB of data transfer, taking approximately three days to download to the author's external hard drive using the author's residential internet connection.

4.3 - Harvesting Embodied Energy Data

The Athena Impact Estimator software (Athena Institute, 2010) was the source of all embodied energy data used in the Toronto Pilot. This project focuses solely on the embodied contributions of each building's thermal insulation, windows, thermally massive concrete layer, and fuel consumption. This section details the calculation of the unit values used in the Pilot.

4.3.1 - Thermal Insulation Embodied Energy

Six different thermal insulation types are included in the Toronto Pilot: blown cellulose, expanded polystyrene board, fiberglass batt, polyisocyanurate board, Rockwool batt, and extruded polystyrene board. For each insulation type, a `1m X 1m X 25.4mm` volume was modeled with the Athena Impact Estimator (Athena Institute, 2010). From the total embodied energy calculated for this volume, a unit embodied energy value was calculated with the units [kWh/m^3] insulation. This value can then be multiplied by the volume of insulation present in each design to obtain a total level of embodied energy. The results of these calculations follow in sections 4.3.1.1-4.3.1.6.

4.3.1.1 - Blown Cellulose

The summary of the embodied environmental impacts for the test sample of cellulose insulation is found in Table 7, below.

Table 7 - Summary of Athena Impact Estimator results for a 1m x 1m x 25.4mm volume of blown cellulose insulation, installed in Toronto, ON (Athena Institute, 2010).

Blown Cellulose	**Manufacturing**			**Construction**	**End-Of-Life**	**Total Effects**
	Material	Transportation	**Total**	Transportation	Transportation	
Primary Energy Consumption MJ	1.63e+00	2.48e-01	**1.87e+00**	3.03e-01	5.09e-02	**2.23e+00**
Weighted Resource Use kg	9.44e-01	1.68e-04	**9.44e-01**	2.06e-04	3.47e-05	**9.44e-01**
Global Warming Potential (kg CO2 eq)	1.04e-01	4.76e-04	**1.04e-01**	5.84e-04	9.81e-05	**1.05e-01**
Acidification Potential (moles of H+ eq)	4.62e-02	1.50e-04	**4.63e-02**	1.84e-04	3.09e-05	**4.66e-02**
HH Respiratory Effects Potential (kg PM2.5 eq)	2.48e-04	1.81e-07	**2.48e-04**	2.21e-07	3.72e-08	**2.48e-04**
Eutrophication Potential (kg N eq)	7.44e-06	1.56e-07	**7.59e-06**	1.91e-07	2.92e-08	**7.81e-06**
Ozone Depletion Potential (kg CFC-11 eq)	4.53e-10	1.95e-14	**4.53e-10**	2.39e-14	4.02e-15	**4.53e-10**
Smog Potential (kg NOx eq)	1.57e-04	3.35e-06	**1.60e-04**	4.11e-06	6.91e-07	**1.65e-04**

This total embodied energy from the Athena Impact Estimator can be converted to the desired units using the following calculation:

`(2.23 MJ/m`^{3}`)*(1000mm)/(25.4mm)*1.05*(0.27777 kWh/MJ) = 26.0 [kWh/m`^{3}`]`

The `1.05` multiplication factor is present to apply a 5% waste factor on insulation installation. This result of `26 kWh/m`^{3} is then multiplied by each building's total volume of insulation, in the database, to give the total insulation embodied energy were blown cellulose to be installed. Referring back to Table 7, the other environmental impact factors present could easily be converted into equivalent values per cubic meter of cellulose insulation, and used as additional optimizing metrics in future research.

4.3.1.2 - Expanded Polystyrene

The summary of the embodied environmental impacts for the test sample of expanded polystyrene is found in Table 8, below.

Table 8 - Summary of Athena Impact Estimator results for a 1m x 1m x 25.4mm volume of rigid expanded polystyrene insulation, installed in Toronto, ON (Athena Institute, 2010).

EPS	**Manufacturing**			**Construction**	**End-Of-Life**	**Total Effects**
	Material	Transportation	**Total**	Transportation	Transportation	
Primary Energy Consumption MJ	3.82e+01	8.87e-04	**3.82e+01**	7.94e-02	5.73e-02	**3.83e+01**
Weighted Resource Use kg	8.38e-01	1.36e-07	**8.38e-01**	5.41e-05	3.90e-05	**8.38e-01**
Global Warming Potential (kg CO2 eq)	1.95e+00	1.02e-07	**1.95e+00**	1.53e-04	1.10e-04	**1.95e+00**
Acidification Potential (moles of H+ eq)	8.48e-01	1.11e-07	**8.48e-01**	4.83e-05	3.48e-05	**8.48e-01**
HH Respiratory Effects Potential (kg PM2.5 eq)	2.62e-03	1.38e-10	**2.62e-03**	5.81e-08	4.18e-08	**2.62e-03**
Eutrophication Potential (kg N eq)	3.89e-04	1.21e-10	**3.89e-04**	5.00e-08	3.29e-08	**3.89e-04**
Ozone Depletion Potential (kg CFC-11 eq)	4.42e-11	4.43e-18	**4.42e-11**	6.27e-15	4.52e-15	**4.42e-11**
Smog Potential (kg NOx eq)	3.94e-02	2.67e-09	**3.94e-02**	1.08e-06	7.77e-07	**3.94e-02**

This total embodied energy from the Athena Impact Estimator can be converted to the desired units using the following calculation:

`(38.3 MJ/m`^{3}`)*(1000mm)/(25.4mm)*1.05*(0.27777 kWh/MJ) = 446.8 [kWh/m`^{3}`]`

The `1.05` multiplication factor is present to apply a 5% waste factor on insulation installation. This result of `446.8 kWh/m`^{3} is then multiplied by each building's total volume of insulation, in the database, to give the total insulation embodied energy were rigid expanded polystyrene to be installed. Referring back to Table 8, the other environmental impact factors present could easily be converted into equivalent values per cubic meter of rigid expanded polystyrene, and used as additional optimizing metrics in future research.

4.3.1.3 - Fiberglass Batt

The summary of the embodied environmental impacts for the test sample of fiberglass batt insulation is found in Table 9, below.

Table 9 - Summary of Athena Impact Estimator results for a 1m x 1m x 25.4mm volume of fiberglass batt insulation, installed in Toronto, ON (Athena Institute, 2010).

Fiberglass	**Manufacturing**			**Construction**	**End - Of - Life**	**Total Effects**
	Material	Transportation	**Total**	Transportation	Transportation	
Primary Energy Consumption MJ	1.58e+01	9.53e-02	**1.59e+01**	6.16e-02	4.93e-02	**1.60e+01**
Weighted Resource Use kg	1.36e+00	6.50e-05	**1.36e+00**	4.20e-05	3.36e-05	**1.36e+00**
Global Warming Potential (kg CO2 eq)	1.02e+00	1.81e-04	**1.02e+00**	1.19e-04	9.51e-05	**1.02e+00**
Acidification Potential (moles of H+ eq)	4.89e-01	5.78e-05	**4.89e-01**	3.75e-05	3.00e-05	**4.90e-01**
HH Respiratory Effects Potential (kg PM2.5 eq)	1.02e-02	6.95e-08	**1.02e-02**	4.50e-08	3.60e-08	**1.02e-02**
Eutrophication Potential (kg N eq)	1.28e-04	5.99e-08	**1.28e-04**	3.88e-08	2.83e-08	**1.28e-04**
Ozone Depletion Potential (kg CFC-11 eq)	1.81e-10	7.44e-15	**1.81e-10**	4.86e-15	3.89e-15	**1.81e-10**
Smog Potential (kg NOx eq)	2.17e-03	1.29e-06	**2.17e-03**	8.36e-07	6.69e-07	**2.17e-03**

This total embodied energy from the Athena Impact Estimator can be converted to the desired units using the following calculation:

$$(16.0\ \mathrm{MJ/m^3})*(1000\mathrm{mm})/(25.4\mathrm{mm})*1.05*(0.27777\ \mathrm{kWh/MJ}) = 186.8\ [\mathrm{kWh/m^3}]$$

The `1.05` multiplication factor is present to apply a 5% waste factor on insulation installation. This result of $186.8\ \mathrm{kWh/m^3}$ is then multiplied by each building's total volume of insulation, in the database, to give the total insulation embodied energy were fiberglass batt to be installed. Referring back to Table 9, the other environmental impact factors present could easily be converted into equivalent values per cubic meter of fiberglass batt insulation, and used as additional optimizing metrics in future research.

4.3.1.4 - Polyisocyanurate

The summary of the embodied environmental impacts for the test sample of rigid polyisocyanurate insulation is found in Table 10, below.

Table 10 - Summary of Athena Impact Estimator results for a 1m x 1m x 25.4mm volume of polyisocyanurate, installed in Toronto, ON (Athena Institute, 2010).

Polyisocyanurate	Manufacturing			Construction	End - Of - Life	Total Effects
	Material	Transportation	**Total**	Transportation	Transportation	
Primary Energy Consumption MJ	6.15e+01	3.49e-02	**6.15e+01**	2.08e-01	7.32e-02	**6.18e+01**
Weighted Resource Use kg	1.58e+00	2.10e-05	**1.58e+00**	1.41e-04	4.99e-05	**1.58e+00**
Global Warming Potential (kg CO2 eq)	6.27e+00	5.74e-05	**6.27e+00**	4.00e-04	1.41e-04	**6.27e+00**
Acidification Potential (moles of H+ eq)	1.34e+00	1.86e-05	**1.34e+00**	1.26e-04	4.45e-05	**1.34e+00**
HH Respiratory Effects Potential (kg PM2.5 eq)	5.07e-03	2.24e-08	**5.07e-03**	1.52e-07	5.35e-08	**5.07e-03**
Eutrophication Potential (kg N eq)	4.16e-04	1.93e-08	**4.16e-04**	1.31e-07	4.20e-08	**4.17e-04**
Ozone Depletion Potential (kg CFC-11 eq)	1.09e-09	2.35e-15	**1.09e-09**	1.64e-14	5.78e-15	**1.09e-09**
Smog Potential (kg NOx eq)	1.00e-02	4.17e-07	**1.00e-02**	2.82e-06	9.93e-07	**1.00e-02**

This total embodied energy from the Athena Impact Estimator can be converted to the desired units using the following calculation:

```
(61.8 MJ/m3)*(1000mm)/(25.4mm)*1.05*(0.27777 kWh/MJ) = 720.7 [kWh/m3]
```

The `1.05` multiplication factor is present to apply a 5% waste factor on insulation installation. This result of `720.7 kWh/m`^{3} is then multiplied by each building's total volume of insulation, in the database, to give the total insulation embodied energy were rigid polyisocyanurate to be installed. Referring back to Table 10, the other environmental impact factors present could easily be converted into equivalent values per cubic meter of rigid polyisocyanurate insulation, and used as additional optimizing metrics in future research.

4.3.1.5 - Rockwool Batt

The summary of the embodied environmental impacts for the test sample of Rockwool batt insulation is found in Table 11, below.

Table 11 - Summary of Athena Impact Estimator results for a 1m x 1m x 25.4mm volume of Rockwool batt, installed in Toronto, ON (Athena Institute, 2010).

Rockwool	Manufacturing			Construction	End - Of - Life	Total Effects
	Material	Transportation	**Total**	Transportation	Transportation	
Primary Energy Consumption MJ	2.63e+01	7.43e-01	**2.70e+01**	6.41e-02	4.93e-02	**2.72e+01**
Weighted Resource Use kg	5.40e+00	4.96e-04	**5.40e+00**	4.37e-05	3.36e-05	**5.40e+00**
Global Warming Potential (kg CO2 eq)	3.14e+00	1.39e-03	**3.14e+00**	1.24e-04	9.51e-05	**3.14e+00**
Acidification Potential (moles of H+ eq)	3.43e+00	4.42e-04	**3.43e+00**	3.90e-05	3.00e-05	**3.43e+00**
HH Respiratory Effects Potential (kg PM2.5 eq)	4.70e-02	5.32e-07	**4.70e-02**	4.68e-08	3.60e-08	**4.70e-02**
Eutrophication Potential (kg N eq)	2.55e-03	4.58e-07	**2.55e-03**	4.04e-08	2.83e-08	**2.55e-03**
Ozone Depletion Potential (kg CFC-11 eq)	1.89e-08	5.70e-14	**1.89e-08**	5.06e-15	3.89e-15	**1.89e-08**
Smog Potential (kg NOx eq)	5.79e-02	9.88e-06	**5.79e-02**	8.70e-07	6.69e-07	**5.79e-02**

This total embodied energy from the Athena Impact Estimator can be converted to the desired units using the following calculation:

```
(27.2 MJ/m3)*(1000mm)/(25.4mm)*1.05*(0.27777 kWh/MJ) = 316.7[kWh/m3]
```

The `1.05` multiplication factor is present to apply a 5% waste factor on insulation installation. This result of `316.7 kWh/m`^{3} is then multiplied by each building's total volume of insulation, in the database, to give the total insulation embodied energy were Rockwool batt to be installed. Referring back to Table 11, the other environmental impact factors present could easily be converted into equivalent values per cubic meter of rigid Rockwool batt, and used as additional optimizing metrics in future research.

4.3.1.6 - Extruded Polystyrene

The summary of the embodied environmental impacts for the test sample of extruded polystyrene insulation is found in Table 12, on the following page.

Table 12 - Summary of Athena Impact Estimator results for a 1m x 1m x 25.4mm volume of extruded polystyrene, installed in Toronto, ON (Athena Institute, 2010).

XPS	**Manufacturing**			**Construction**	**End - Of - Life**	**Total Effects**
	Material	Transportation	**Total**	Transportation	Transportation	
Primary Energy Consumption MJ	7.63e+01	1.77e-03	**7.63e+01**	1.22e-01	9.78e-02	**7.65e+01**
Weighted Resource Use kg	1.68e+00	2.72e-07	**1.68e+00**	8.33e-05	6.67e-05	**1.68e+00**
Global Warming Potential (kg CO2 eq)	3.90e+00	2.03e-07	**3.90e+00**	2.36e-04	1.89e-04	**3.90e+00**
Acidification Potential (moles of H+ eq)	1.70e+00	2.23e-07	**1.70e+00**	7.43e-05	5.95e-05	**1.70e+00**
HH Respiratory Effects Potential (kg PM2.5 eq)	5.24e-03	2.76e-10	**5.24e-03**	8.93e-08	7.15e-08	**5.24e-03**
Eutrophication Potential (kg N eq)	7.79e-04	2.42e-10	**7.79e-04**	7.70e-08	5.62e-08	**7.79e-04**
Ozone Depletion Potential (kg CFC-11 eq)	8.84e-11	8.87e-18	**8.84e-11**	9.65e-15	7.72e-15	**8.84e-11**
Smog Potential (kg NOx eq)	7.88e-02	5.35e-09	**7.88e-02**	1.66e-06	1.33e-06	**7.88e-02**

This total embodied energy from the Athena Impact Estimator can be converted to the desired units using the following calculation:

```
(76.5 MJ/m3)*(1000mm)/(25.4mm)*1.05*(0.27777 kWh/MJ) = 893.1[kWh/m3]
```

The `1.05` multiplication factor is present to apply a 5% waste factor on insulation installation. This result of `893.1 kWh/m`^{3} is then multiplied by each building's total volume of insulation, in the database, to give the total insulation embodied energy were extruded polystyrene to be installed. Referring back to Table 12, the other environmental impact factors present could easily be converted into equivalent values per cubic meter of extruded polystyrene, and used as additional optimizing metrics in future research.

4.3.2 - Window Embodied Energy

Five different window construction types were included in the Toronto Pilot project: single glaze, clear double glaze, lowE double glaze, lowE triple glaze, and lowE quadruple glaze. For simplicity, window frames were not included in the pilot, so the window glazing fills the complete open window geometry. The Athena Impact Estimator does not currently house a large window database, so the embodied energy of all Toronto Pilot window constructions, were calculated by scaling the impacts of two double glaze constructions. Matthew Bowick of the Athena Institute verified this method as accurate within the error tolerances of the Impact Estimator (Bowick, 2010). Table 13, shown below, summarizes the environmental impacts of 1m² of clear, air-filled double glaze window construction. Similarly, Table 14 summarizes the impacts of the second glazing type, a lowE coated, argon-filled double glaze window.

Table 13 - Summary of Athena Impact Estimator calculated environmental effects for 1m² of clear, air filled double glazing in Toronto (Athena Institute, 2010).

standard double glazing	**Manufacturing**		**Construction**	**End - Of - Life**	**Total Effects**
	Material	Transportation	Transportation	Transportation	
Primary Energy Consumption MJ	1.96e+02	2.83e+00	7.46e+00	1.19e+00	**2.07e+02**
Weighted Resource Use kg	3.72e+01	1.91e-03	5.08e-03	8.13e-04	**3.72e+01**
Global Warming Potential (kg CO2 eq)	3.06e+01	5.33e-03	1.44e-02	2.30e-03	**3.07e+01**
Acidification Potential (moles of H+ eq)	1.62e+01	1.70e-03	4.53e-03	7.26e-04	**1.62e+01**
HH Respiratory Effects Potential (kg PM2.5 eq)	4.04e-01	2.04e-06	5.45e-06	8.72e-07	**4.04e-01**
Eutrophication Potential (kg N eq)	8.89e-03	1.76e-06	4.70e-06	6.85e-07	**8.90e-03**
Ozone Depletion Potential (kg CFC-11 eq)	1.01e-08	2.18e-13	5.89e-13	9.42e-14	**1.01e-08**
Smog Potential (kg NOx eq)	1.60e-01	3.80e-05	1.01e-04	1.62e-05	**1.60e-01**

Table 14 - Summary of Athena Impact Estimator calculated environmental effect for 1m² of lowE coated, argon filled double glazing (Athena Institute, 2010).

low e tin argon filled glazing	**Manufacturing**		**Construction**	**End - Of - Life**	**Total Effects**
	Material	Transportation	Transportation	Transportation	
Primary Energy Consumption MJ	1.96e+02	2.93e+00	7.46e+00	1.19e+00	**2.08e+02**
Weighted Resource Use kg	3.76e+01	1.97e-03	5.08e-03	8.13e-04	**3.76e+01**
Global Warming Potential (kg CO2 eq)	3.06e+01	5.52e-03	1.44e-02	2.30e-03	**3.07e+01**
Acidification Potential (moles of H+ eq)	1.62e+01	1.76e-03	4.53e-03	7.26e-04	**1.62e+01**
HH Respiratory Effects Potential (kg PM2.5 eq)	4.04e-01	2.11e-06	5.45e-06	8.72e-07	**4.04e-01**
Eutrophication Potential (kg N eq)	8.90e-03	1.82e-06	4.70e-06	6.85e-07	**8.90e-03**
Ozone Depletion Potential (kg CFC-11 eq)	1.01e-08	2.26e-13	5.89e-13	9.42e-14	**1.01e-08**
Smog Potential (kg NOx eq)	1.60e-01	3.93e-05	1.01e-04	1.62e-05	**1.60e-01**

Converting the units into kWh, the clear double glaze contains `57.6 kWh/m²` embodied energy, while the lowE double glaze contains `57.8 kWh/m²`. As mentioned above, the results of Table 13 and Table 14 were used to estimate the embodied energy of all five window constructions within the Toronto Pilot. This is feasible as the majority of embodied impacts within a window are within the glass panes, so the effects of a single glaze clear window are approximately 50% of the effects of a clear double glaze window. Similarly, the effects of a triple glaze or quadruple glaze window are 150% and 200% of a double glaze, respectively. A summary of the calculated embodied energy per square meter, using this method, is presented in Table 15, on the following page.

Table 15 - Embodied energy per square meter of the Toronto Pilot window constructions (Athena Institute, 2010).

Type	Window Construction	Embodied Energy [kWh/m2]
101	clear single glazing	28.8
102	clear double glazing	57.6
103	lowE double glazing	57.8
104	lowE triple glazing	86.7
105	lowE quadruple glazing	115.6

These values in Table 15 were then applied to the overall window areas present in each design scenario to calculate the total embodied energy of the Toronto Pilot window constructions. Again, window frames were not included for simplicity, but should be included in future expansion of this research.

4.3.3 - Thermal Mass Embodied Energy

In the Toronto Pilot, thermal mass is modeled as a variable thickness of concrete on the interior side of thermal insulation, on all exposed surfaces. The embodied environmental factors for 1m^3 concrete were calculated using Athena's Impact Estimator; these calculation results are shown in Table 16 below.

Table 16 - Summary of embodied environmental impact factors for 1m3 of 20MPa concrete in Ontario (Athena Institute, 2010).

Concrete 20MPa	Manufacturing		Construction	End - Of - Life		Total Effects
	Material	Transportation	Transportation	Material	Transportation	
Primary Energy Consumption MJ	1.31e+03	9.30e+01	1.39e+02	1.21e+02	7.40e+01	**1.74e+03**
Weighted Resource Use kg	2.69e+03	6.40e-02	9.45e-02	2.83e+00	5.04e-02	**2.70e+03**
Global Warming Potential (kg CO2 eq)	2.10e+02	1.78e-01	2.67e-01	7.85e+00	1.43e-01	**2.18e+02**
Acidification Potential (moles of H+ eq)	5.89e+01	5.69e-02	8.43e-02	4.35e-01	4.50e-02	**5.95e+01**
HH Respiratory Effects Potential (kg PM2.5 eq)	6.46e-01	6.84e-05	1.01e-04	4.14e-04	5.40e-05	**6.46e-01**
Eutrophication Potential (kg N eq)	2.30e-02	5.90e-05	8.73e-05	2.99e-04	4.25e-05	**2.35e-02**
Ozone Depletion Potential (kg CFC-11 eq)	5.81e-07	7.30e-12	1.09e-11	3.54e-10	5.84e-12	**5.81e-07**
Smog Potential(kg NOx eq)	5.07e-01	1.27e-03	1.88e-03	5.59e-03	1.00e-03	**5.17e-01**

The four thicknesses of this layer, 0.01mm, 50mm, 150mm, and 300mm are meant to approximately emulate the thermal massiveness of four building types: wood frame construction, brick veneer finish, double brick construction, and massive construction types such as adobe or rammed earth. Converted to appropriate units, the embodied energy of concrete is `482.8 kWh/m³`. This value is multiplied by the volume of the thermal mass layer within each Toronto Pilot design to calculate the total embodied energy within that layer.

4.3.4 - Fuel Source Embodied Energy

Finally, the embodied environmental effect of the operational energy consumed by each building design is included in the Toronto Pilot analysis. Using data from the Athena Impact Estimator, the impacts of consuming electricity and natural gas in Ontario were calculated; the result of these calculations is shown below in Table 17 and Table 18. In Table 17, the consumption of `1kWh` site energy results in `7.29MJ`, or `2.03kWh` of primary energy consumption.

Table 17 - Summary of embodied environmental impact factors for the site consumption of 1 kWh electricity, averaged in Ontario(Athena Institute, 2010).

ON electricity	**Total Effects**
Primary Energy Consumption MJ	**7.29e+00**
Weighted Resource Use kg	**2.62e-01**
Global Warming Potential (kg CO2 eq)	**2.78e-01**
Acidification Potential (moles of H+ eq)	**1.06e-01**
HH Respiratory Effects Potential (kg PM2.5 eq)	**5.79e-04**
Eutrophication Potential (kg N eq)	**6.19e-06**
Ozone Depletion Potential (kg CFC-11 eq)	**3.25e-13**
Smog Potential (kg NOx eq)	**1.08e-04**

Similarly, shown in Table 18, the site consumption of 1m3 of natural gas results in the primary energy consumption of `41.9MJ` of primary energy. Converting units using the average energy density of natural gas in Ontario, `38.7MJ/m³` (Athena Institute, 2010), the site consumption of `1kWh` natural gas results in `1.08kWh` primary energy consumption. These factors are applied to the annual energy consumption in the database.

Table 18 - Summary of embodied environmental impact factors for the site consumption of 1m³ of natural gas, averaged in Ontario (Athena Institute, 2010).

ON natural gas	**Total Effects**
Primary Energy Consumption MJ	**4.19e+01**
Weighted Resource Use kg	**7.78e-01**
Global Warming Potential (kg CO2 eq)	**2.33e+00**
Acidification Potential (moles of H+ eq)	**9.77e-01**
HH Respiratory Effects Potential (kg PM2.5 eq)	**4.64e-03**
Eutrophication Potential (kg N eq)	**8.27e-05**
Ozone Depletion Potential (kg CFC-11 eq)	**3.35e-13**
Smog Potential (kg NOx eq)	**6.46e-04**

4.4 - Database and Results Generation

The final construction phase of the Toronto Pilot was to sift through the operational energy simulation results, extract the desired information, and combine this with the embodied energy information in a format that is easily manipulated for analysis. A database is an excellent format for dealing with such a vast amount of organized information. Sections 4.4.1-4.4.2 contain a detailed explanation of how the important simulation results were extracted, and all the information was combined into a database.

4.4.1 - Simulation Results Extraction

EnergyPlus simulations generate 16 different results files, which relay various calculated results and details logged during simulation. Of most interest to the Toronto Pilot, the simulations generate a `.csv` file that contains the detailed operational energy usage per month, for an entire year. The first step after downloading the simulation results, was to move the `.csv` file from each simulation into a common folder, as they were nested within the 24 silo directories. To accomplish this, the following UNIX commands were used from the author's laptop Terminal line:

```
find /Volumes/DigLib1/stu/Instance2/run2 -type f -name '*.csv' -exec mv -n {}
                                              <B>/Volumes/DigLib1/stu/simIDF/. \;
```

This process, repeated for each of the 24 silo directories, searches through the `runX` directory for `.csv` file types, and moves them to the `simIDF` directory. Once all 1080000 CSV result files were combined into a single directory, the next task was data extraction. The Toronto Pilot only required the extraction of yearly operational energy for each simulation, though there is far more information within these simulation files. This data was extracted from each simulation's `.csv` file using Python code, that extracted each month's averaged operational heating and cooling load (Watts), and converted these loads to kWh of annual energy consumption using the appropriate hour-weighting of each month. The `.csv` file format varies with the number of building surfaces in a building; the addition of a storey results in 8 more surfaces, 8 more `.csv` data columns, and thus the Python code must be tailored to search in the appropriate `.csv` cell location, else the incorrect data will be extracted. This extraction code is included in the database generation code, and will be discussed further in the next section.

4.4.2 - Database Construction

FileMaker Pro was selected as the database program for the Toronto Pilot based upon numerous excellent online reviews. It proved capable of meeting the project's needs, and thus can be considered a successful selection. An easy way to create a large database is to input all the required data in a tab delimited text file, where each record's information is tabbed across a single line, and a new line represents a new entry. FileMaker Pro allows for the first line entry to be converted to column headings, so that the complete database can be defined within this tab delimited text file. For each of the 1080 000 Toronto Pilot designs, the initial database generation included the following information: simulation#, the Manipulated Simulation Parameters, the annual operational heating and cooling energy consumption, the total window area, and the volume of concrete. This data was gathered for each permutation using a Python executable called `Database.py`. Once executed, the code generated a tab delimited text file with all of the above information.

This database text file was then opened using FileMaker Pro, and the initial database was automatically populated; a process that could not be done manually. Next, new database columns were generated for the embodied energy factors. FileMaker Pro allows for the use of Microsoft Excel-like equations. For example, a column was calculated using the unit embodied energies for each insulation type, annual electric heating, natural gas heating, thermal mass, and window. With the addition of these embodied energy columns, the database contained all of the data required to begin the lifetime energy consumption analysis. Through this analysis, additional columns were created on demand, such as the Total Lifetime Energy consumption of electrically heated buildings with a lifetime of 50 years, using column equations such as:

```
LCA50yrElectric = totalannualprimaryelectric*50 + embodiedInsulation +
            embodiedWindow*2 + embodiedThermalMass
```

This type of calculation is applied to every design record in the database, all of which can then be plotted for a visual trend analysis.

Chapter 5 - Toronto Pilot Example Results

The major relational analysis of the optimization database has been left for future study, as it in itself has the magnitude of a master's thesis. The majority of work in this thesis work went towards laying the foundation for future research. However, some example optimization results have been generated based on a visual trend analysis and some simply statistical calculations. The power of the Full Scale Optimization method is shown through the transparency and wide perspective of the results data. These example results are the focus of this chapter, and include 4 foci: 1) the full scope analysis of lifetime energy consumption, 2) the least and greatest 1% lifetime energy consumption groups, 3) the best and worst 100 lifetime performances, and 4) how the results interact with the 2006 Ontario Building Code design requirements. These example analyses follow in sections 5.1-5.4.

5.1 - Lifetime Energy Consumption

This analysis first focuses on the relative magnitudes of embodied, annual operational, and lifetime energy consumption, across the entire range of Toronto Pilot design permutations. Figure 23 compares embodied energy with annual operational energy, using cellulose insulation and electric heating. Figure 24 has a similar comparison using extruded polystyrene insulation and gas heating. In Figure 23, it appears that a building design with cellulose insulation and electric heating will generally have annual operational energy consumption and embodied energy of the same magnitude. However, in Figure 24, it appears that a building with extruded polystyrene (XPS) generally has greater embodied energy that its annual operational energy. Since annual operational energy is consumed every year of a building's lifetime, and the embodied is only consumed more than once if a component is replaced, operational energy tends to dominant a building's lifetime energy consumption. Figure 25 and Figure 26 show the 50 year energy consumption of the Toronto Pilot designs, with electric heat and cellulose insulation, and with gas heat and extruded polystyrene insulation, respectively. These results agree with existing research, (PHIUS, 2010), that operational energy dominates the lifetime energy consumption of a building. This appears to be the case regardless of heating source of insulation embodied energy. It is also apparent that a chosing XPS over cellulose insulation will result in a greater lifetime consumption of energy.

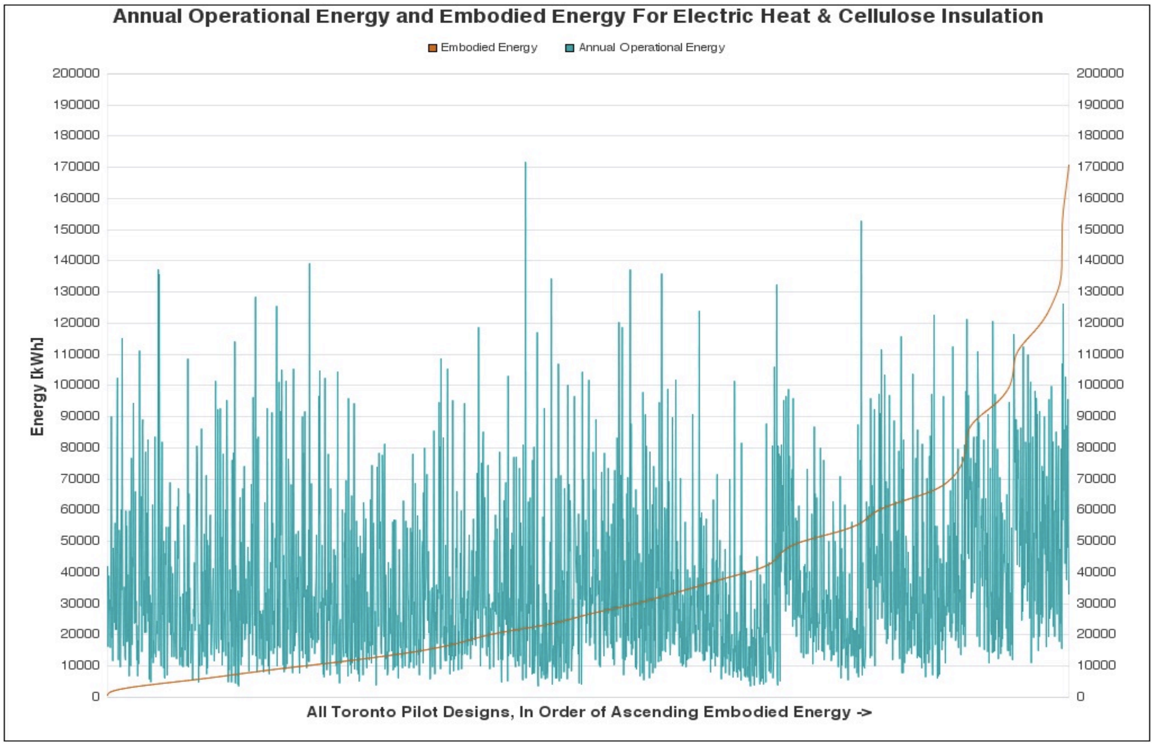

Figure 23 - A plot comparing the magnitude of annual operational primary energy and embodied energy of the Toronto Pilot designs. Embodied energy includes cellulose insulation, windows, and thermal mass.

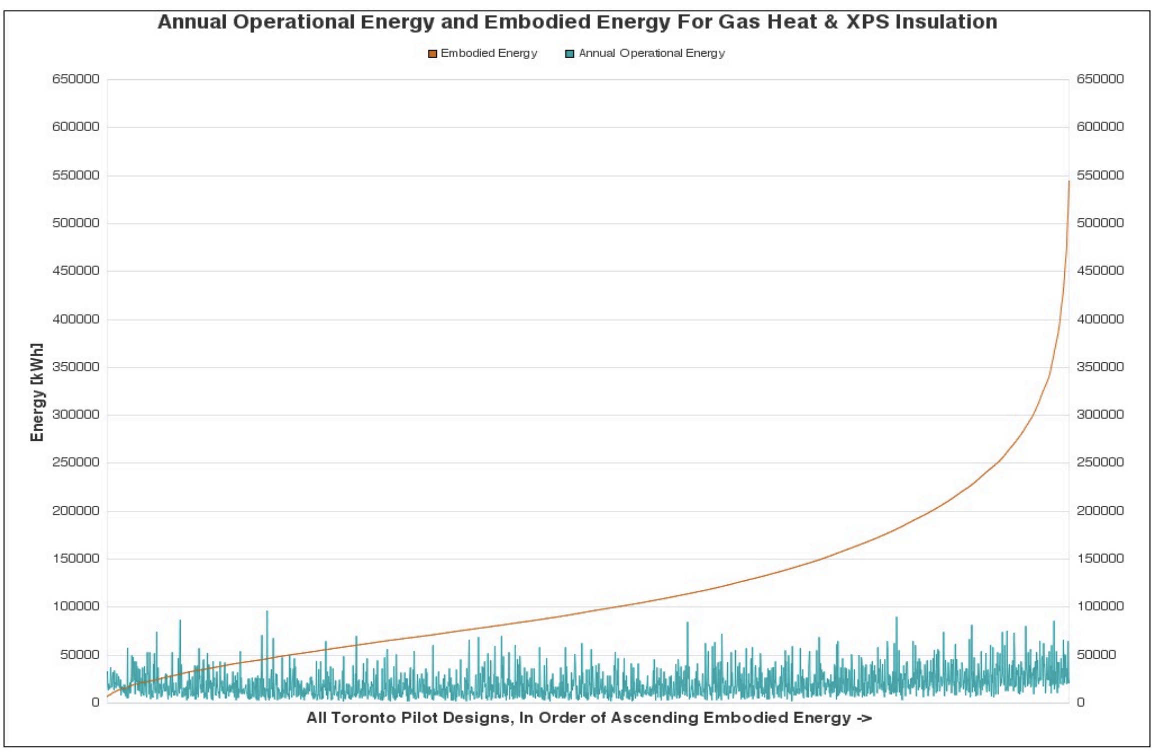

Figure 24 - A plot comparing the magnitude of annual operation primary energy and embodied energy of the Toronto Pilot designs. Embodied energy includes extruded polystyrene insulation, windows, and thermal mass.

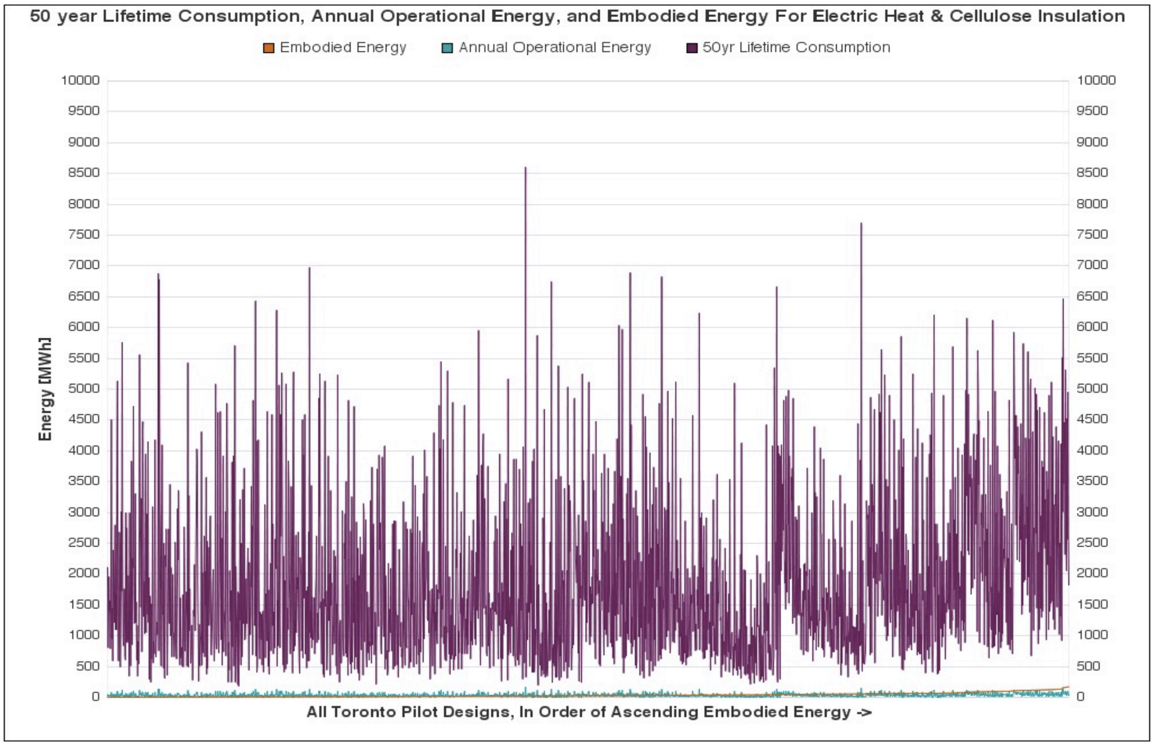

Figure 25 - A plot comparing the magnitude of annual operational energy, embodied energy, and 50 year lifetime consumption of primary energy using electric heat & cooling. Embodied energy includes cellulose insulation, windows, and thermal mass.

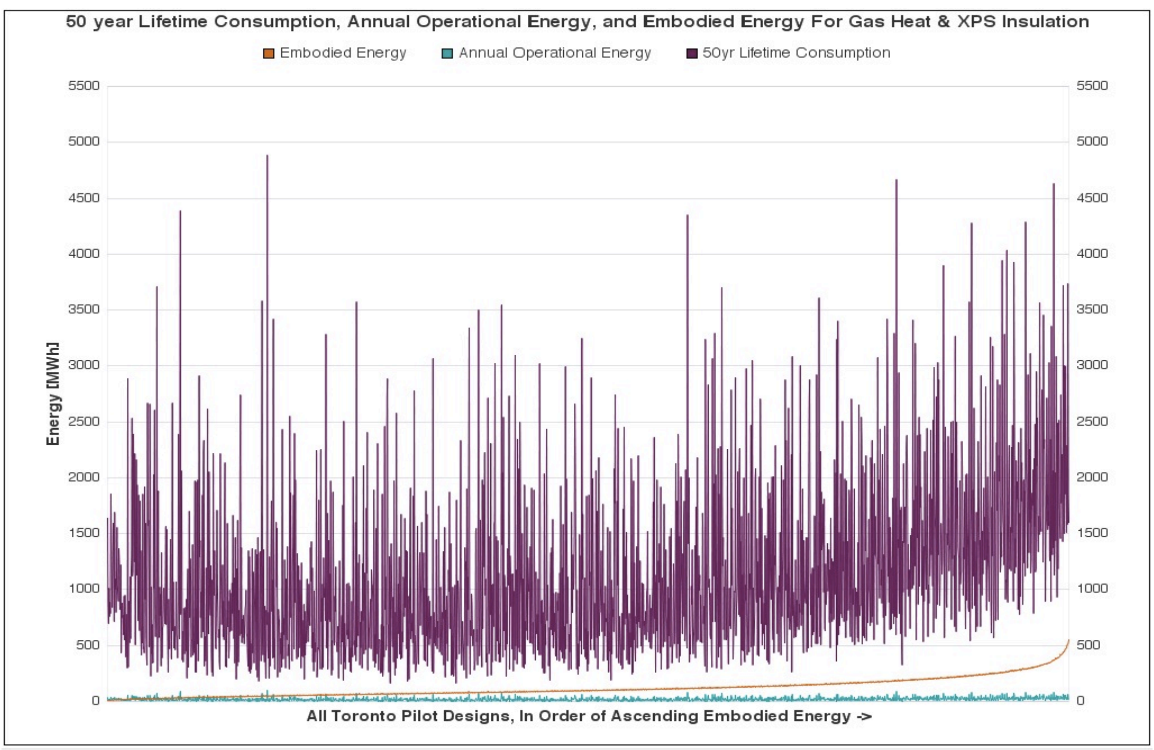

Figure 26 - A plot comparing the magnitude of annual operation energy, embodied energy, and 50 year lifetime consumption of primary energy using gas heat and electric cooling. Embodied energy includes extruded polystyrene insulation, windows, and thermal mass.

Note that there is no visible relationship between annual operational energy and embodied energy in Figure 23 and Figure 24. There is also no dominant trend visible between lifetime energy consumption and embodied energy in Figure 25 and Figure 26. This is unexpected, as the increases in embodied window, insulation, & thermal mass energy are a direct result of what are generally considered as 'Energy Saving Design Measures'. These example results show that the magnitude of embodied energy in itself is not a good predictor of operational energy consumption or lifetime energy consumption; other parameters must be more dominant.

The example analysis also focuses on the overall range of lifetime energy consumption of each design. This data was organized in descending consumption and plotted, producing Figure 27 - Figure 30, on the following pages. Four distinct scenarios were investigated: 1) 50 year consumption of electric heat, 2) 100 year consumption of electric heat, 3) 50 year consumption of gas heat, and 4) 100 year consumption of gas heat. In all scenarios, it was assumed that the windows would need to be replaced every 25 years, so the embodied energy of each replacement is included.

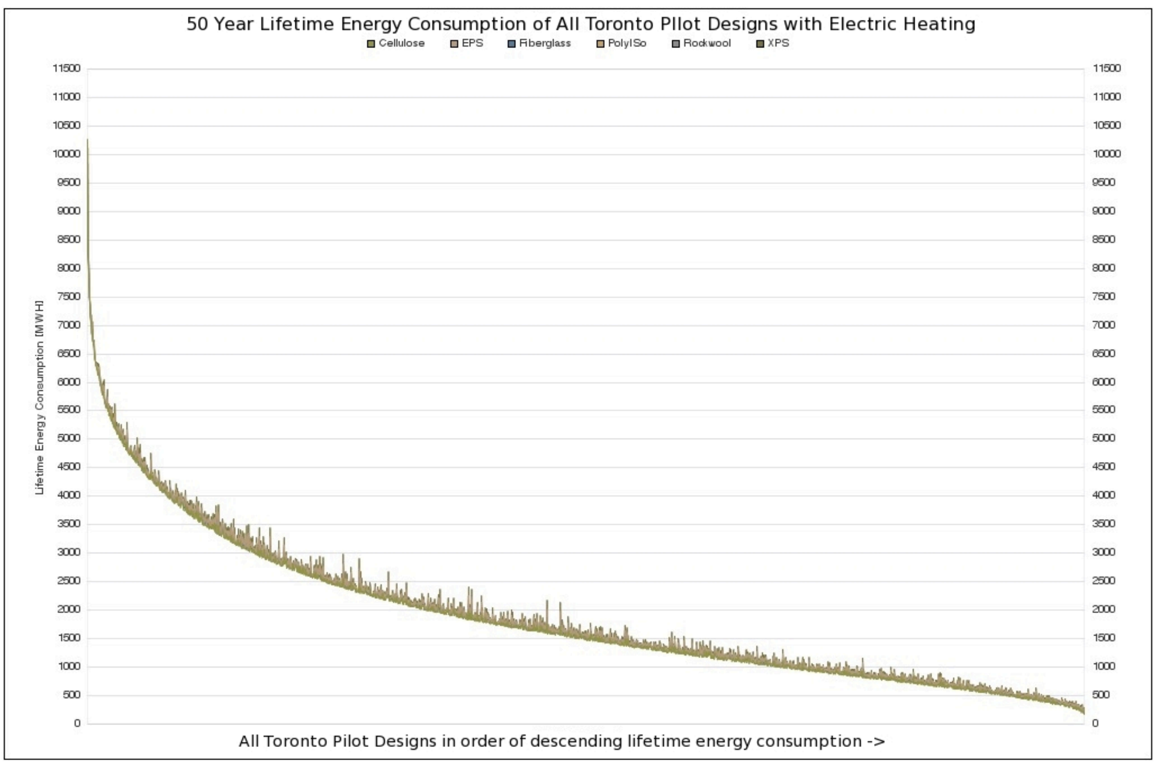

Figure 27 - The 50 year Lifetime Energy Consumption for all Toronto Pilot building designs, using electric heating and cooling. The total lifetime energy consumption of each design is plotted for each type of insulation installed, in order of descending consumption.

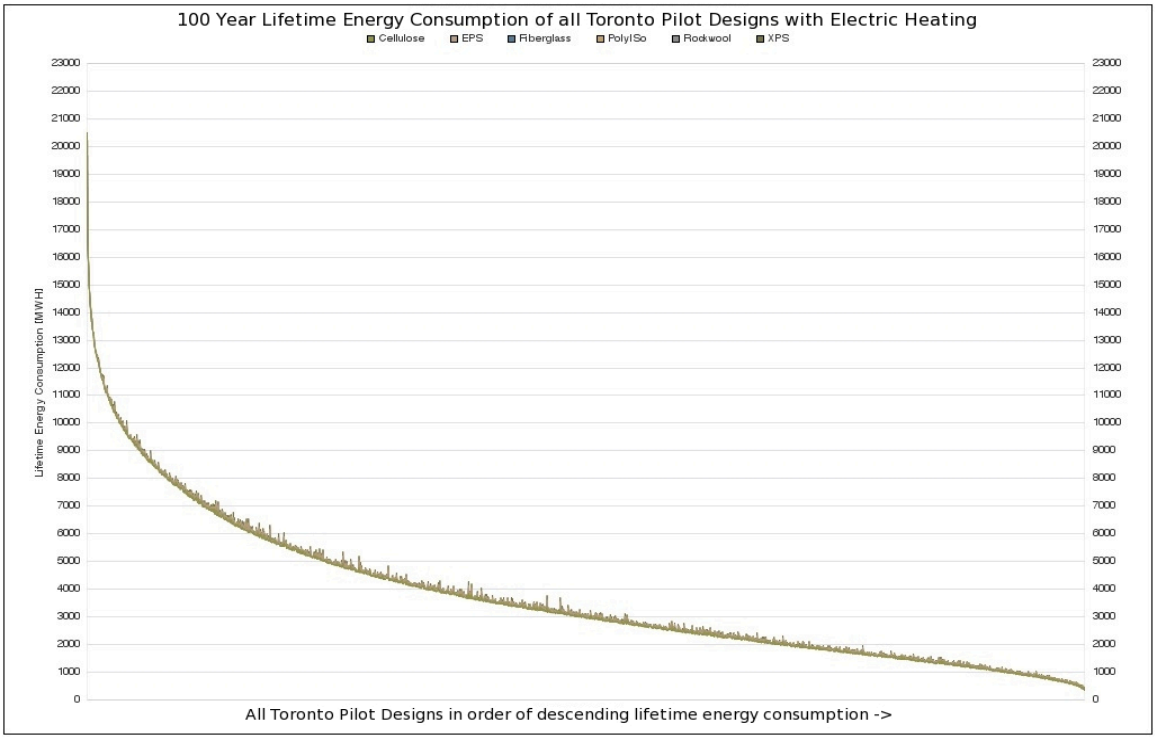

Figure 28 - The 100 year Lifetime Energy Consumption for all Toronto Pilot building designs, using electric heating and cooling. The total lifetime energy consumption of each design is plotted for each type of insulation installed, in order of descending consumption.

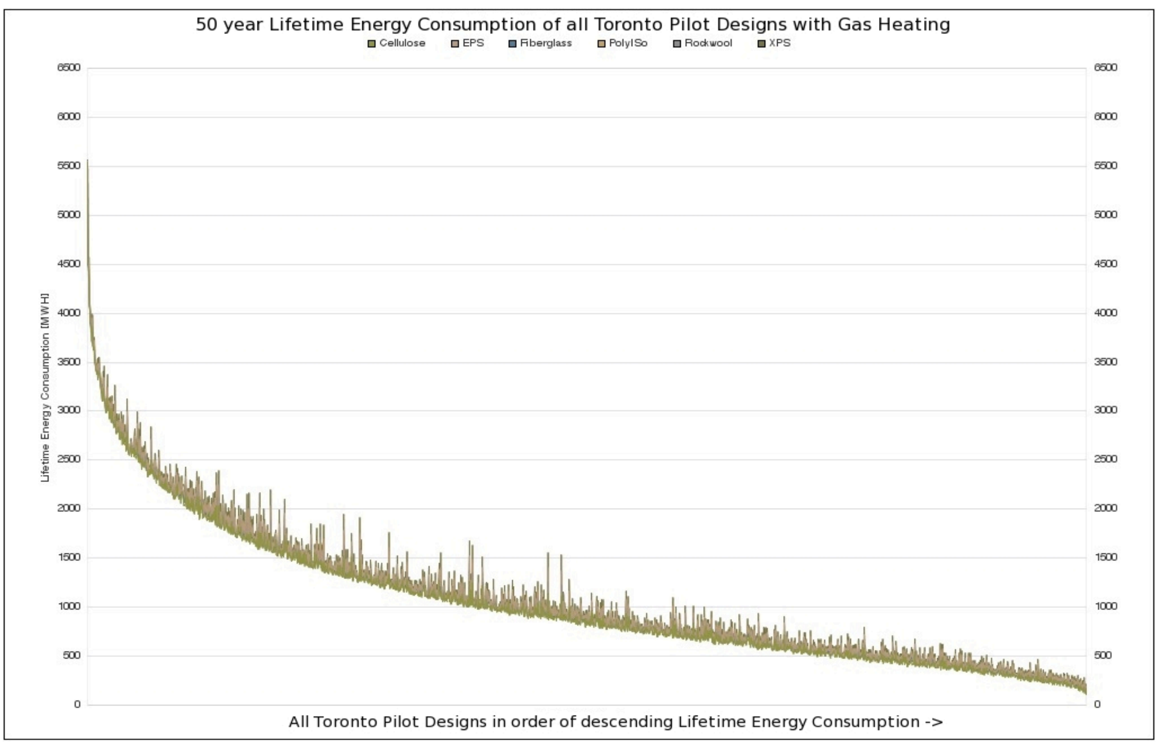

Figure 29 - The 50 year Lifetime Energy Consumption for all Toronto Pilot building designs, using gas heating and electric cooling. The total lifetime energy consumption of each design is plotted for each type of insulation installed, in descending order.

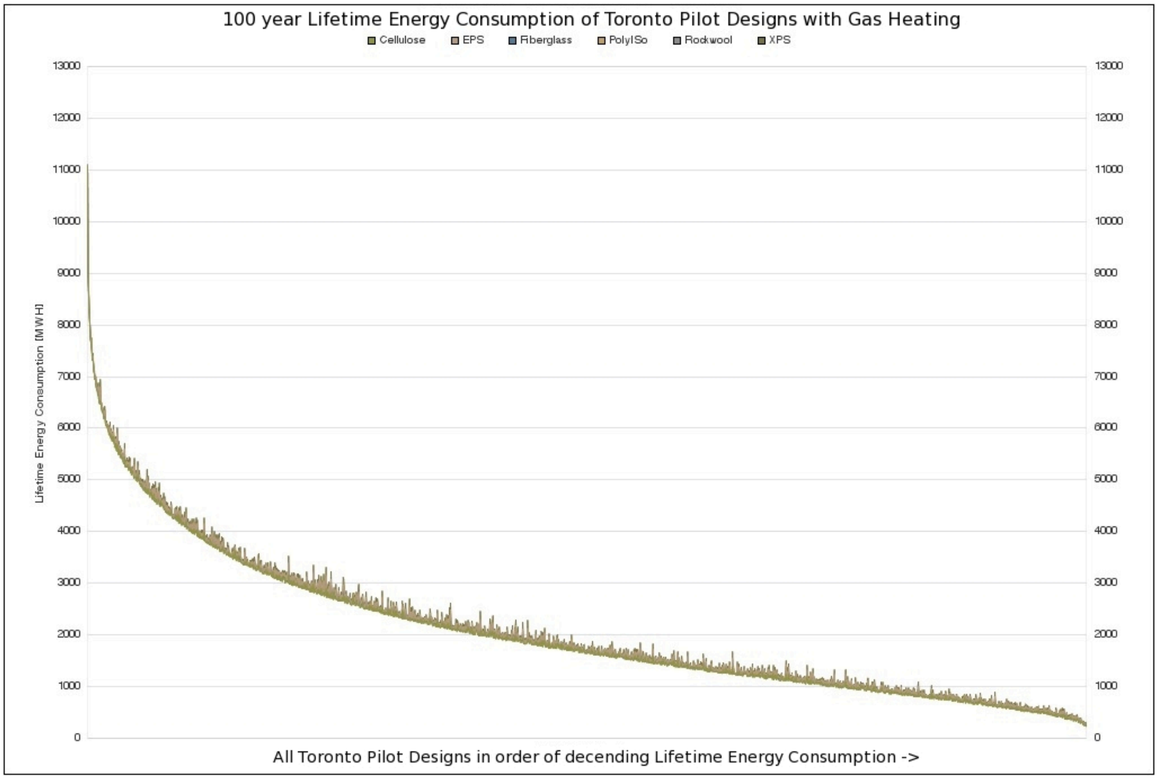

Figure 30 - The 100 year Lifetime Energy Consumption for all Toronto Pilot building designs, using gas heating and electric cooling. The total lifetime energy consumption of each design is plotted for each type of insulation installed, in descending order.

These example results show that even by going to the extremes of RSI 25 thermal insulation, quadruple glazed windows, and 300mm concrete thermal mass envelope thickness, there is no scenario where the embodied energy of construction becomes the dominant factor in lifetime energy consumption. Within the scope of windows, thermal mass, and insultion, it would appear that the operational energy savings of any design measure dominates the lifetime energy balance; embodied energy is less dominant.

Similarly, even though extruded polystyrene insulation (XPS) embodies 34 times the energy that blown cellulose does, the six different insulation type plots are virtually indistinguishable on the scale of 50 or 100 years' energy consumption (Figure 27-Figure 30). This is not to say that the selection of energy-dense insulation vs energy-sparse insulation is irrelevent, clearly in the spirit of energy conservation, energy-sparse insulations should be favoured. However, the results show that there are design choices available that have such a large impact on lifetime energy consumption that they should be considered prior to less-impacting decisions such as insulation type. Note also the unsmooth nature of the plots in. Since varying amounts of different insulation types are required to meet the prescribed rsi value, the difference in embodied insulation energy changes between designs, which causes the unsmooth nature of the plots in Figure 27 to Figure 30. The overall performance extremes for these four lifetime consumption cases are presented in Table 19 below.

Table 19 - Extreme performance summary of four lifetime energy consumption types based upon Toronto Pilot database data. Units are [MWh].

Type	Highest Consumption	Lowest Consumption	Reduction Factor
50 year Electric Heat	10267.5	119.4	85
100 year Electric Heat	20514.5	235.7	86
50 year Gas Heat	5569.1	81.8	67
100 year Gas Heat	11109.8	160.5	68

The overall range in performance is large; the worst performing electrically heated design consumes 85 times more energy over a 50 year period than the best performing design. It's approximately constant that doubling the lifetime of the building results in a doubling of the overall energy usage, which is a result of the dominance of operational energy on the lifetime consumption.

Progressing from the overall results, it is interesting to plot single design parameters against overall lifetime energy consumption, to search for visual evidence that certain parameter values have a dominant effect on the overall building's performance. These plots can be found in Figure 31 - Figure 39 on the following pages. The observer will notice that these plots begin to stretch the limits of visual analysis, as only very strong relationships are visible to the naked eye, on the scale of 1 080 000 data points across a page's width.

In Figure 31, the influence of adding a basement on lifetime energy consumption is shown as a bar graph. 'Without a basement' has a '0' value, and appears as white space, which 'With a basement' has a '1' value, and appears as a colored bar. It is difficult to recognize any strong relationship from a visual analysis of this data, though the colored bars seem slightly denser toward the right side, indicating that the presence of a basement helps lower overall lifetime energy consumption. In Figure 32, the influence of East/West window to wall area is shown. Again, the relationship isn't clear, though it generally seems that lower window areas seem more common with lowered lifetime energy consumption.

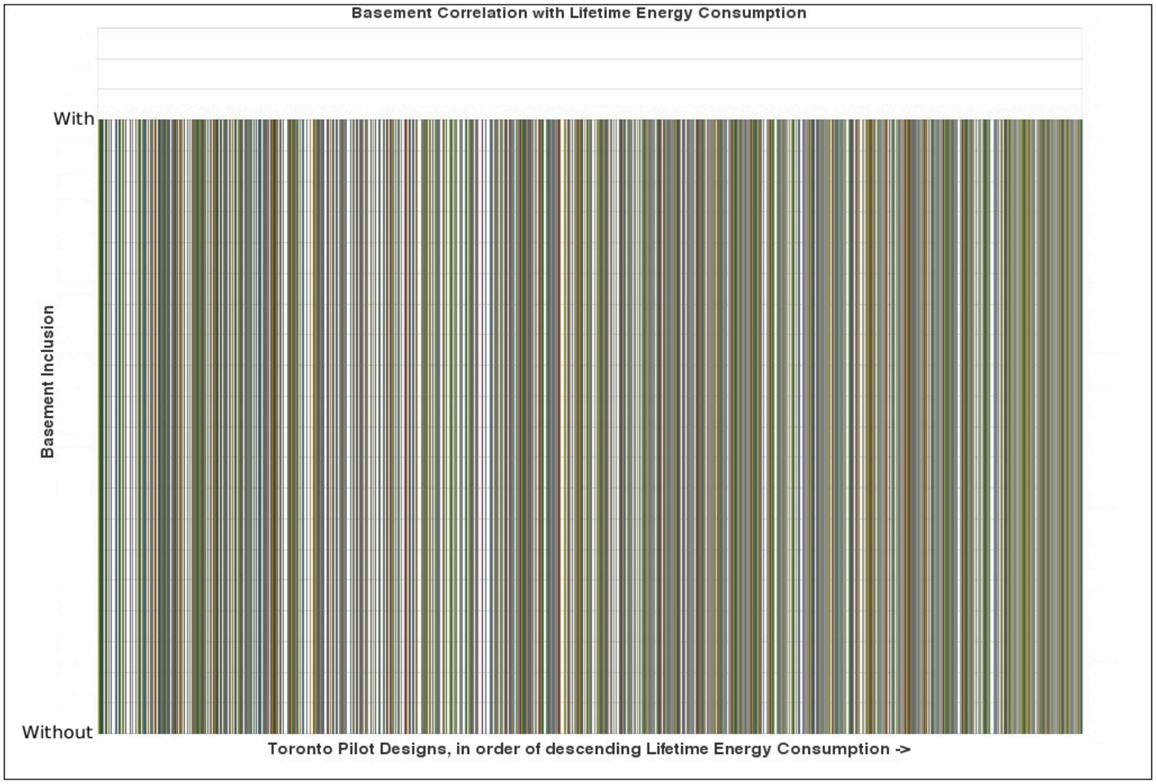

Figure 31 - Generated from the Toronto Pilot database, a plot of basement 'value' for all Toronto Pilot designs arranged according to descending 50 year lifetime energy consumption, with 50yr electric heat, and cellulose insulation. The y axis depicts the presence of basement.

In Figure 33, the influence of home size on lifetime energy consumption is shown. Here a stronger general relationship is clearly visible; the smaller the home size, the lower the lifetime energy consumption will tend to be. This result is logical, and helps validate the results data. In Figure 34, another strong relationship is visible, that a more airtight home will consume less energy over its lifetime than a less airtight design. Though these two figures present relationships that are clear to the human eye, this visual analysis is hardly scientific, and leaves many unanswered questions. Even when a strong relationship is present, there are cases where an opposite extreme value still results in low lifetime energy consumption; the relation doesn't appear to be absolute.

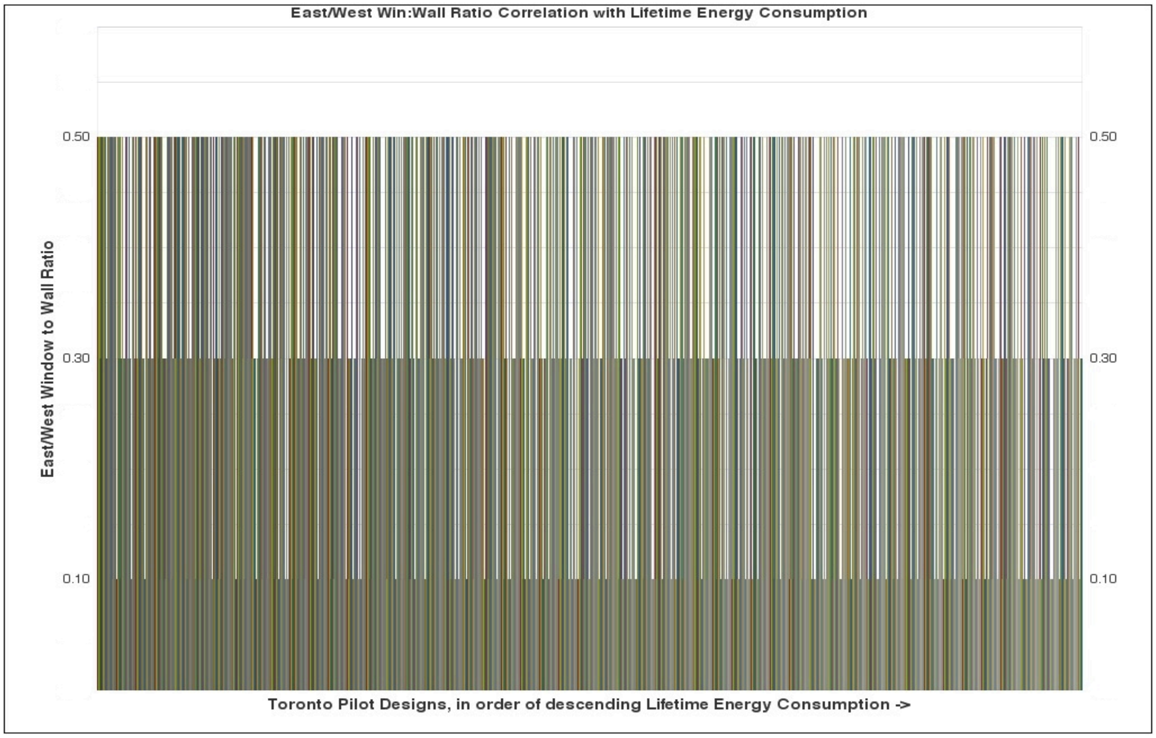

Figure 32 - Generated from the Toronto Pilot database, a plot of East/West window to wall ratio of all Toronto Pilot Designs arranged in order of descending 50 year lifetime energy consumption, with electric heat, cellulose insulation. The y axis depicts the 3 levels of window area, 10%, 30% and 50%.

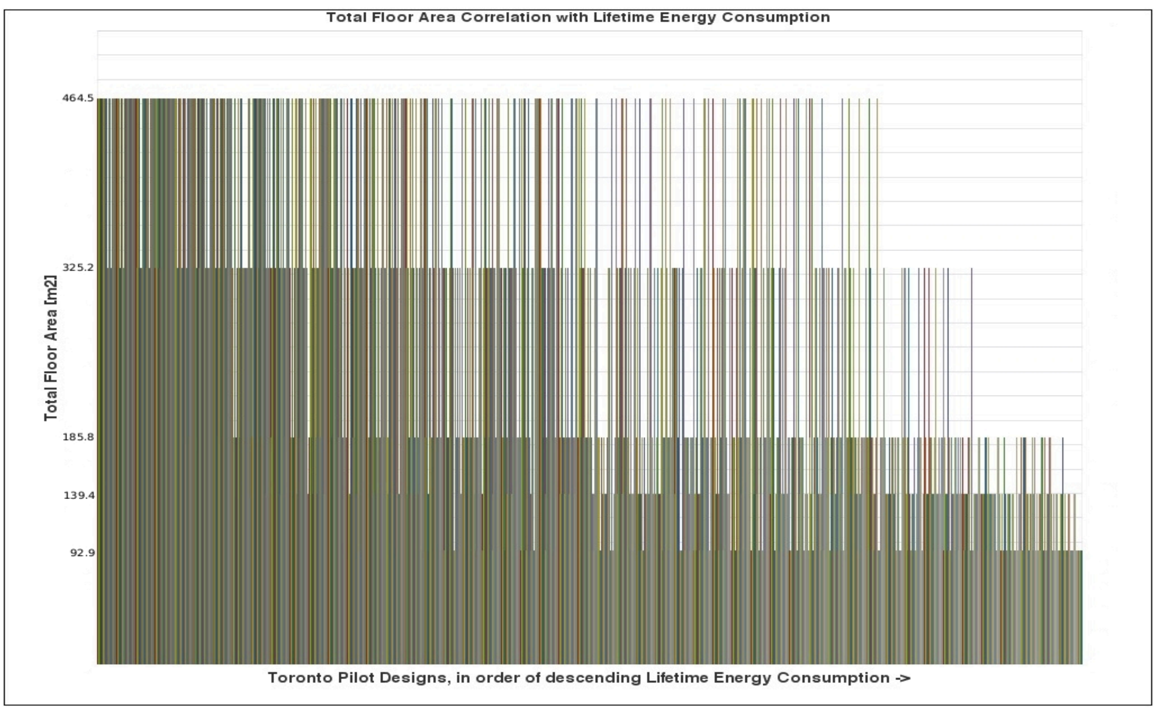

Figure 33 - Generated from the Toronto Pilot database, a plot of Total Floor area of all Toronto Pilot designs arranged in order of descending 50 year lifetime energy consumption, with electric heat, and cellulose insulation. The y axis depicts the 5 sizes of home included, 92.9m², 139.4m², 185.8m², 325.2m², and 464.5m².

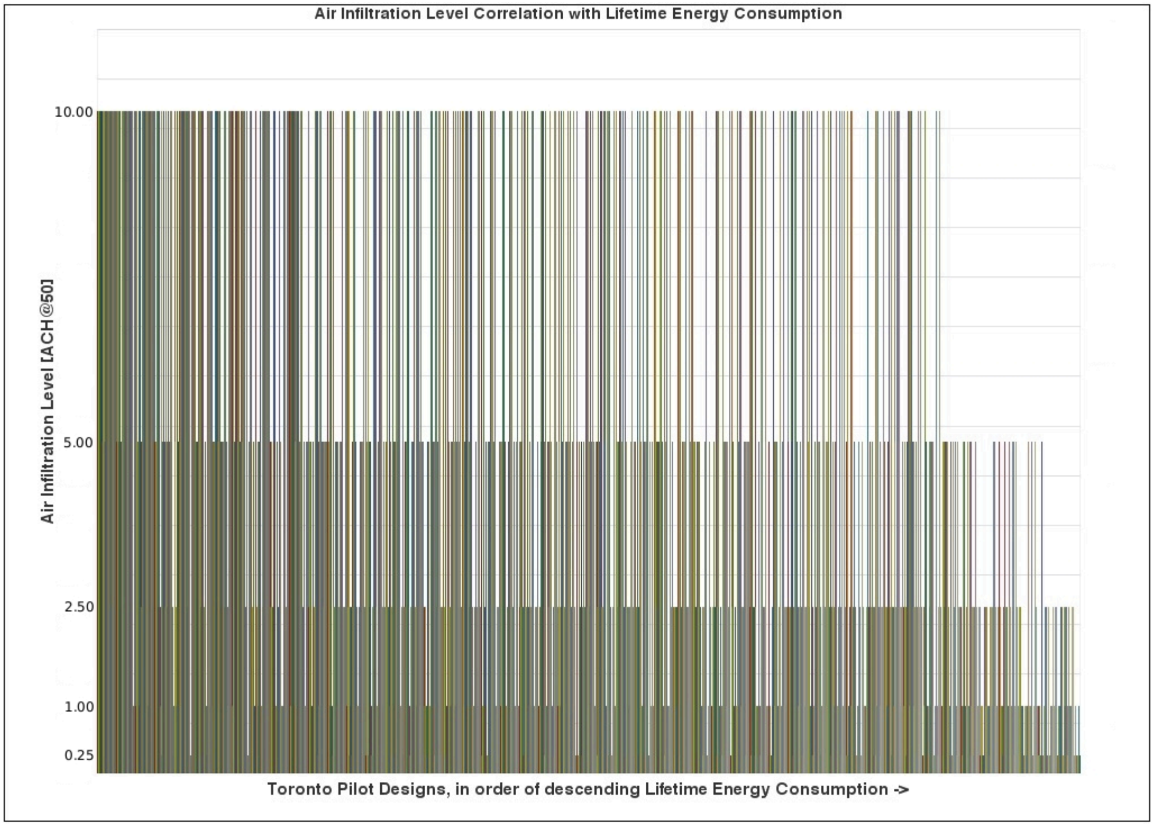

Figure 34 - Generated from the Toronto Pilot database, a plot of Infiltration level of all Toronto Pilot designs arranged in order of descending 50 year lifetime energy consumption, with electric heat, and cellulose insulation. The y axis depicts the 5 levels of infiltration tested, 10, 5, 2.5, 1, and 0.25 [ACH@50Pa].

In Figure 35, the influence of insulation level on lifetime energy consumption is shown. Very surprisingly, the relationship is quite unclear; there only seems to be a faint trend that higher insulation levels lead to lower lifetime energy consumption, which is the intuitive conclusion. It appears that the influence of disruptive parameters like varied building size, number of stories, basement presence, etc have greater effect than the level of insulation. While a statistical analysis should be conducted for validation, this appears to be an important result. If home size and configuration have greater effect on lifetime energy consumption that the level of insulation installed, the designers need to be fully aware of this fact when trying to create the best performing sustainable buildings. The influence of Shape Ratio on lifetime energy consumption is shown in Figure 36, and no tangible trend is observable using the simple example analysis method.

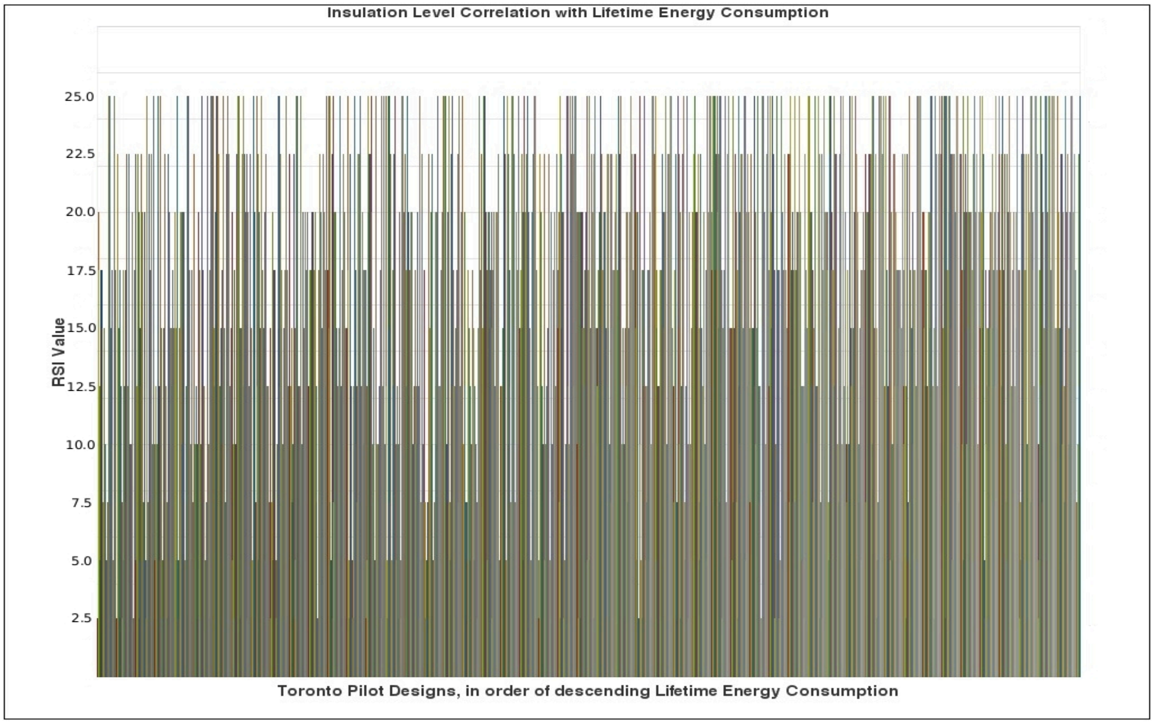

Figure 35 - Generated from the Toronto Pilot database, a plot of Insulation level of all Toronto Pilot designs arranged in descending 50 year lifetime energy consumption with electric heat, and cellulose insulation. The y axis depicts the 10 levels of insulation tested, 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, and 25 [rsi].

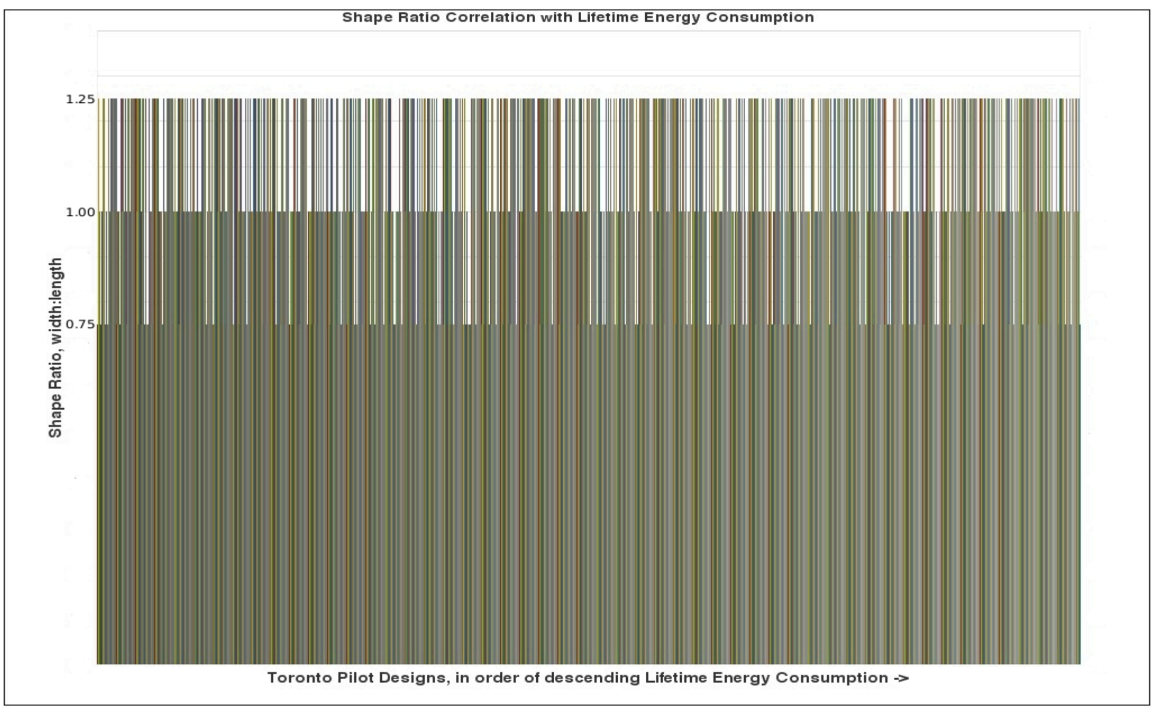

Figure 36 - Generated from the Toronto Pilot database, a plot of Shape Ratio of all Toronto Pilot designs arranged in descending 50 year lifetime energy consumption with electric heat, and cellulose insulation. The y axis depicts the 3 shape ratios 0.75, 1, and 1.25 (south width:length).

In Figure 37 below, the influence of South Window to Wall ratio is shown. Another surprise, the results are quite unclear, though a slight trend of smaller window area aiding lower lifetime energy consumption is apparent. This result is counter-intuitive, as many modern design strategies involve larger south windows to capture solar gains (Van Lengen, 2008). Indeed, high performance windows in a Toronto climate can be net producers of energy throughout the heating season, (Passive House Planning Package, 2007). It is possible that the Solar Heat Gain Factor (SHGF) of the 5 window designs is impacting the results, especially in the lower u-value units.

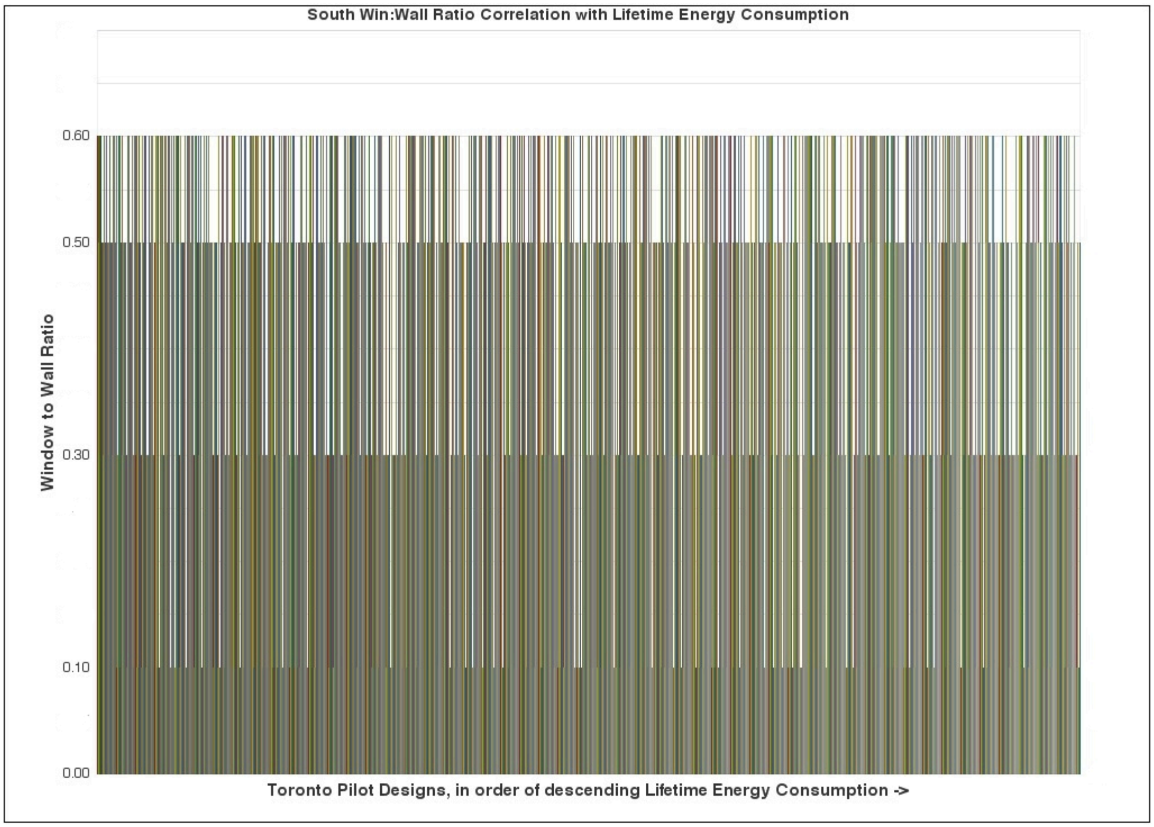

Figure 37 - Generated from the Toronto Pilot database, a plot of South Window to Wall ratio of all Toronto Pilot designs arranged in descending 50 year lifetime energy consumption with electric heat, and cellulose insulation. The y-axis depicts the 5 levels of South window area tested, 10%, 30%, 50%, and 60%.

In Figure 38, the influence of Thermal Mass is shown, and again no strong relationship is apparent, to the surprise of the author. In Figure 39 below, the influence of Window Performance level on lifetime energy consumption is shown. Here at least, the expected strong relationship is present, that lower window u-value leads to lower lifetime energy consumption.

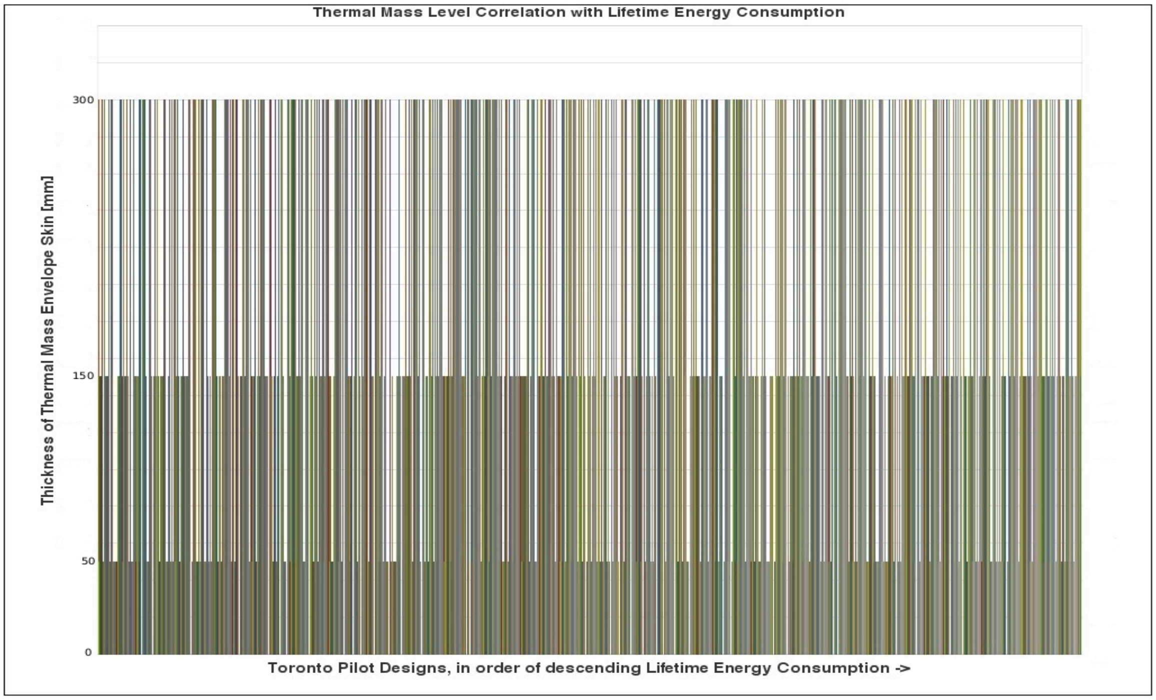

Figure 38 - Generated from the Toronto Pilot database, a plot of Thermal Mass level of all Toronto Pilot designs arranged in descending 50 year lifetime energy consumption with electric heat, and cellulose insulation. The y-axis depicts the 4 levels of Thermal Mass tested, 0.01, 50, 150, and 300 [mm] concrete within the envelope.

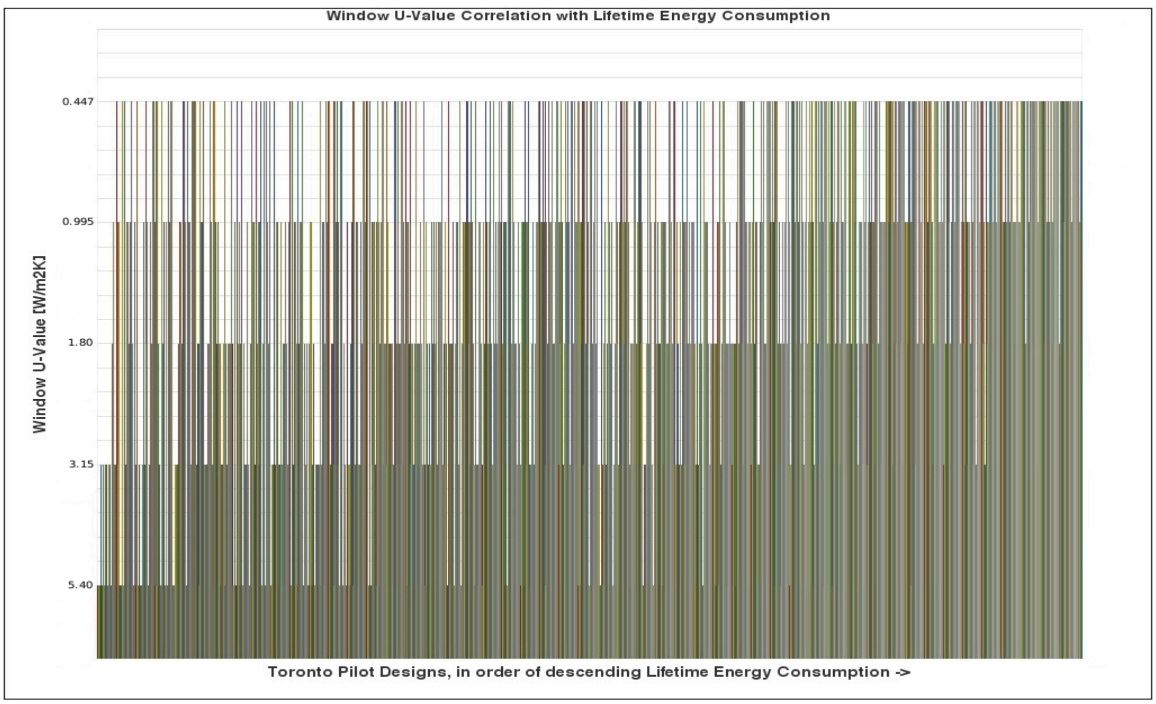

Figure 39 - Generated from the Toronto Pilot database, a plot of Window Performance level of all Toronto Pilot designs arranged in descending 50 year lifetime energy consumption with electric heat, and cellulose insulation. The y-axis depicts the 5 levels of Window Performance tested, 101- clear single glaze, 102 - clear double glaze, 103 - lowE double glaze, 104 - lowE triple glaze, and 105 - lowE quadruple glaze.

From this section's results, it would appear that certain design parameters such as window performance, infiltration level, and home size have the most dominant affect on overall lifetime energy consumption. The weaker affect of parameters like insulation level, thermal mass level, and south glazing size is unexpected. It is clear that the above process has reached the limits of visual results interpretation, and a numerical analysis is required to take the investigation further. The next two sections present a simple numerical analysis of the extreme ranges of lifetime energy consumption within the Toronto Pilot design scope.

5.2 - Top 1% and Worst 1% Performance

Extending the investigation beyond the visual analysis in section 5.1, the Toronto Pilot designs with the 1% greatest and least lifetime energy consumption are presented in this section. The frequency of occurrence of each parameter value within the least 1% lifetime energy consumption group has been tabulated in Table 20. Of these top performing 1% designs, 87.3% used a basement to increase sub-grade area, and only 12.7% did not. The other highest occurrences are found with total area (83.6% with 92.9m^2), window performance (77.6% with quadruple glazing), and infiltration (62.9% with 0.25ACH@50Pa).

For better clarity, the values in Table 20 have been plotted in Figure 40. Similar to the general trends visible in section 5.1, the concentration of single values from total area, window performance, and infiltration are dominant. In addition, however, the addition of a basement has the highest value concentration of all, and the East/West window to wall ratio of 10% has a greater than 50% occurrence. Again, contrary to the author's expectations, the occurrence frequency of insulation values, thermal mass values, and South window to wall ratio are quite balanced. It would appear that the selection of certain design values of basement, total area, window performance, and infiltration have the greatest chance of producing an extremely high performing building.

Table 20 - Frequency of occurrence for each design parameter value within the top 1% lifetime energy consumption performance (least energy consumed). Values generated using Toronto Pilot database.

NumStories	3		2		1					
Frequency (count, %)	2672	24.6%	3826	35.3%	4352	40.1%				
Basement	0		1							
Frequency (count, %)	1381	12.7%	9469	87.3%						
Total Area	464.5		325.2		185.8		139.4		92.9	
Frequency (count, %)	0	0.0%	0	0.0%	120	1.1%	1655	15.3%	9075	83.6%
Shape Ratio	0.75		1		1.25					
Frequency (count, %)	3376	31.1%	3853	35.5%	3621	33.4%				
SouthWin:Wall	0.6		0.5		0.3		0.1			
Frequency (count, %)	1869	17.2%	2175	20.0%	2940	27.1%	3866	35.6%		
East/West Win:Wall	0.5		0.3		0.1					
Frequency (count, %)	1816	16.7%	3186	29.4%	5848	53.9%				
Window Performance	101		102		103		104		105	
Frequency (count, %)	0	0.0%	28	0.3%	435	4.0%	1962	18.1%	8425	77.6%
Infiltration	0.667		0.334		0.167		0.067		0.01667	
Frequency (count, %)	0	0.0%	0	0.0%	478	4.4%	3551	32.7%	6821	62.9%
Thermal Mass	0.00001		0.05		0.15		0.3			
Frequency (count, %)	2065	19.0%	2338	21.5%	2959	27.3%	3488	32.1%		
RSI Value	2.5		5		7.5		10		12.5	
Frequency (count, %)	0	0.0%	64	0.6%	217	2.0%	473	4.4%	825	7.6%
	15		17.5		20		22.5		25	
	1154	10.6%	1521	14.0%	1871	17.2%	2222	20.5%	2503	23.1%

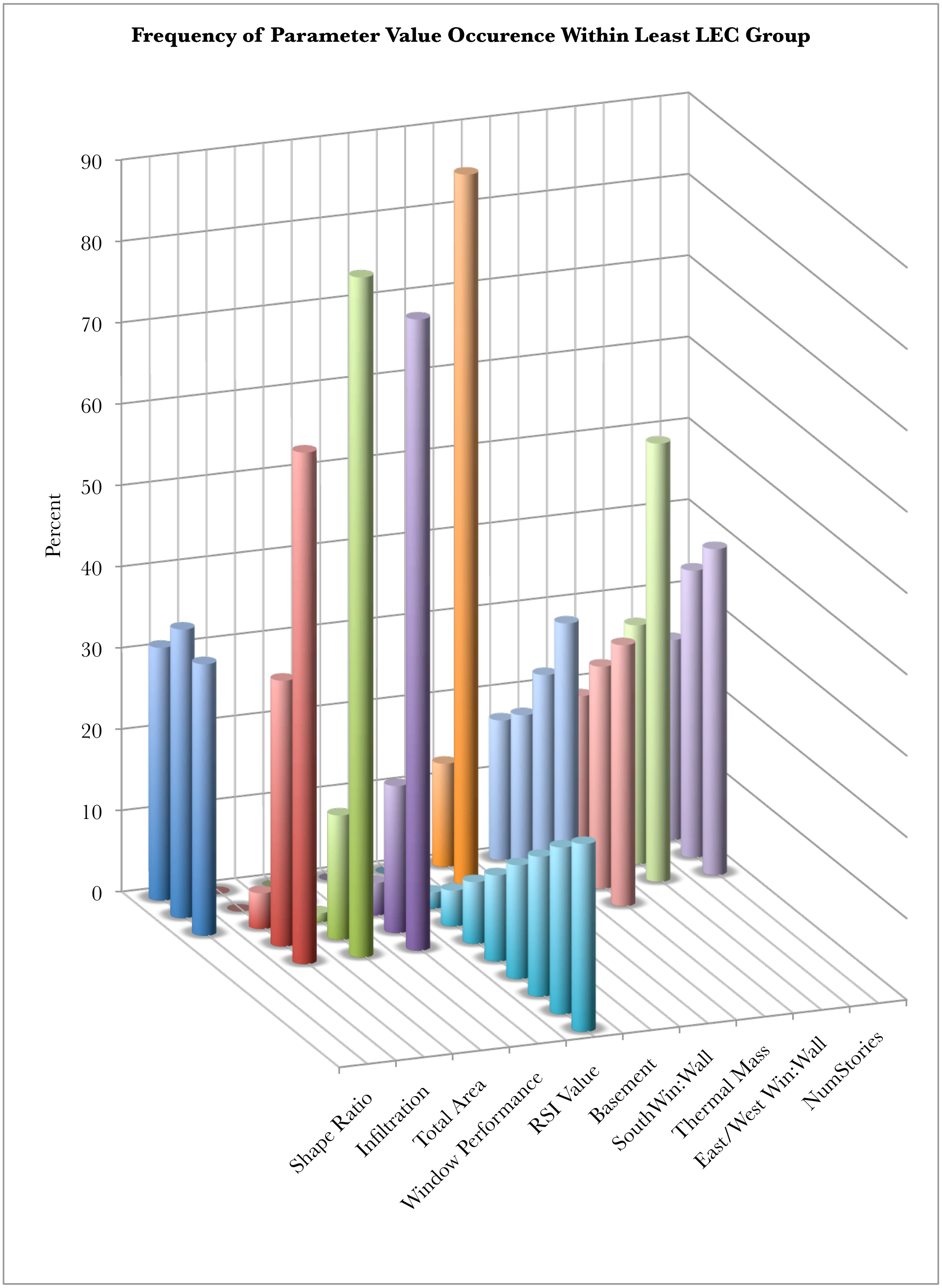

Figure 40 - Frequency of occurrence of design parameter values within the least 1% Lifetime Energy Consumption (LEC) group. Each parameter is plotted sequentially in the order of ascending frequency of occurrence.

The parameter value occurrence frequency of the greatest 1% lifetime energy consumption group is tabulated in Table 21 below. The results are similar to those of the top 1% group; certain values of infiltration, window performance, total building area, East/West glazing area, and basement have the most frequent occurrence. The data from Table 21 is plotted in Figure 41.

Table 21 - Frequency of occurrence for each design parameter value within the bottom 1% lifetime energy consumption performance (most energy consumed). Values generated using Toronto Pilot database.

NumStories	1		2		3					
Frequency (count, %)	2686	24.9%	3086	28.6%	5030	46.6%				
Basement	1		0							
Frequency (count, %)	2968	27.5%	7834	72.5%						
Total Area	92.9		139.4		185.8		325.2		464.5	
Frequency (count, %)	0	0.0%	0	0.0%	0	0.0%	877	8.1%	9925	91.9%
Shape Ratio	1.25		1		0.75					
Frequency (count, %)	3192	29.6%	3259	30.2%	4351	40.3%				
SouthWin:Wall	0.1		0.3		0.5		0.6			
Frequency (count, %)	1928	17.8%	2326	21.5%	2963	27.4%	3585	33.2%		
East/West Win:Wall	0.1		0.3		0.5					
Frequency (count, %)	1381	12.8%	3039	28.1%	6382	59.1%				
Window Performance	105		104		103		102		101	
Frequency (count, %)	152	1.4%	198	1.8%	380	3.5%	2044	18.9%	8028	74.3%
Infiltration	0.01667		0.067		0.167		0.334		0.667	
Frequency (count, %)	56	0.5%	127	1.2%	367	3.4%	1448	13.4%	8804	81.5%
Thermal Mass	0.3		0.15		0.05		0.00001			
Frequency (count, %)	1989	18.4%	2328	21.6%	2963	27.4%	3522	32.6%		
RSI Value	25		22.5		20		17.5		15	
Frequency (count, %)	634	5.9%	651	6.0%	673	6.2%	711	6.6%	754	7.0%
	12.5		10		7.5		5		2.5	
	828	7.7%	921	8.5%	1109	10.3%	1515	14.0%	3006	27.8%

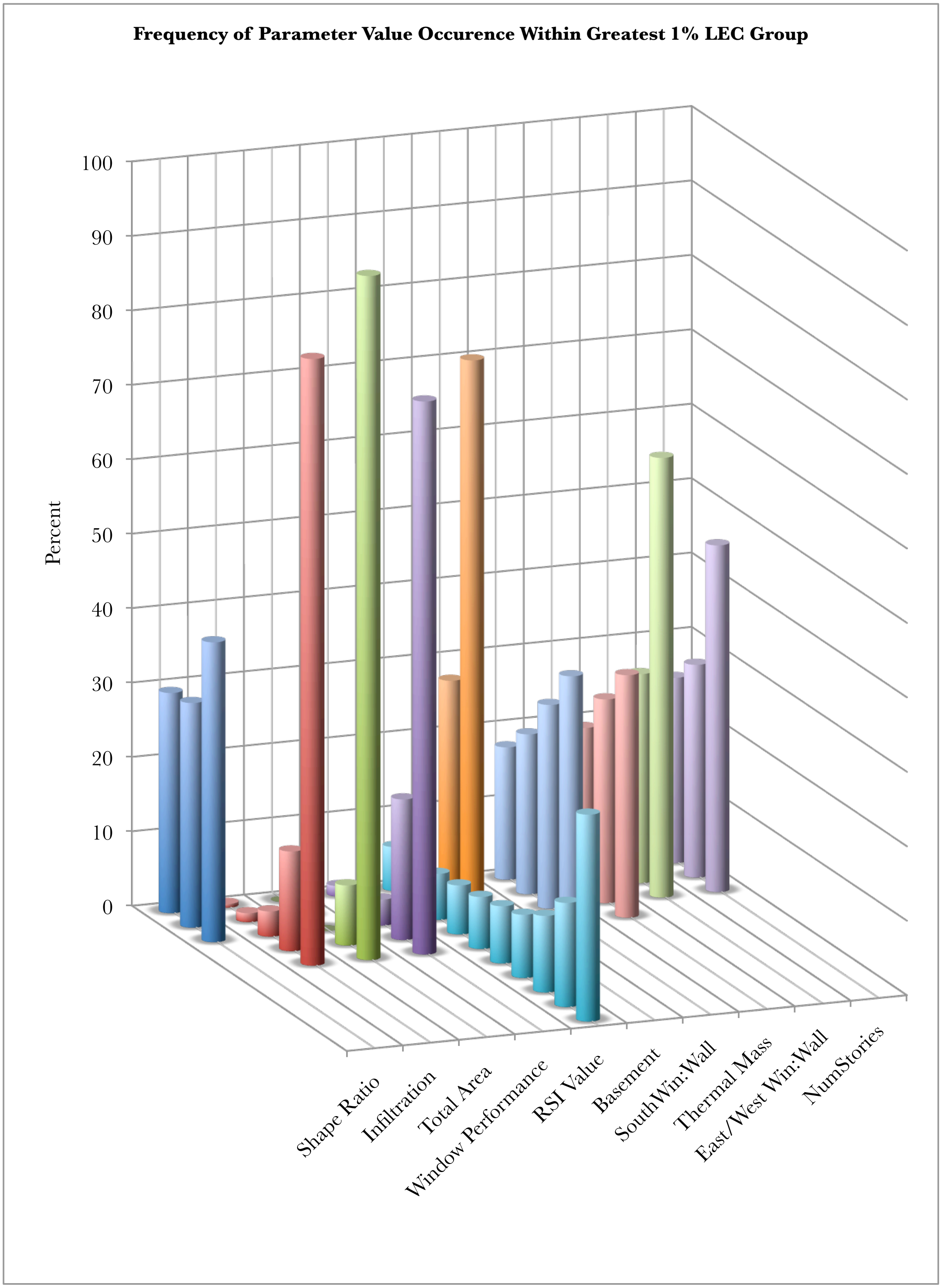

Figure 41 - Frequency of occurrence of design parameter values within the greatest 1% Lifetime Energy Consumption (LEC) group. Each parameter is plotted sequentially in the order of ascending frequency of occurrence.

These results bolster the idea that the influence of certain parameters, namely basement, total area, infiltration, window performance, and East/West window area, dominate the overall lifetime energy consumption of a building. This is not to suggest that parameters such as insulation level and South window area are irrelevant, but that perhaps the more dominant parameters should be addressed first in an optimized design process. Note that these results do not suggest that simply adding a basement to an existing home design will result in a reduction of lifetime energy consumption. Figure 42 elaborates on the definition of geometry within the Toronto Pilot.

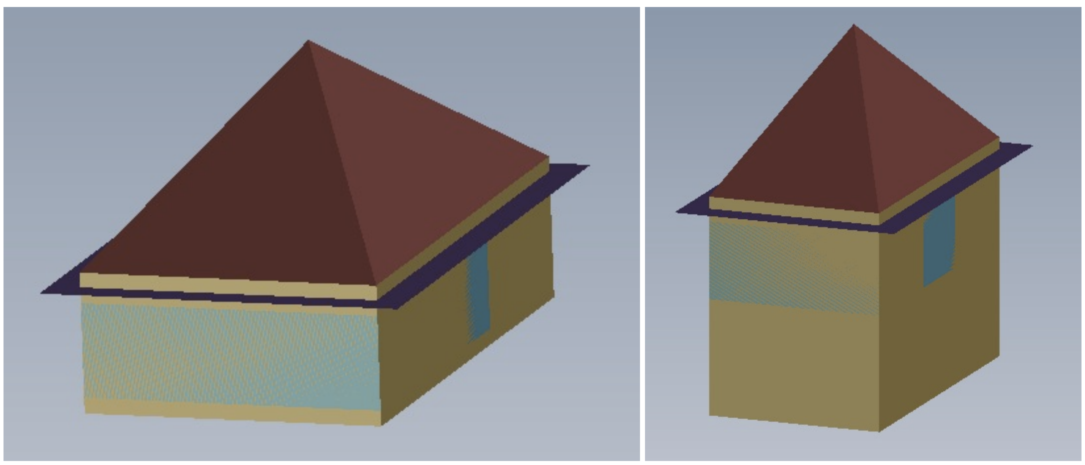

Figure 42 - Two designs with identical design parameters, except that the right has a basement and the left does not. All geometry within the Toronto Pilot is defined in this manner; the basement's sub-grade area is included in the Total Floor Area.

Basement area is included in the building's total area as defined in the Toronto Pilot. The results are suggesting that for a 100m^2 home, the lowest lifetime energy consumption occurs if 50m^2 of this area is underground, instead of all above ground. Figure 42 shows a 100m^2 single floor home and a 100m^2 single floor home with basement; it is clear why the later consumes less energy. It is highly interesting that simple geometry changes like this appear to have the greatest impact on lifetime energy consumption.

5.3 - Top 50 and Worst 50 Designs

To give the reader a better understanding of the design scenarios that make up the Toronto Pilot, this section presents the complete design makeup and overall performance of the top 50 and bottom 50 permutations, in Table 22 and Table 23.

Table 22 - Top performing 50 designs within Toronto Pilot scope, under 50 year lifetime of energy usage with electric heating and cellulose insulation.

#	# Stor	Basement	Total Area [m²]	Shape Ratio	South W:W Ratio	E/W W:W Ratio	North W:W Ratio	Wind. Cons.	Infiltr. [@50Pa]	Insul Level [rsi]	Therm Mass [m]	Win Emb [MWh /25yr]	T.M. Emb. [MWh]	Cell. Insul. Emb. [MWh]	Prim. Ener. [MWh /yr]	50yr LCA [MWh]
1	2	1	92.90	1.25	0.1	0.1	0.1	105	0.25	25	0.000	0.79	0.00	3.22	1.54	81.84
2	2	1	92.90	1.00	0.1	0.1	0.1	105	0.25	25	0.000	0.77	0.00	3.17	1.55	82.16
3	3	1	92.90	1.25	0.1	0.1	0.1	105	0.25	25	0.000	0.68	0.00	3.36	1.58	83.94
4	2	1	92.90	0.75	0.1	0.1	0.1	105	0.25	25	0.000	0.80	0.00	3.26	1.60	84.68
5	3	1	92.90	1.00	0.1	0.1	0.1	105	0.25	25	0.000	0.67	0.00	3.30	1.61	84.99
6	2	1	92.90	1.00	0.1	0.1	0.1	105	0.25	23	0.000	0.77	0.00	2.85	1.62	85.58
7	2	1	92.90	1.25	0.1	0.1	0.1	105	0.25	23	0.000	0.79	0.00	2.90	1.62	85.60
8	2	1	92.90	1.25	0.1	0.1	0.1	105	0.25	25	0.050	0.79	6.29	3.22	1.51	86.71
9	2	1	92.90	1.00	0.1	0.1	0.1	105	0.25	25	0.050	0.77	6.17	3.17	1.52	86.98
10	1	1	92.90	1.25	0.1	0.1	0.1	105	0.25	25	0.000	0.97	0.00	3.25	1.65	87.84
11	1	1	92.90	1.00	0.1	0.1	0.1	105	0.25	25	0.000	0.94	0.00	3.21	1.66	88.20
12	3	1	92.90	1.25	0.1	0.1	0.1	105	0.25	25	0.050	0.68	6.70	3.36	1.54	88.24
13	3	1	92.90	0.75	0.1	0.1	0.1	105	0.25	25	0.000	0.70	0.00	3.40	1.67	88.36
14	2	1	92.90	0.75	0.1	0.1	0.1	105	0.25	23	0.000	0.80	0.00	2.93	1.68	88.45
15	3	1	92.90	1.00	0.1	0.1	0.1	105	0.25	25	0.050	0.67	6.57	3.30	1.56	89.38
16	2	1	92.90	1.00	0.3	0.1	0.1	105	0.25	25	0.000	1.16	0.00	3.08	1.68	89.48
17	2	1	92.90	1.25	0.1	0.1	0.1	105	0.25	23	0.050	0.79	6.29	2.90	1.58	89.52
18	1	1	92.90	1.25	0.1	0.1	0.1	105	0.25	23	0.000	0.97	0.00	2.93	1.69	89.59
19	2	1	92.90	1.00	0.1	0.1	0.1	105	0.25	23	0.050	0.77	6.17	2.85	1.58	89.62
20	2	1	92.90	0.75	0.1	0.1	0.1	105	0.25	25	0.050	0.80	6.36	3.26	1.57	89.65
21	1	1	92.90	0.75	0.1	0.1	0.1	105	0.25	25	0.000	0.98	0.00	3.28	1.69	89.69
22	3	1	92.90	1.25	0.1	0.1	0.1	105	0.25	23	0.000	0.68	0.00	3.02	1.71	89.73
23	1	1	92.90	1.00	0.1	0.1	0.1	105	0.25	23	0.000	0.94	0.00	2.89	1.70	89.78
24	3	1	92.90	1.00	0.1	0.1	0.1	105	0.25	23	0.000	0.67	0.00	2.97	1.71	89.93
25	2	1	92.90	0.75	0.3	0.1	0.1	105	0.25	25	0.000	1.09	0.00	3.19	1.69	89.97
26	2	1	92.90	1.00	0.1	0.1	0.1	105	0.25	20	0.000	0.77	0.00	2.53	1.74	90.87
27	1	1	92.90	1.00	0.3	0.1	0.1	105	0.25	25	0.000	1.42	0.00	3.16	1.70	90.91
28	2	1	92.90	1.25	0.3	0.1	0.1	105	0.25	25	0.000	1.27	0.00	3.11	1.71	90.98
29	1	1	92.90	0.75	0.3	0.1	0.1	105	0.25	25	0.000	1.34	0.00	3.24	1.70	91.16
30	2	1	92.90	1.25	0.1	0.1	0.1	105	0.25	20	0.000	0.79	0.00	2.58	1.74	91.22
31	1	1	92.90	0.75	0.1	0.1	0.1	105	0.25	23	0.000	0.98	0.00	2.95	1.73	91.52
32	1	1	92.90	1.25	0.3	0.1	0.1	105	0.25	25	0.000	1.56	0.00	3.19	1.71	91.98
33	1	1	92.90	1.00	0.3	0.1	0.1	105	0.25	23	0.000	1.42	0.00	2.84	1.73	92.28
34	2	1	92.90	0.75	0.1	0.1	0.1	105	0.25	23	0.050	0.80	6.36	2.93	1.63	92.47
35	1	1	92.90	1.25	0.1	0.1	0.1	105	0.25	20	0.000	0.97	0.00	2.60	1.76	92.47
36	1	1	92.90	1.00	0.1	0.1	0.1	105	0.25	20	0.000	0.94	0.00	2.57	1.76	92.57
37	2	1	92.90	1.00	0.3	0.1	0.1	105	0.25	23	0.000	1.16	0.00	2.77	1.75	92.77
38	3	1	92.90	1.25	0.1	0.1	0.1	105	0.25	23	0.050	0.68	6.70	3.02	1.63	92.83
39	1	1	92.90	0.75	0.3	0.1	0.1	105	0.25	23	0.000	1.34	0.00	2.92	1.74	92.84
40	3	1	92.90	0.75	0.1	0.1	0.1	105	0.25	25	0.050	0.70	6.79	3.40	1.63	92.99
41	3	1	92.90	1.00	0.1	0.1	0.1	105	0.25	23	0.050	0.67	6.57	2.97	1.65	93.33
42	1	1	92.90	1.25	0.1	0.1	0.1	105	0.25	25	0.050	0.97	6.09	3.25	1.64	93.41
43	1	1	92.90	1.25	0.3	0.1	0.1	105	0.25	23	0.000	1.56	0.00	2.87	1.75	93.43
44	2	1	92.90	0.75	0.3	0.1	0.1	105	0.25	23	0.000	1.09	0.00	2.87	1.77	93.49
45	1	1	92.90	1.00	0.1	0.1	0.1	105	0.25	25	0.050	0.94	5.99	3.21	1.65	93.74
46	3	1	92.90	0.75	0.1	0.1	0.1	105	0.25	23	0.000	0.70	0.00	3.06	1.79	93.75
47	2	1	92.90	1.00	0.1	0.1	0.1	105	0.25	20	0.050	0.77	6.17	2.53	1.67	93.84
48	2	1	92.90	1.25	0.1	0.1	0.1	105	0.25	20	0.050	0.79	6.29	2.58	1.67	94.03
49	2	1	92.90	1.00	0.3	0.1	0.1	105	0.25	25	0.050	1.16	6.09	3.08	1.65	94.14
50	2	1	92.90	0.75	0.1	0.1	0.1	105	0.25	20	0.000	0.80	0.00	2.61	1.80	94.17

Scanning over the design parameters present in Table 22, the high frequency of certain parameters is again visible. Within the top 50 performers, all have a basement, minimal total area, minimal glazing on the East and West exposures, maximum window performance, and minimum infiltration. Within this tiny sub-group, there is high frequency of minimal south glazing, high levels of insulation, and low levels of thermal mass. Among the worst 50 performers, the 1% results carry through, with a very high occurrence frequency of no basement, maximum total area, maximum East/West glazing, minimal window performance, and maximum infiltration. Again, as compared to the 1% analysis, there are additionally frequent values of maximum number of stories, maximum South glazing, minimal insulation, and minimal thermal mass. These two groups are statistically insignificant however, at less than 1/10000th of a percent of the population, so these results are shown more as a snapshot of how the design parameters describe a home, and less for trend investigation.

Table 22 and Table 23 give the reader some idea of the magnitude of data generated with the Full Scope Optimization method. Consider that, with 50 entries per page, simply listing the full definition of the 1 080 000 different design scenarios within the Toronto Pilot would require 21 600 pages. All told, the 700GB of data generated for this project simply cannot be represented in paper form. For these reasons, only a sample `.IDF` file has been included in Appendix D. If the reader requires a deeper look at the Toronto Pilot data, all data are all available electronically.

Table 23 - Worst performing 50 designs within Toronto Pilot scope, under 50-year lifetime of energy usage with electric heating and cellulose insulation.

#	# Stor.	Basement	Total Area [m²]	Shape Ratio	South W:W Ratio	E/W W:W Ratio	North W:W Ratio	Wind. Cons.	Infiltr. [@50]	Insul Level [rsi]	Therm Mass [m]	Win Emb [MWh /25yr]	T.M. Emb. [MWh]	Cell. Insul. Emb. [kWh]	Prim. Ener. [MWh /yr]	50yr LCA [MWh]
1	3	0	464.5	0.75	60%	50%	10%	101	10	2.5	0.000	2.0	0.0	865	110.8	5545
2	3	0	464.5	0.75	50%	50%	10%	101	10	2.5	0.000	1.9	0.0	875	109.8	5494
3	3	0	464.5	0.75	60%	50%	10%	101	10	2.5	0.050	2.0	17.1	865	107.9	5416
4	3	0	464.5	0.75	30%	50%	10%	101	10	2.5	0.000	1.8	0.0	897	107.8	5396
5	3	0	464.5	0.75	50%	50%	10%	101	10	2.5	0.050	1.9	17.1	875	106.7	5357
6	3	0	464.5	0.75	10%	50%	10%	101	10	2.5	0.000	1.6	0.0	919	106.1	5311
7	3	0	464.5	1.25	60%	50%	10%	101	10	2.5	0.000	1.8	0.0	882	105.9	5297
8	3	0	464.5	1.00	60%	50%	10%	101	10	2.5	0.000	1.8	0.0	863	105.9	5297
9	1	0	464.5	0.75	60%	50%	10%	101	10	2.5	0.000	3.5	0.0	1779	105.3	5272
10	1	0	464.5	0.75	50%	50%	10%	101	10	2.5	0.000	3.3	0.0	1785	104.8	5247
11	3	0	464.5	0.75	30%	50%	10%	101	10	2.5	0.050	1.8	17.3	897	104.5	5247
12	2	0	464.5	0.75	60%	50%	10%	101	10	2.5	0.000	2.4	0.0	1067	104.4	5224
13	3	0	464.5	0.75	60%	50%	10%	101	10	5.0	0.000	2.0	0.0	1729	104.2	5217
14	3	0	464.5	1.00	50%	50%	10%	101	10	2.5	0.000	1.7	0.0	878	104.2	5214
15	3	0	464.5	0.75	60%	50%	10%	101	10	2.5	0.150	2.0	51.2	865	102.9	5202
16	1	0	464.5	0.75	30%	50%	10%	101	10	2.5	0.000	3.0	0.0	1798	103.9	5202
17	2	0	464.5	0.75	50%	50%	10%	101	10	2.5	0.000	2.3	0.0	1076	103.5	5181
18	3	0	464.5	1.25	50%	50%	10%	101	10	2.5	0.000	1.7	0.0	900	103.5	5179
19	3	0	464.5	0.75	60%	50%	10%	101	10	5.0	0.050	2.0	17.1	1729	103.1	5177
20	3	0	464.5	1.00	60%	50%	10%	101	10	2.5	0.050	1.8	16.8	863	102.9	5166
21	3	0	464.5	1.25	60%	50%	10%	101	10	2.5	0.050	1.8	17.0	882	102.9	5165
22	1	0	464.5	0.75	10%	50%	10%	101	10	2.5	0.000	2.8	0.0	1810	103.1	5160
23	3	0	464.5	0.75	10%	50%	10%	101	10	2.5	0.050	1.6	17.4	919	102.6	5152
24	3	0	464.5	0.75	50%	50%	10%	101	10	5.0	0.000	1.9	0.0	1751	102.9	5149
25	3	0	464.5	0.75	50%	50%	10%	101	10	2.5	0.150	1.9	51.4	875	101.6	5134
26	1	0	464.5	1.00	60%	50%	10%	101	10	2.5	0.000	3.2	0.0	1778	102.1	5111
27	3	0	464.5	0.75	50%	50%	10%	101	10	5.0	0.050	1.9	17.1	1751	101.6	5105
28	3	0	464.5	0.75	60%	50%	10%	101	10	2.5	0.300	2.0	102.4	865	99.9	5100
29	2	0	464.5	0.75	30%	50%	10%	101	10	2.5	0.000	2.2	0.0	1094	101.9	5100
30	3	0	464.5	0.75	60%	50%	10%	101	10	5.0	0.150	2.0	51.2	1729	100.7	5091
31	1	0	464.5	1.25	60%	50%	10%	101	10	2.5	0.000	3.1	0.0	1789	101.6	5090
32	3	0	464.5	0.75	60%	50%	10%	101	10	7.5	0.000	2.0	0.0	2594	101.6	5088
33	2	0	464.5	0.75	60%	50%	10%	101	10	2.5	0.050	2.4	18.4	1067	101.2	5086
34	1	0	464.5	1.00	50%	50%	10%	101	10	2.5	0.000	3.0	0.0	1787	101.3	5075
35	3	0	464.5	0.75	60%	50%	10%	101	10	5.0	0.300	2.0	102.4	1729	99.3	5074
36	3	0	464.5	1.00	50%	50%	10%	101	10	2.5	0.050	1.7	16.8	878	101.0	5072
37	3	0	464.5	0.75	60%	50%	10%	101	10	7.5	0.050	2.0	17.1	2594	101.0	5072
38	3	1	464.5	0.75	60%	50%	10%	101	10	2.5	0.000	1.7	0.0	798	101.3	5069
39	3	0	464.5	1.00	30%	50%	10%	101	10	2.5	0.000	1.5	0.0	907	101.2	5066
40	1	0	464.5	0.75	60%	50%	10%	101	10	2.5	0.050	3.5	22.6	1779	100.6	5061
41	3	0	464.5	0.75	60%	50%	10%	101	10	7.5	0.300	2.0	102.4	2594	98.8	5050
42	1	0	464.5	1.25	50%	50%	10%	101	10	2.5	0.000	2.9	0.0	1799	100.6	5039
43	3	0	464.5	0.75	60%	50%	10%	101	10	7.5	0.150	2.0	51.2	2594	99.6	5039
44	2	0	464.5	0.75	50%	50%	10%	101	10	2.5	0.050	2.3	18.4	1076	100.3	5037
45	3	0	464.5	1.25	50%	50%	10%	101	10	2.5	0.050	1.7	17.2	900	100.3	5035
46	1	0	464.5	0.75	50%	50%	10%	101	10	2.5	0.050	3.3	22.8	1785	100.0	5032
47	2	0	464.5	0.75	10%	50%	10%	101	10	2.5	0.000	2.0	0.0	1112	100.5	5030
48	3	0	464.5	0.75	60%	50%	10%	101	10	10.0	0.300	2.0	102.4	3458	98.3	5027
49	3	0	464.5	0.75	50%	50%	10%	101	10	2.5	0.300	1.9	102.8	875	98.4	5027
50	3	1	464.5	0.75	50%	50%	10%	101	10	2.5	0.000	1.7	0.0	807	100.4	5023

5.4 - 2006 OBC and the Toronto Pilot

The designs within the Toronto Pilot with values that approximate the 2006 Ontario Building Code (OBC) requirements, i.e. `RSI 7.5` ceiling, windows with a U value of `1.8[W/m²K]`, and an air tightness of `5ACH@50Pa`, consume on average 1350 MWh over a 50 year lifetime with cellulose insulation and electric heating. This 2006 OBC performance has been plotted as a black dot within the entire Toronto Pilot performance range, in Figure 43. Within the full performance scope of the entire Toronto Pilot, an OBC 2006 building consumes roughly 10 times less energy than the worst performer, but roughly 10 times more energy than the best performer. When observing the approximate OBC design's location on Figure 43, the build code appears prescribe a design that has moderately low lifetime energy efficiency, within the scale of the Toronto Pilot.

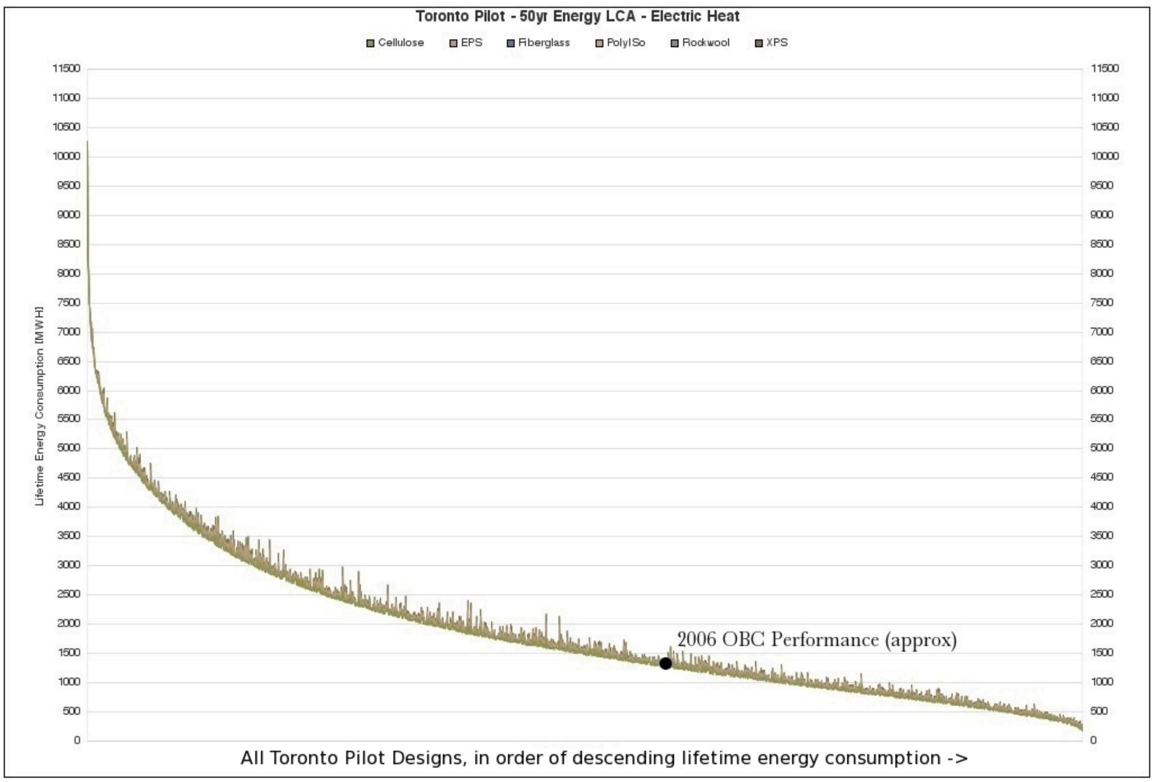

Figure 43 - The 50 year Lifetime Energy Consumption for all Toronto Pilot building designs, using electric heating and cooling. The total lifetime energy consumption of each design is plotted for each type of insulation installed, in order of descending consumption. The approximate performance of a 2006 Ontario Building Code design is denoted by a black dot (Ontario Ministry of Municipal Affairs and Housing-Building and Development Branch, 2008).

However, recalling the data discussed in the introduction, the likely cost-optimized Ontario Building Codes have not been effective at reducing the consumption of energy to a level that doesn't consume nonrenewable resources at an unsustainable rate, nor have they been effective at reducing pollution rates such as carbon dioxide emissions. With this in mind, future new building and retrofitting designs must strive for a performance with a much lower lifetime consumption of energy than code levels. The full range of lifetime energy consumption of the OBC equipped homes is shown in Figure 44.

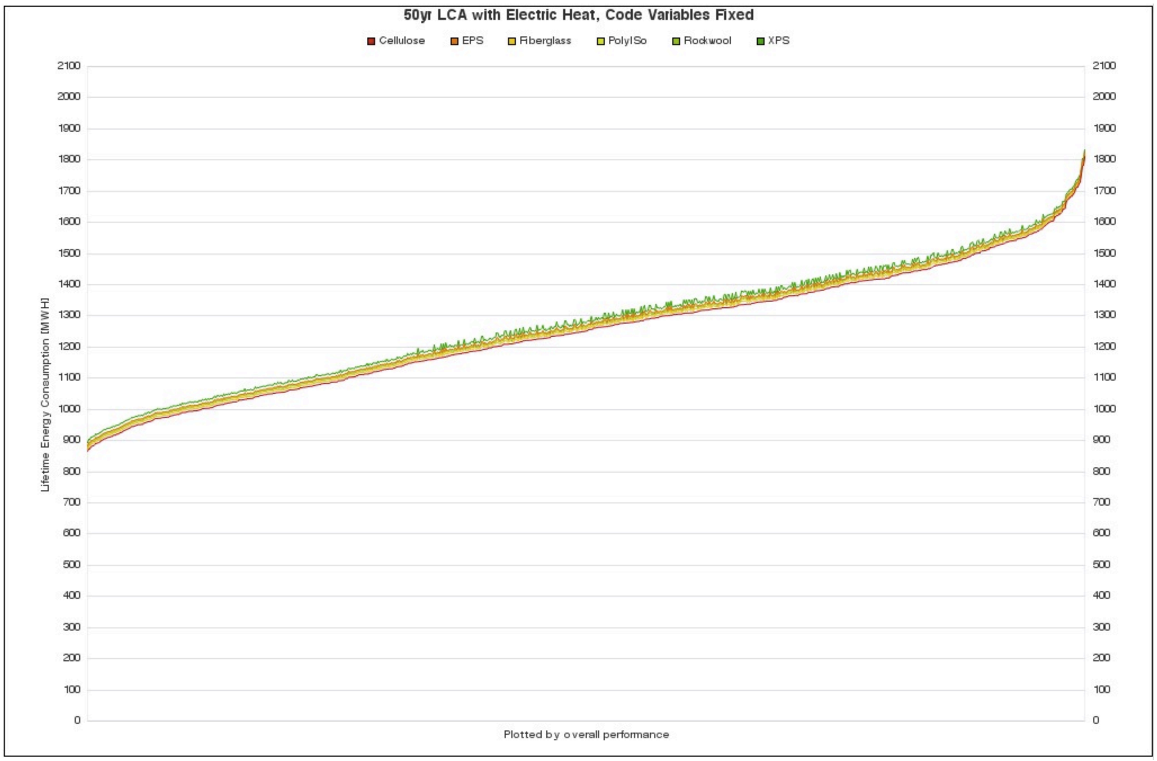

Figure 44 - Range of 50 year lifetime energy consumption of Toronto Pilot designs, when insulation, window performance, and air tightness are held constant at approximately 2006 Ontario Building Code levels of 7.5 rsi ceiling, 1.8 W/m2K windows, and 5ACH@50Pa. Total area is also held constant at the Canadian average of approximately 139.4m².

The performance varies in a somewhat linear fashion over a range of approximately 874 MWh to 1833 MWh total lifetime energy consumption. The next step is to plot each parameter versus overall lifetime energy consumption to see which parameters have the most dominant effect on lifetime energy consumption. The influence of basement, number of stories, East/West glazing, South glazing, shape ratio, and thermal mass on total lifetime energy consumption are shown in the following pages in Figure 45 - Figure 50.

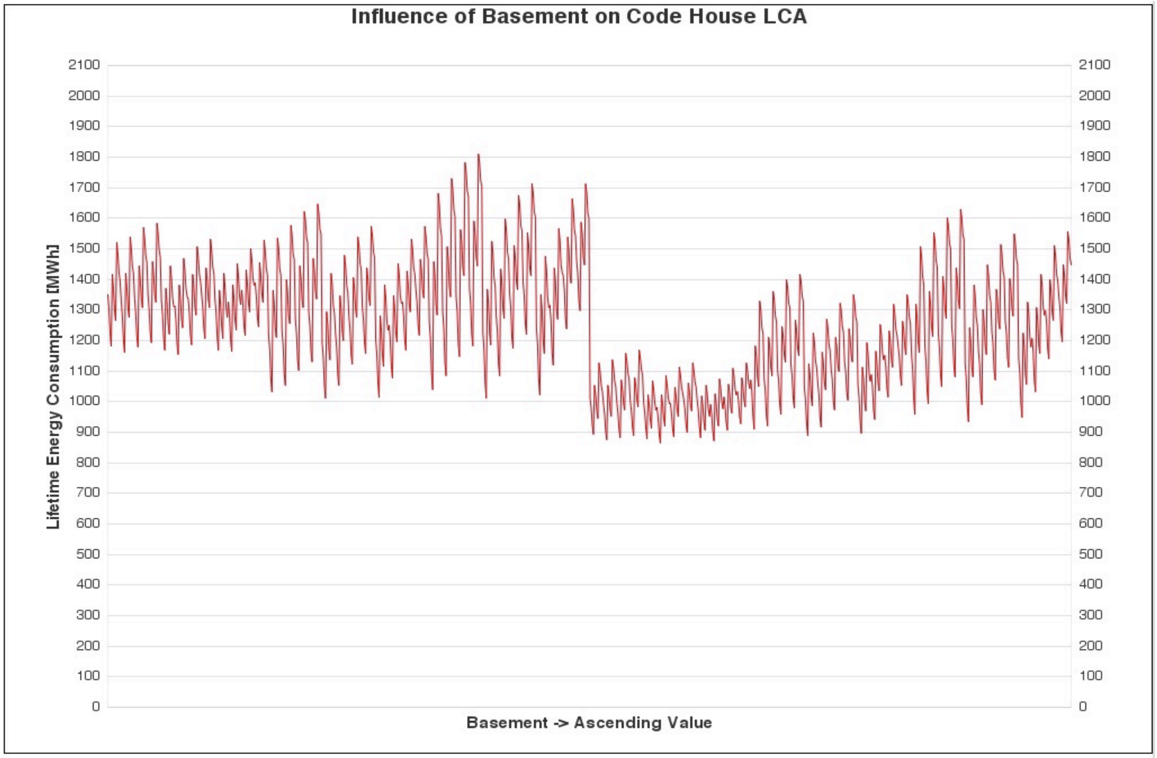

Figure 45 - Influence of basement on lifetime energy consumption of Toronto Pilot designs with insulation, window performance, and air tightness held constant at approximate 2006 Ontario Building Code levels, and total size held constant at Canadian Average home size. 50 year lifetime with electric heating and cellulose insulation also constant.

Shown above, the influence of a basement on lifetime energy consumption is apparent. The right half of the plot in Figure 45, shows that designing with 50% sub grade floor area can drop the overall consumption by roughly 30%, when looking at a single storey building. Figure 45 and Figure 46 correlate nicely; the impact of 1-3 stories, with and without basements disrupts the plot into six fairly distinct zones. It would appear that designing with a basement has less affects as the number of stories increases, as the ratio of sub-grade surface area to above ground surface area decreases, which is intuitive. It would also appear that increasing the number of stories tends to slightly increase consumption, but the total exposed surface area of the building likely drives this.

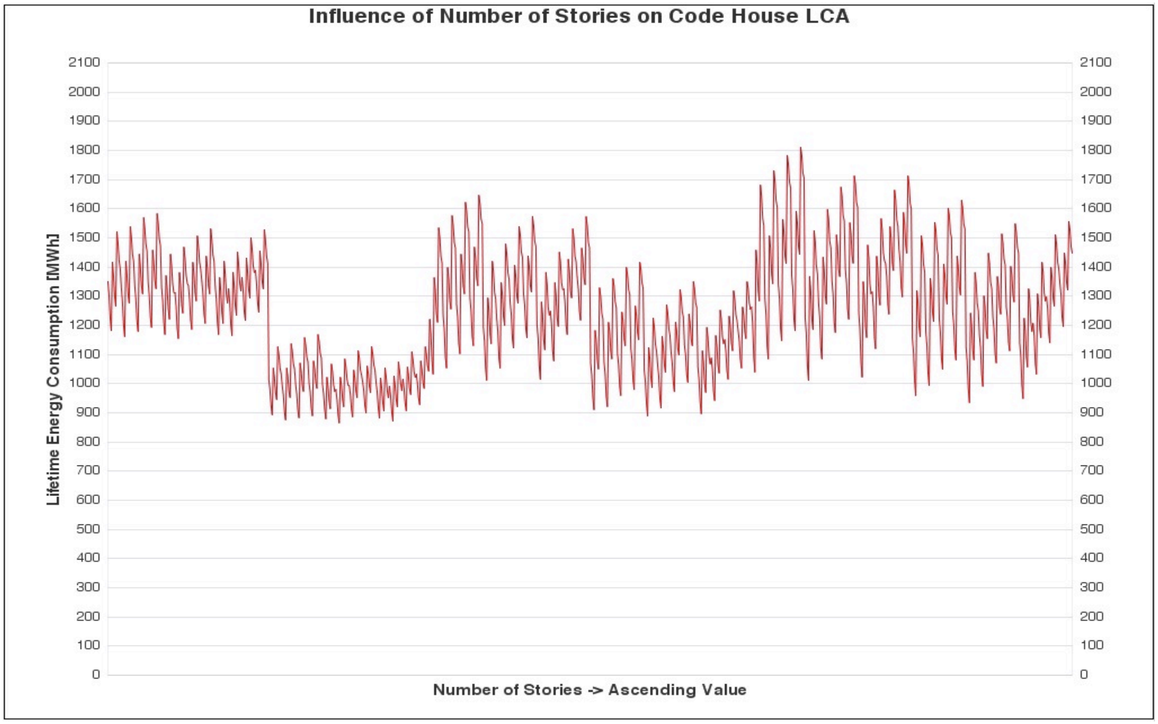

Figure 46 - Influence of number of stories on lifetime energy consumption of Toronto Pilot designs with insulation, window performance, and air tightness held constant at approximate 2006 Ontario Building Code levels, and total size held constant at Canadian Average home size. 50 year lifetime with electric heating and cellulose insulation also constant.

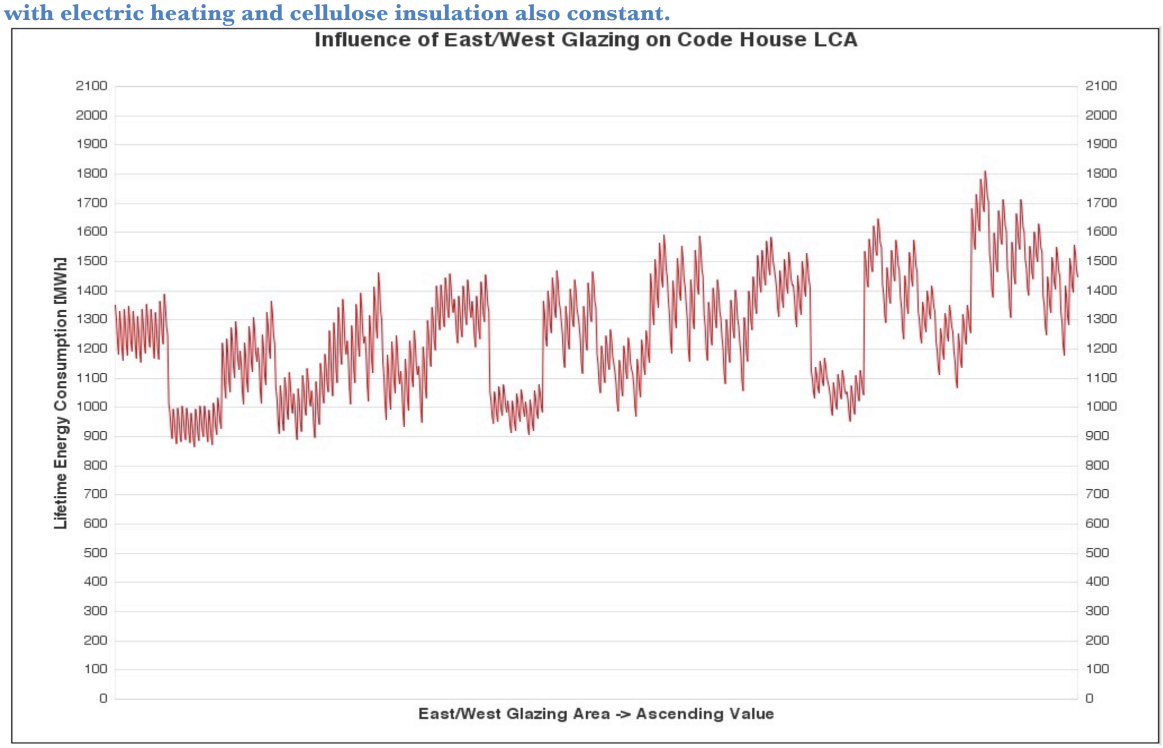

Figure 47 - Influence of East/West glazing ratio on lifetime energy consumption of Toronto Pilot designs with insulation, window performance, and air tightness held constant at approximate 2006 Ontario Building Code levels, and total size held constant at Canadian Average home size. 50 year lifetime with electric heating and cellulose insulation also constant.

Shown in Figure 47 and Figure 48, increased levels of glazing generally tend to increase the lifetime energy consumption of the code building. The relationship seems slightly stronger for East/West glazing than for South glazing. It would appear that windows, as designed in the Toronto Pilot, cause an increase of energy consumption over a building's lifetime. This result is not expected, as high performance windows can often provide a net increase in energy efficiency due to winter solar gains in heating dominated climates (Passive House Planning Package, 2007). It is also not clear which other design parameters are causing the fragmentation of the glazing curves.

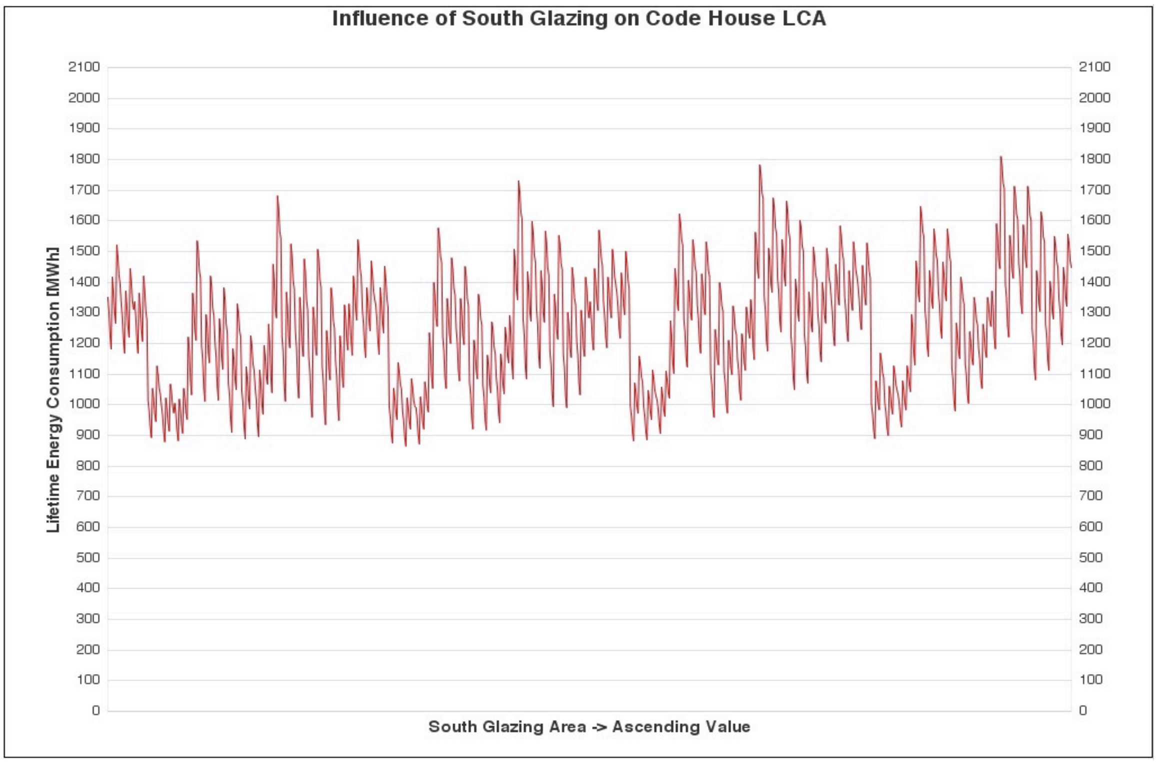

Figure 48 - Influence of South glazing ratio on lifetime energy consumption of Toronto Pilot designs with insulation, window performance, and air tightness held constant at approximate 2006 Ontario Building Code levels, and total size held constant at Canadian Average home size. 50 year lifetime with electric heating and cellulose insulation also constant.

Finally, the influence of Shape Ratio and Thermal Mass are shown in Figure 49 and Figure 50, respectively. Neither parameter seems to have an observationally definable effect on lifetime energy consumption. With statistical analysis, perhaps these relationships can be better defined.

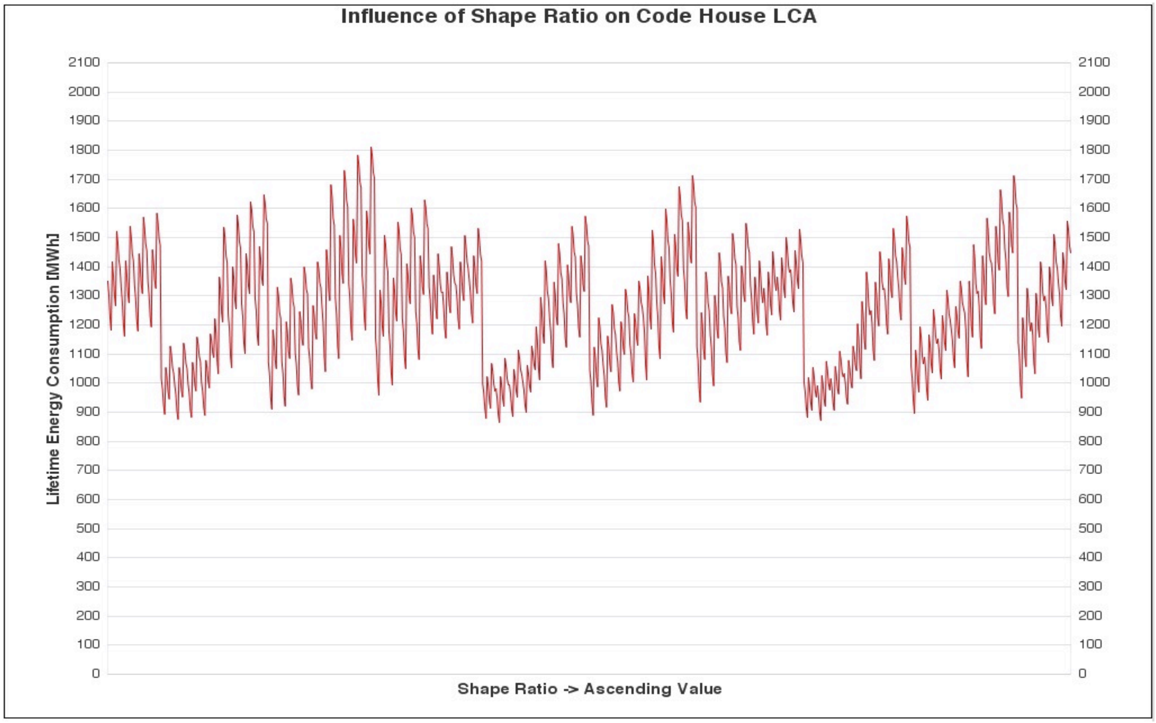

Figure 49 - Influence of Shape Ratio on lifetime energy consumption of Toronto Pilot designs with insulation, window performance, and air tightness held constant at approximate 2006 Ontario Building Code levels, and total size held constant at Canadian Average home size. 50 year lifetime with electric heating and cellulose insulation also constant.

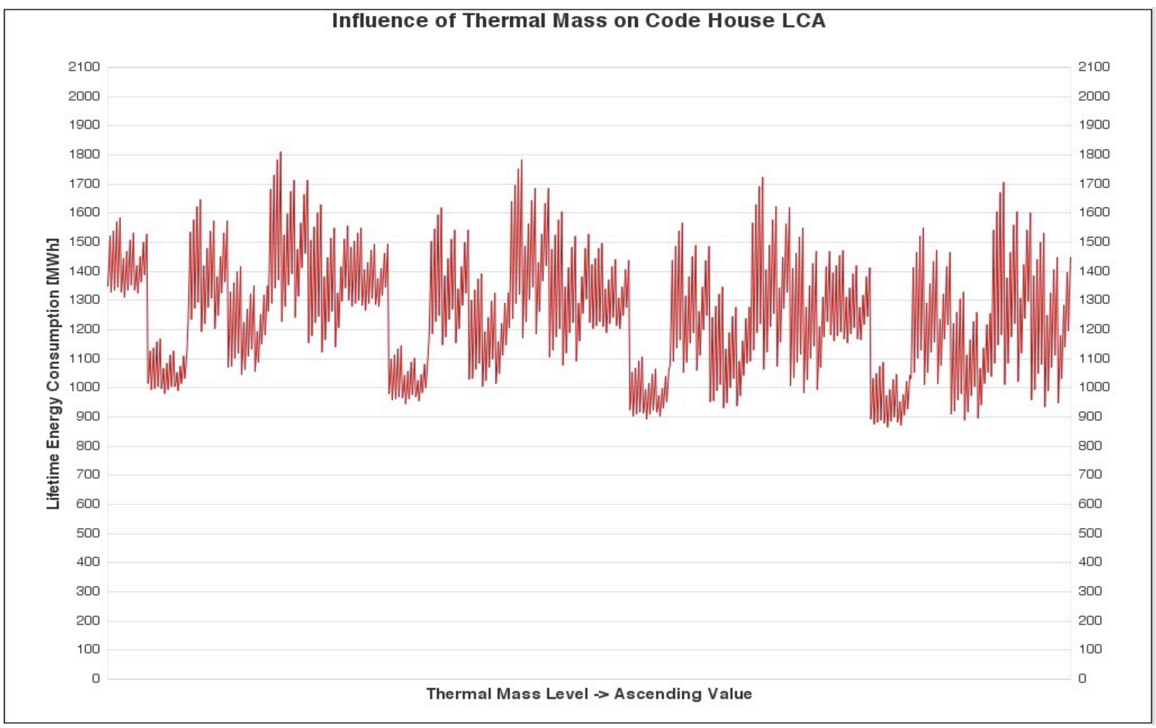

Figure 50 - Influence of Thermal Mass on lifetime energy consumption of Toronto Pilot designs with insulation, window performance, and air tightness held constant at approximate 2006 Ontario Building Code levels, and total size held constant at Canadian Average home size. 50 year lifetime with electric heating and cellulose insulation also constant.

Chapter 6 - Conclusion

The primary goal of this thesis was to prove the relevance of the Full Scale method to broad optimization projects. The underlying motivation was that if applied on a large enough scale, such methods could ultimately remove the uncertainty from complex design optimization decisions that currently face modern 'Green' building designers. This goal was achieved by the successful execution of the Toronto Pilot, within the time frame and budget of a master's level thesis project. The author, a student with little experience in either computer science or building science, generated an optimization database covering 1 080 000 designs in a time period of one year, under a budget of $2500. From this example, more knowledgeable persons with greater resources should easily be able to apply the method on a national scale, to provide the foundation for a scientifically optimized national building code.

The secondary goal of this thesis was to produce new and relevant research on the relative dominance of design parameters on lifetime energy consumption, as the product of achieving the primary thesis goal. Through the example results presented in Chapter 5, the Toronto Pilot database appears to be a valid source of information. The author expects that through a proper statistical analysis, the database will prove a source of greater, more finitely describable, parametric optimization relationships.

Again, the underlying motivation of this thesis is to remove uncertainty in 'Green' building design choices. Already, within the scope of lifetime energy consumption, the example results show that the parameters total building area, basement inclusion, window performance, and infiltration level have the most dominant influence on reducing lifetime energy consumption. With validation, such a result tells the designer that 'Green' design choices don't begin with the envelope and passive solar design, instead they begin with choices like minimizing building size, air-exposed surface area, maximum performance windows, and other design choices that allow for maximum air tightness. Once these more dominant parameters have been defined, then the designer should proceed with selecting glazing ratios, insulation levels, etc. The example results of the Toronto Pilot show that there is no single, discretely 'optimal' design from the perspective of lifetime energy consumption. If there were, design decisions would be greatly simplified. Instead, results show that there is likely an optimal order that design decisions should be made; those parameters that have most influence on lifetime energy consumption should be singled out and optimized first. A 'best practice' guide or tool could be developed to aid designers in minimizing their designs' lifetime energy consumption.

At this point, the discussion has returned to the question of how minimal should a building's lifetime energy be? Example results show that designs exist within the Toronto Pilot that consume approximately 10 times less energy than a modern code-built building in Ontario. Is lowering consumption by a factor of 10 enough, too much, or not enough? The answers to these questions lay in the underlying motivation of energy conservation. From a cost-optimization perspective, the underlying motivation for energy conservation is to save money. If society is striving to lower nonrenewable resource consumption and pollution like carbon dioxide to sustainable levels, then these metrics must be brought into the optimization equation. It is the author's point of view that economics should not be included with these additional optimization metrics. Clearly economics are always important, and will dominate unregulated real-world activity. However, more money can always be printed, but consumed resources remain consumed and pollution is difficult to 'unpollute'.

When searching for optimized building designs that ensure a sustainable future for humanity, cost can cloud the issue. For example, in the Passive House design method, a building's annual energy consumption is reduced until all heating needs can be delivered over the simplest efficient mechanical system possible; a dedicated ventilation system (PHIUS, 2010). John Straube, a prominent building scientist, has argued that Passive House's optimization point is non-optimal, because the extra envelope upgrades required to meet their performance requirements cost more than buying photovoltaic (PV) panels to supplement the home's heating requirements (Straube, 2009). Here, by bringing economics into the argument, energy conservation via insulation has suddenly become equivalent to energy generation via PV panels. Do PV panels have the same lifetime as insulation, the same maintenance requirements, the same embodied energy, the same guaranteed long-term performance, or provide the same minimization of mechanical system size?

After the deeper statistical analysis of the Toronto Pilot, the author would like to see additional optimization metrics included in the Pilot's database, such as lifetime greenhouse gas emission. As the example results show, lifetime energy consumption analysis alone can only lead to the prioritization of design order, but not to a discretely optimized design. With additional metrics to balance opposing relationships, discrete optimization should be possible. This is worth pursuing, as the ultimate goal is to remove uncertainty from the 'Green' building design process, by empowering designers to make transparent, informed choices and to even see how their designs can aspire to more feasible goals.

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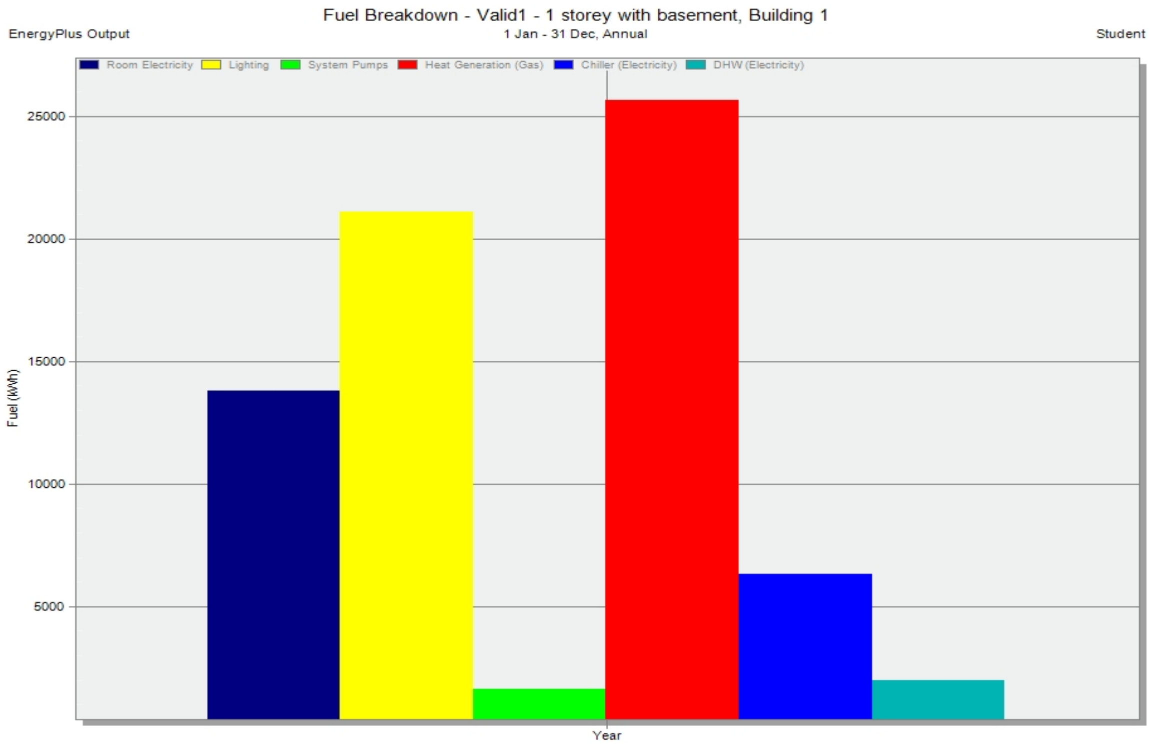
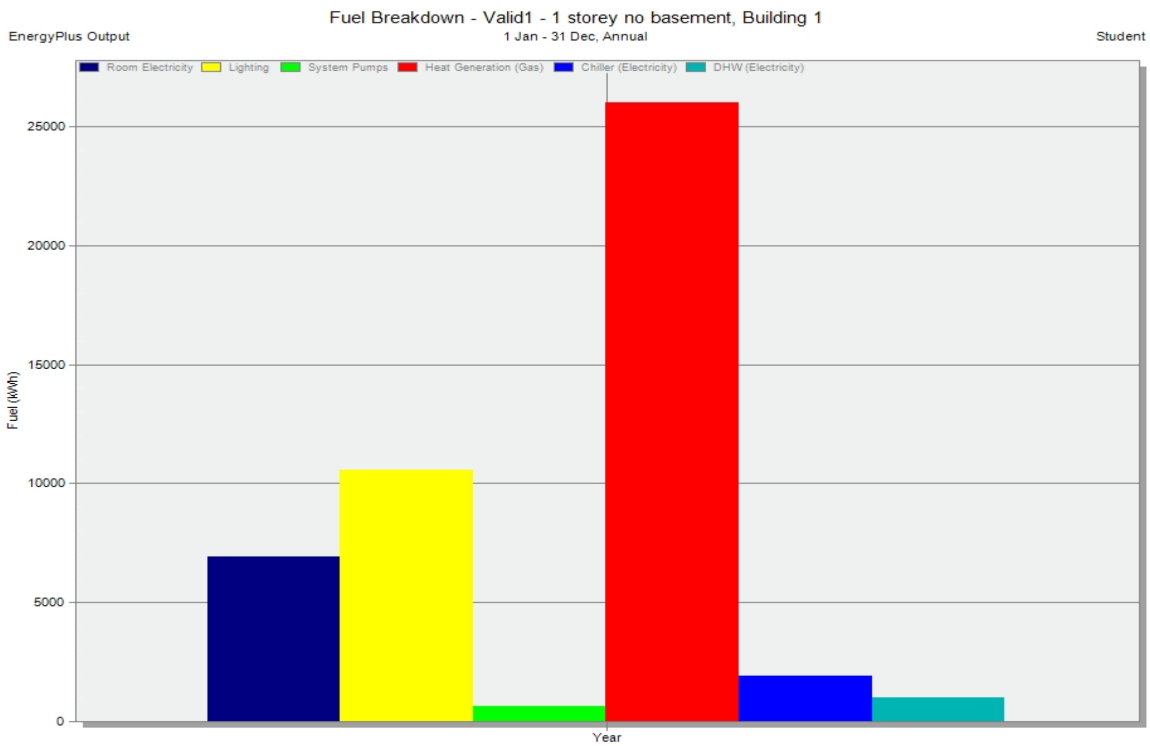
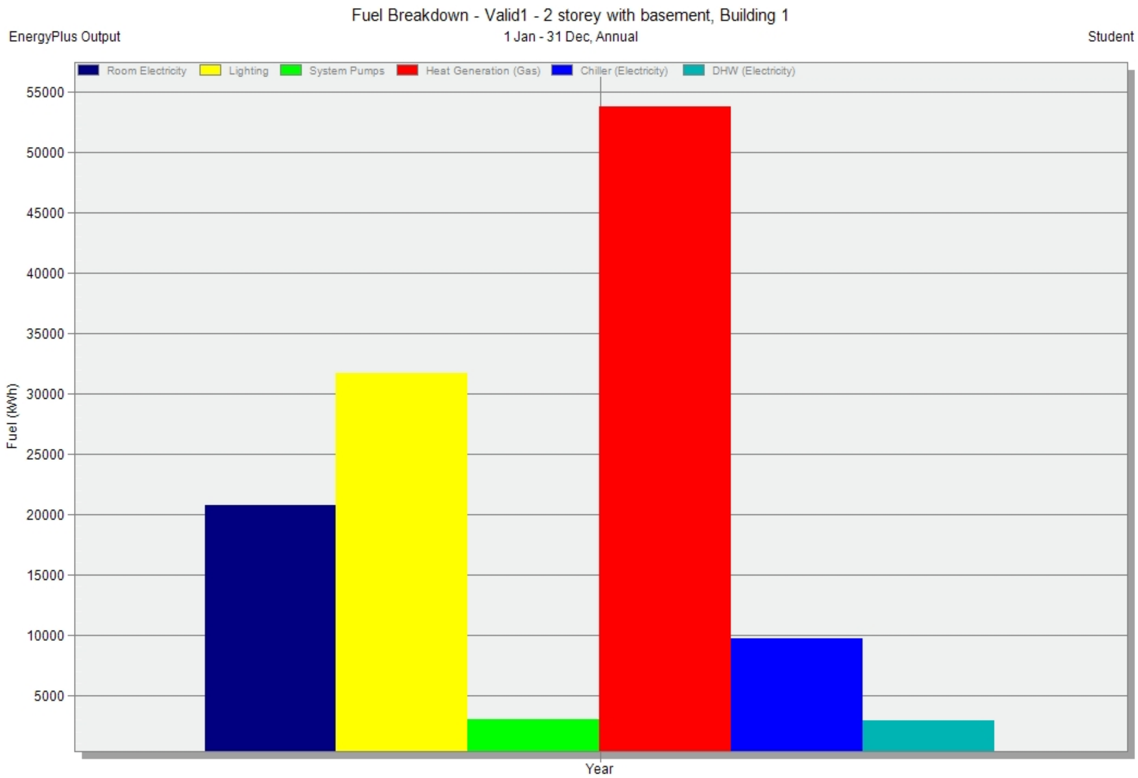
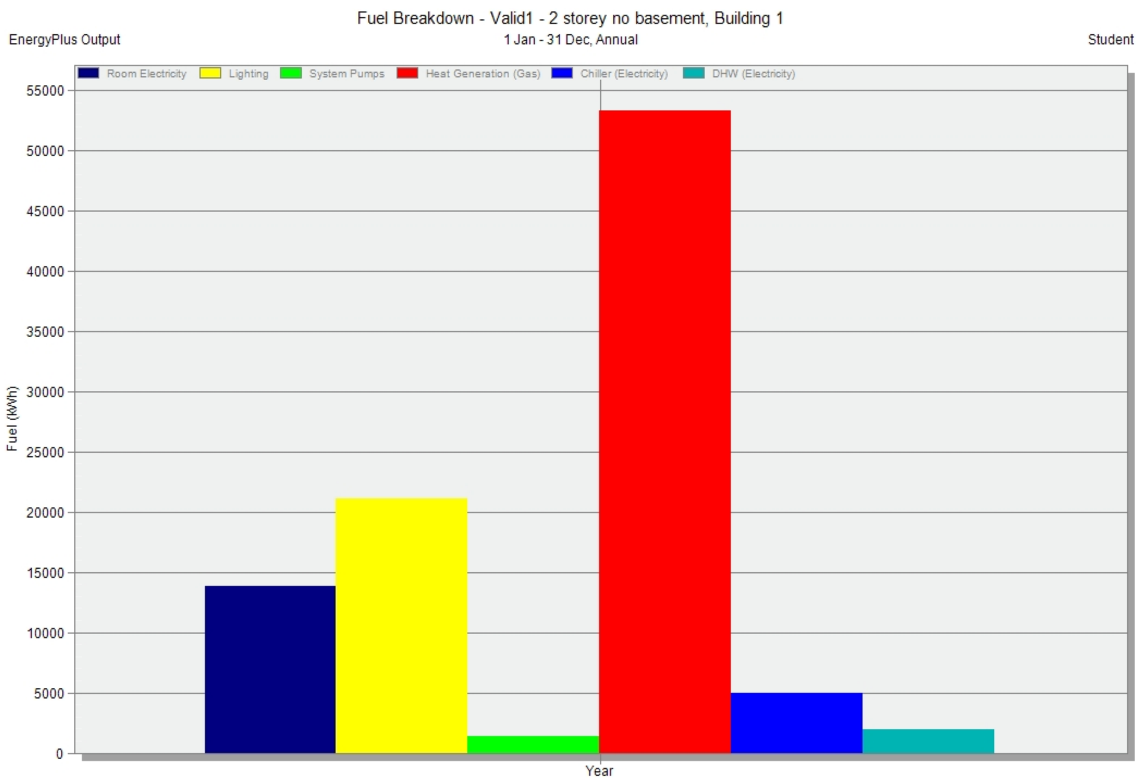
Appendix A - Validation Test Simulation Results

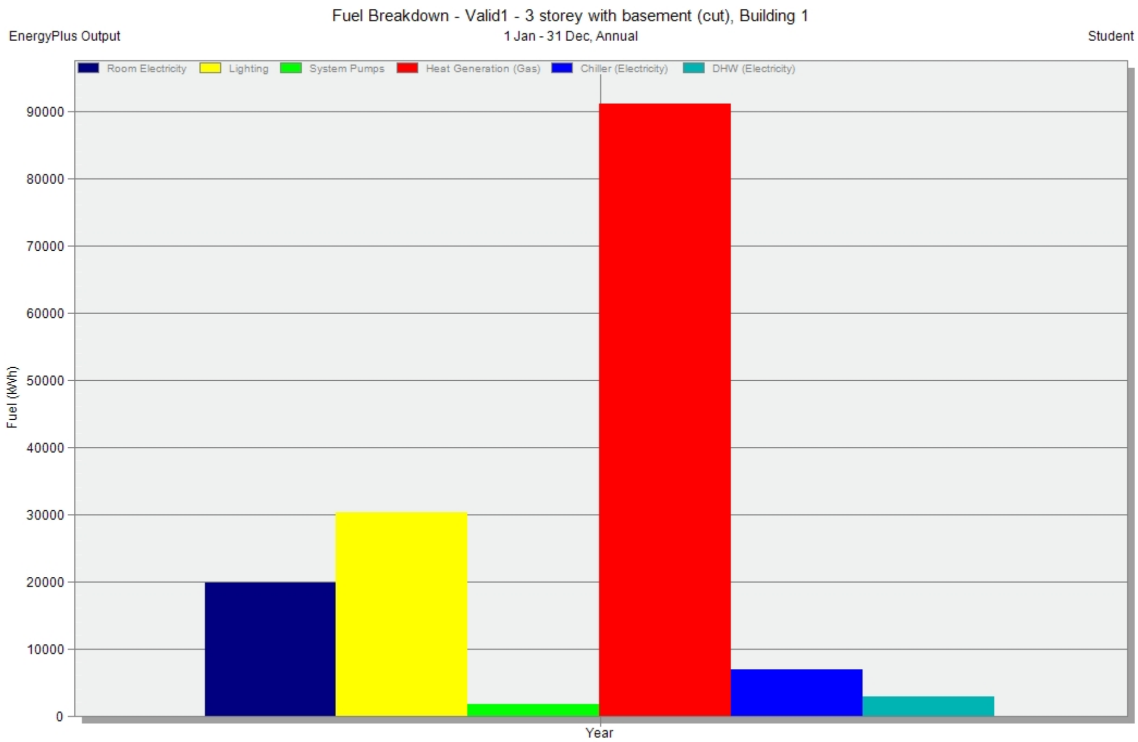
Valid 1 - Basement Influence on Annual Heating/Cooling

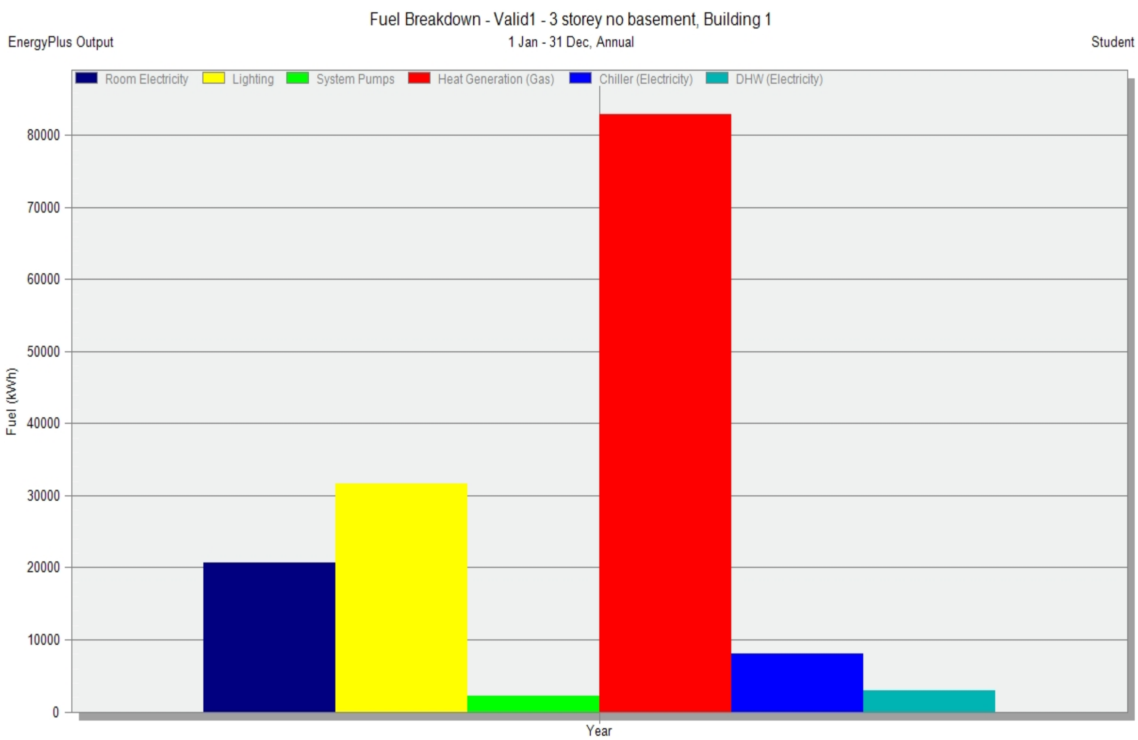


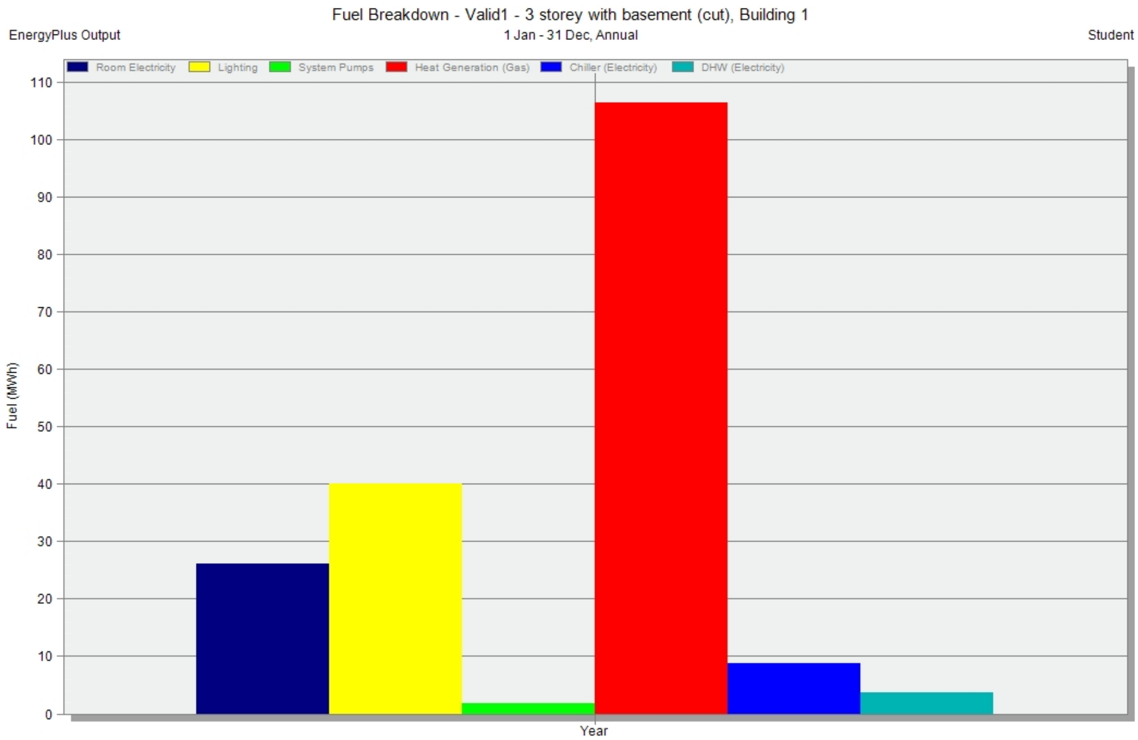


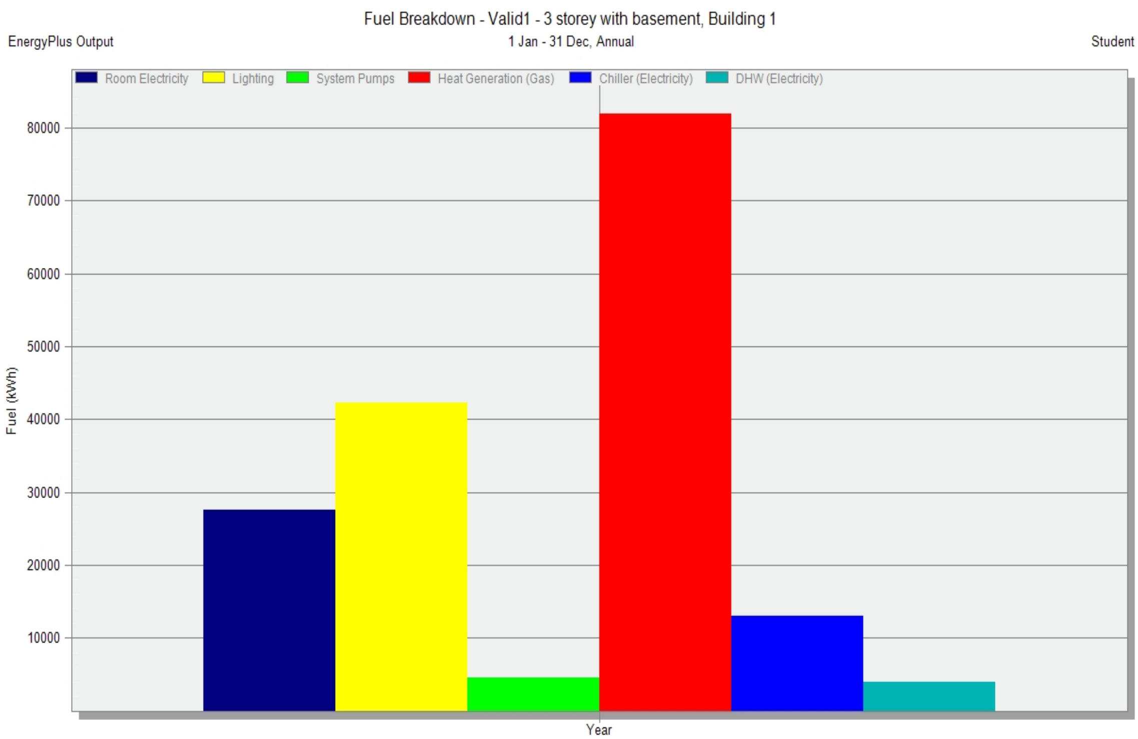

Fuel Breakdown - Valid1 - 2 storey with basement, Building 1
EnergyPlus Output
1 Jan - 31 Dec, Annual
Student
Room Electricity
Lighting
System Pumps
Heat Generation (Gas)
Chiller (Electricity)
DHW (Electricity)
Fuel (kWh)
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
Year


Fuel Breakdown - Valid1 - 2 storey no basement, Building 1
EnergyPlus Output
1 Jan - 31 Dec, Annual
Student
Room Electricity
Lighting
System Pumps
Heat Generation (Gas)
Chiller (Electricity)
DHW (Electricity)
Fuel (kWh)
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Year

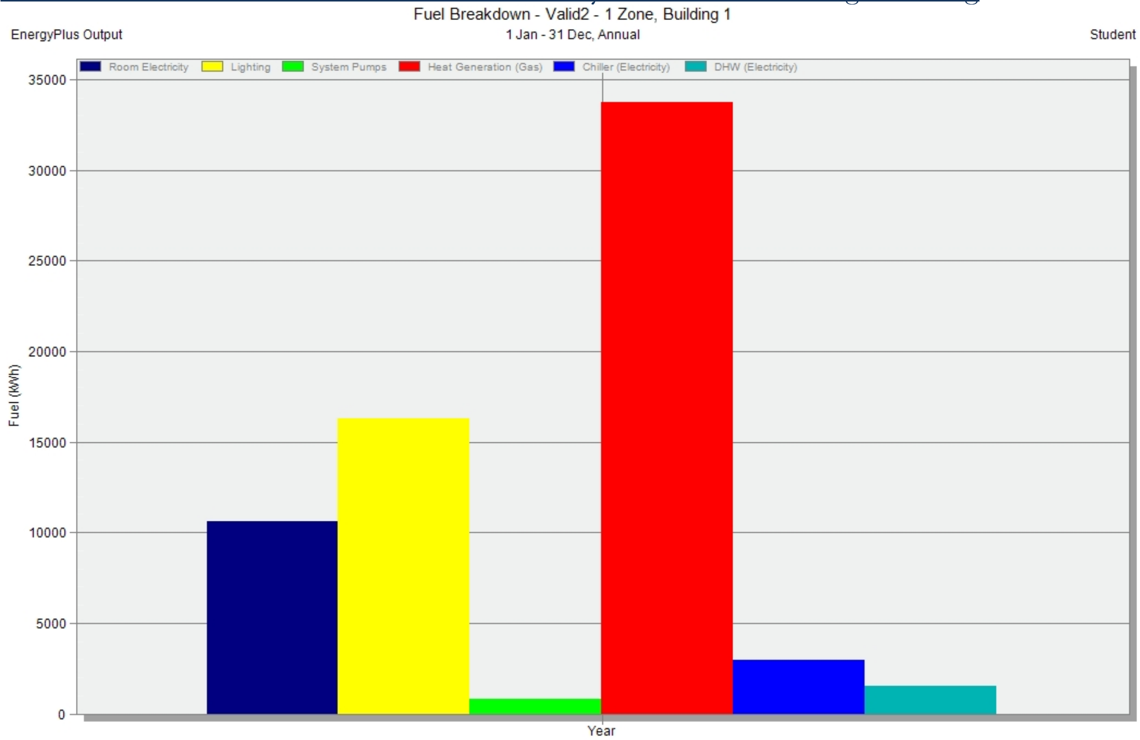

Fuel Breakdown - Valid1 - 3 storey with basement (cut), Building 1
EnergyPlus Output
1 Jan - 31 Dec, Annual
Student
Room Electricity
Lighting
System Pumps
Heat Generation (Gas)
Chiller (Electricity)
DHW (Electricity)
Fuel (kWh)
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Year

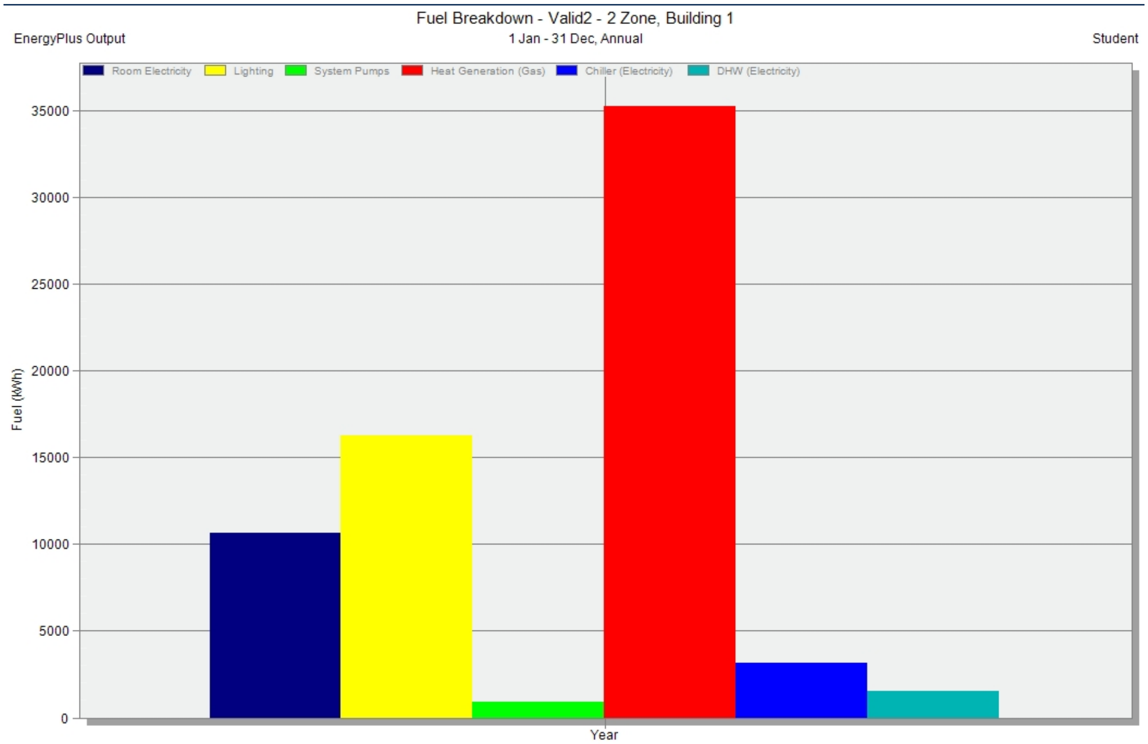

Fuel Breakdown - Valid1 - 3 storey no basement, Building 1
EnergyPlus Output
1 Jan - 31 Dec, Annual
Student
Room Electricity
Lighting
System Pumps
Heat Generation (Gas)
Chiller (Electricity)
DHW (Electricity)
Fuel (kWh)
80000
70000
60000
50000
40000
30000
20000
10000
0
Year

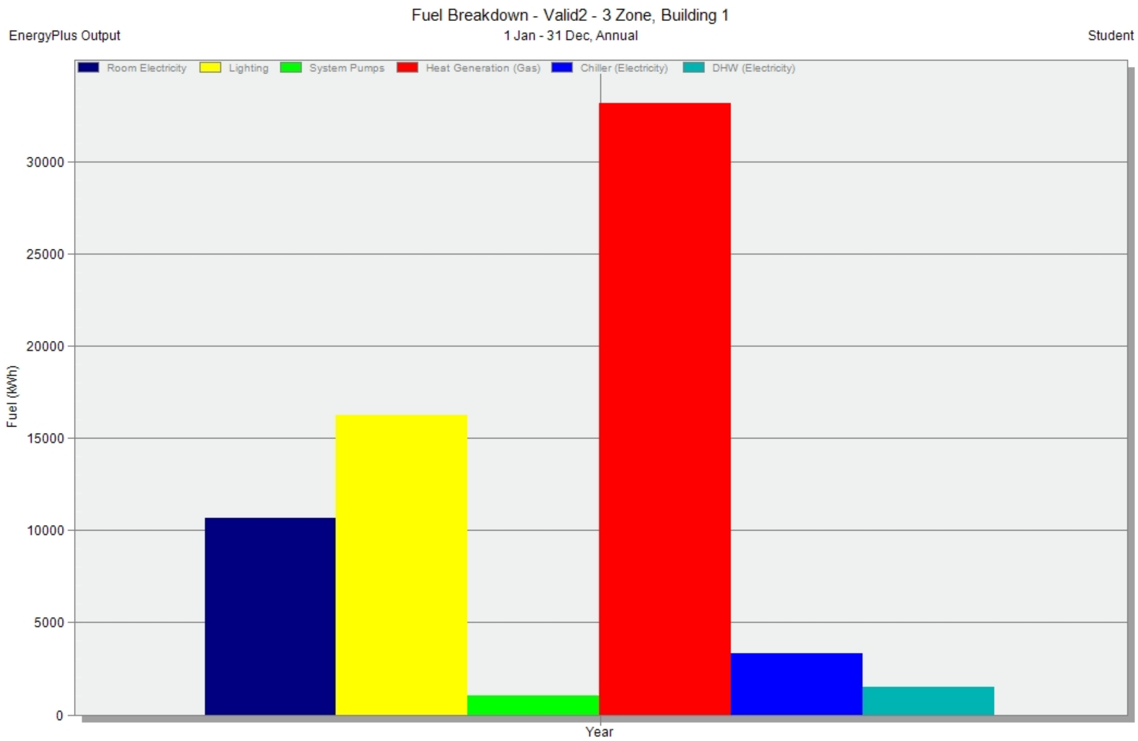

Fuel Breakdown - Valid1 - 3 storey with basement (cut), Building 1
EnergyPlus Output
1 Jan - 31 Dec, Annual
Student
Room Electricity
Lighting
System Pumps
Heat Generation (Gas)
Chiller (Electricity)
DHW (Electricity)
Fuel (MWh)
110
100
90
80
70
60
50
40
30
20
10
0
Year

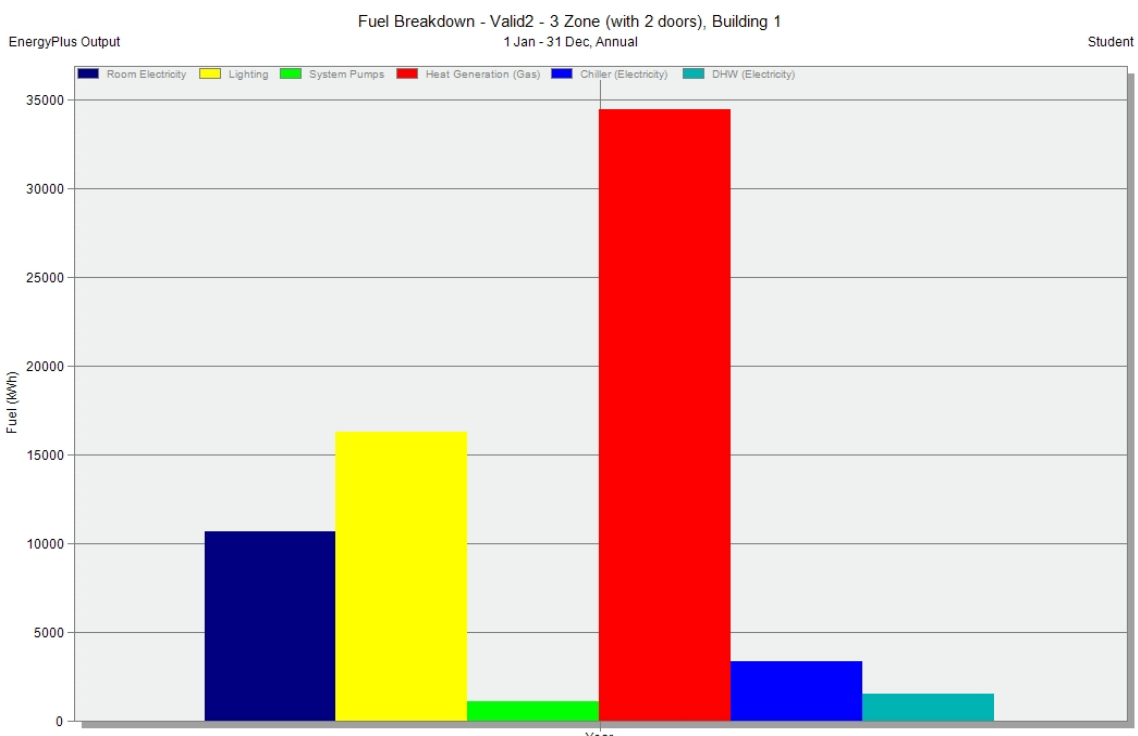

Fuel Breakdown - Valid1 - 3 storey with basement, Building 1
EnergyPlus Output
1 Jan - 31 Dec, Annual
Student
Room Electricity
Lighting
System Pumps
Heat Generation (Gas)
Chiller (Electricity)
DHW (Electricity)
Fuel (kWh)
80000
70000
60000
50000
40000
30000
20000
10000
Year

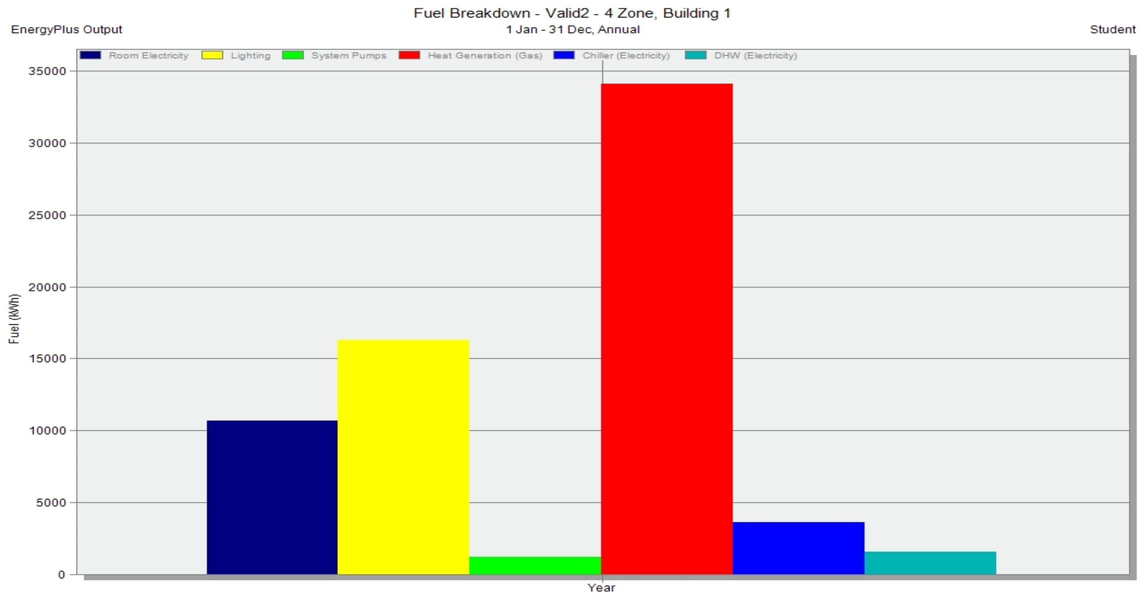
Valid 2 - Influence of Simulation Zone Density on Annual Heating/Cooling

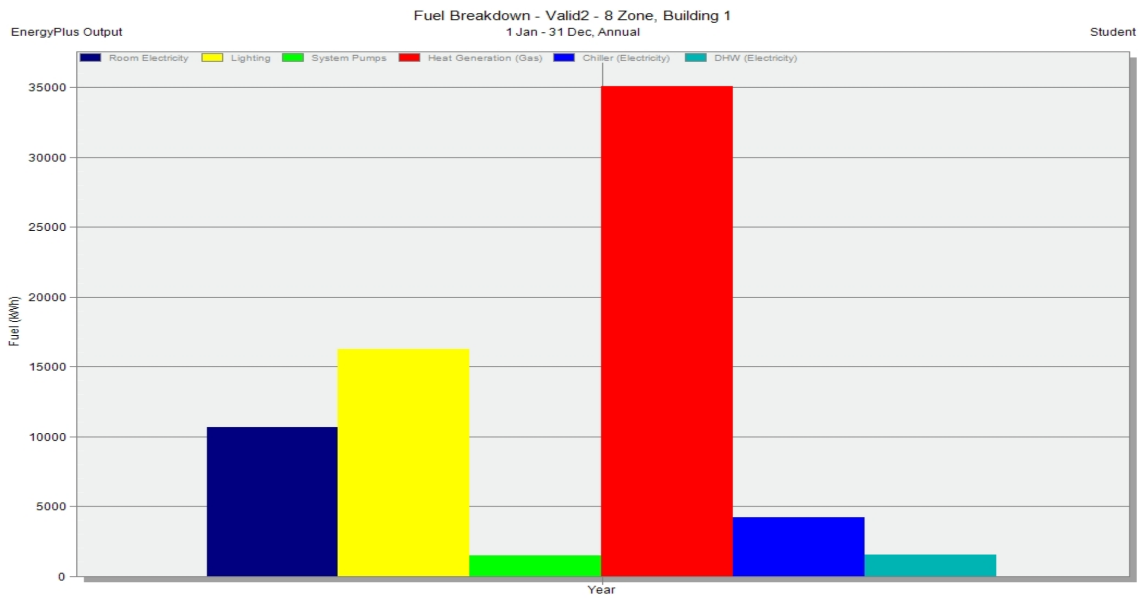





Fuel Breakdown - Valid2 - 3 Zone, Building 1
EnergyPlus Output
1 Jan - 31 Dec, Annual
Student
Room Electricity
Lighting
System Pumps
Heat Generation (Gas)
Chiller (Electricity)
DHW (Electricity)
Fuel (kWh)
Year

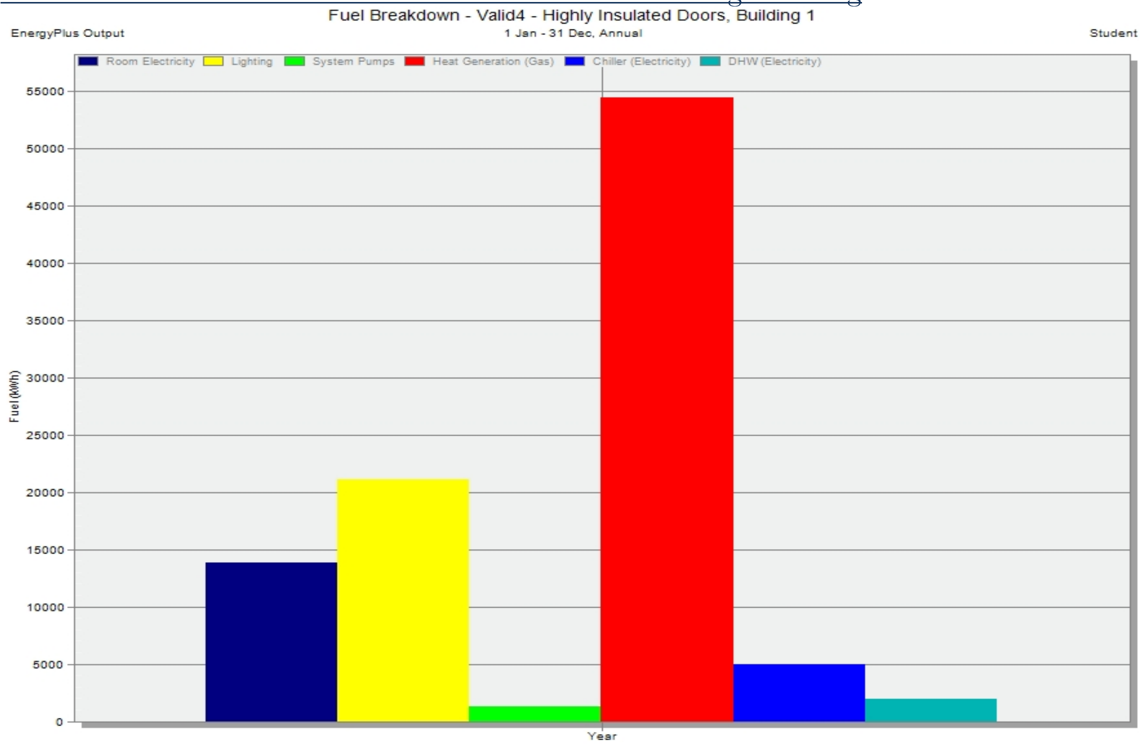

Fuel Breakdown - Valid2 - 3 Zone (with 2 doors), Building 1
EnergyPlus Output
1 Jan - 31 Dec, Annual
Student
Room Electricity
Lighting
System Pumps
Heat Generation (Gas)
Chiller (Electricity)
DHW (Electricity)
Fuel (kWh)
Year

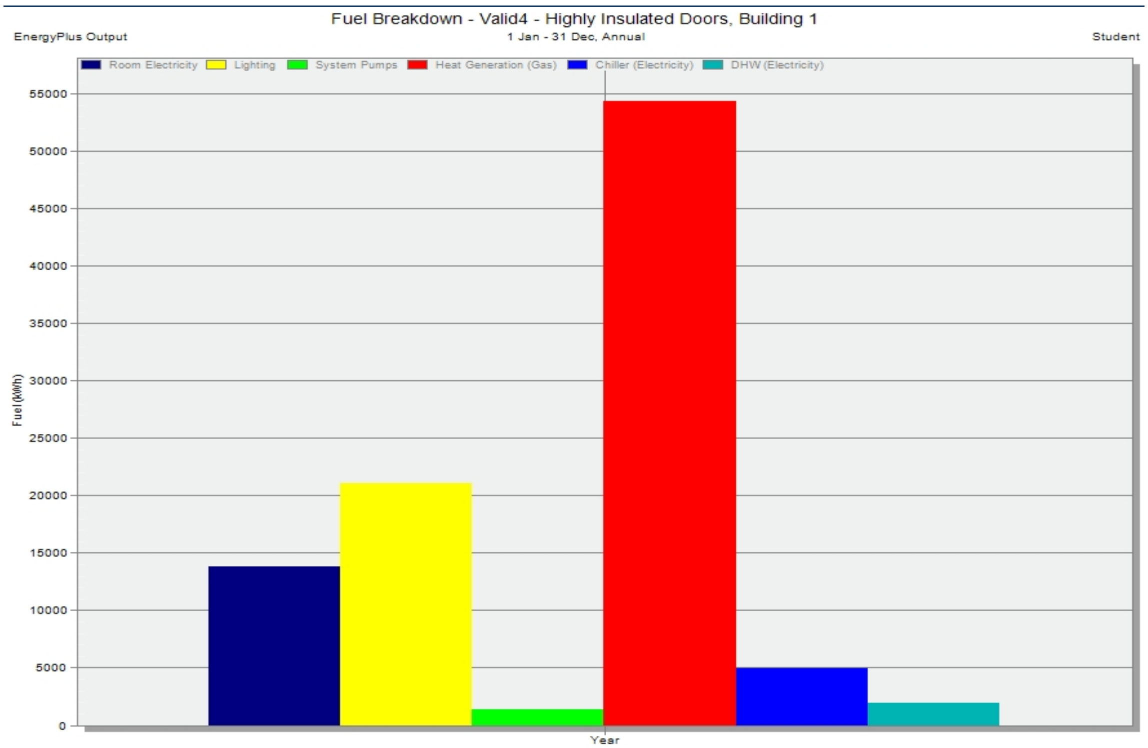




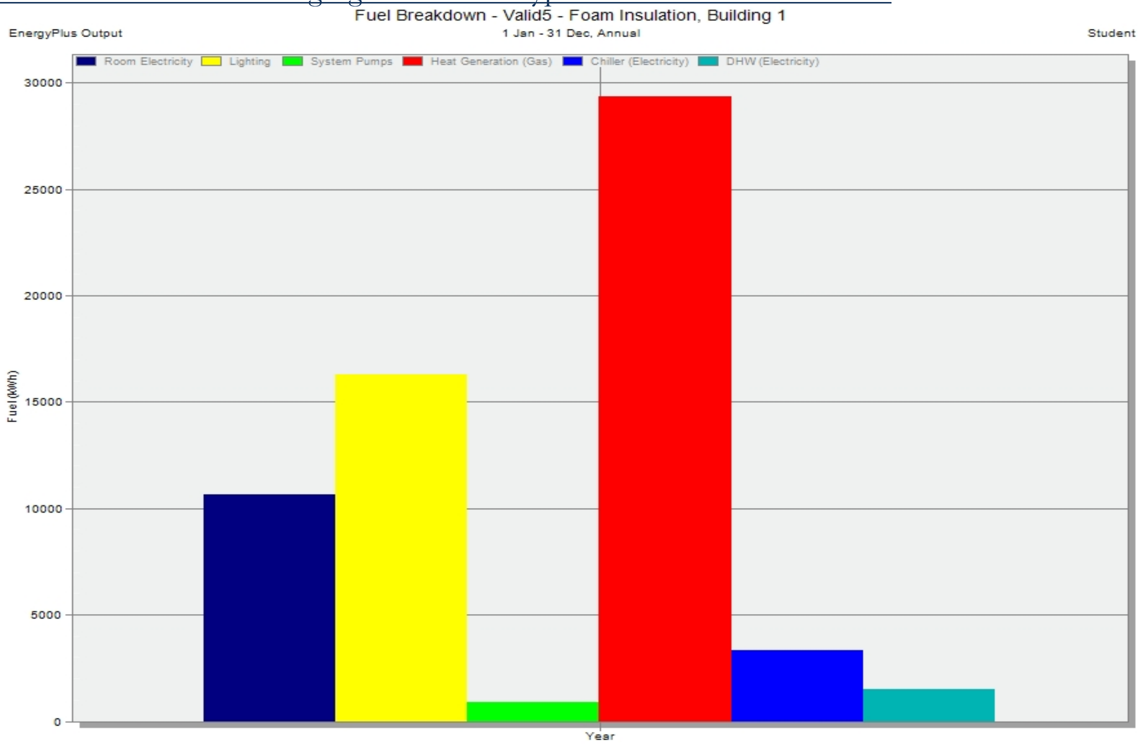
Valid 2 - Sims	Heating Load	% Deviation	Cooling Load	% Deviation
1 zone	33.7	-2%	3	-12%
2 zone	35.3	3%	3.1	-9%
3 zone (no doors)	33.2	-3%	3.3	-3%
3 zone	34.5	0%	3.3	-3%
4 zone	34.4	0%	3.6	5%
8 zone	35.1	2%	4.2	23%
Ave	34.4		3.4	
Std dev	0.804155872		0.435507367	

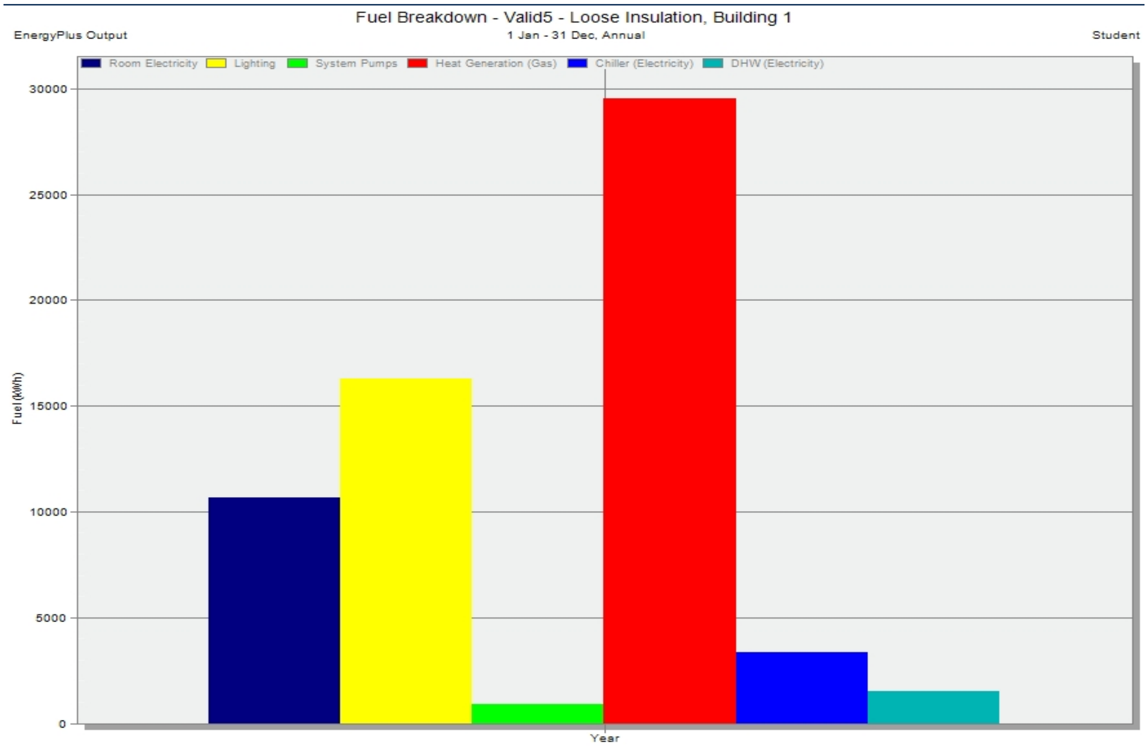
Valid 4 - Influence of Door Insulation on Annual Heating/Cooling



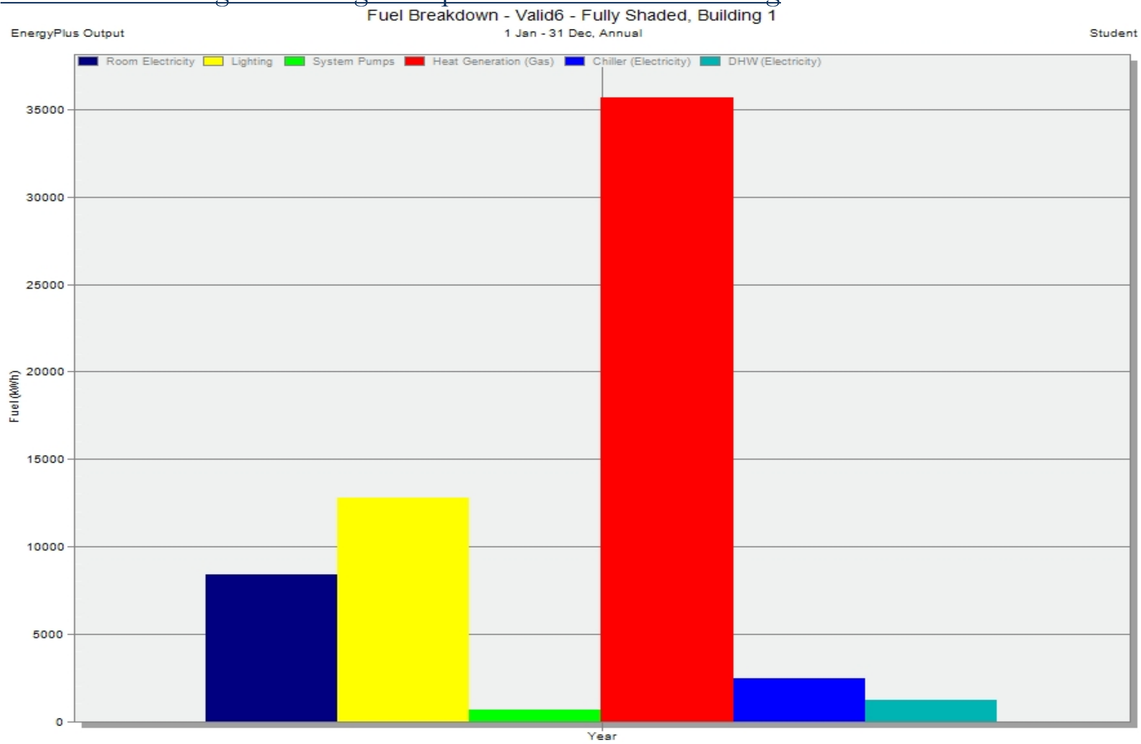


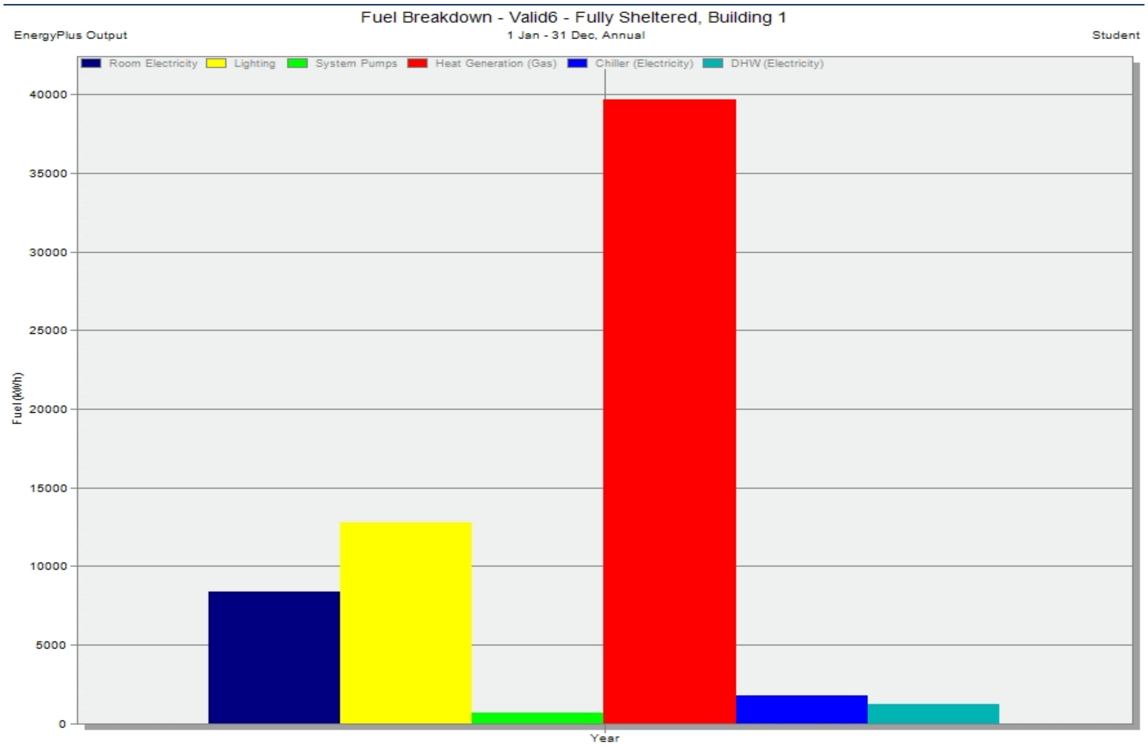
Valid 5 - Affect of Changing Insulation Type with constant RSI value

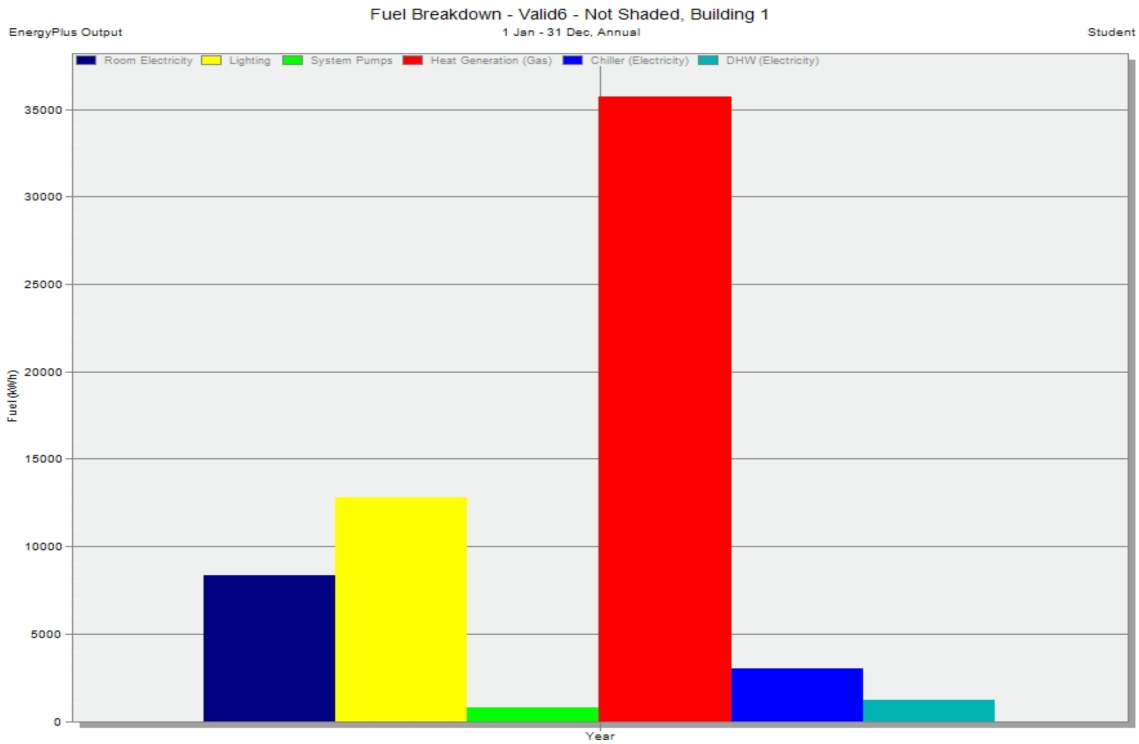




Valid 6 - Building Sheltering Compared to Window Shading






Fuel Breakdown - Valid6 - Not Shaded, Building 1
EnergyPlus Output
1 Jan - 31 Dec, Annual
Student
Room Electricity
Lighting
System Pumps
Heat Generation (Gas)
Chiller (Electricity)
DHW (Electricity)
35000
30000
25000
20000
15000
10000
5000
0
Fuel (kWh)
Year

Appendix B - Amazon Web Services Usage Summary

Amazon Web Services Billing Statement: May 1 - May 31, 2010 Date Printed: June 7, 2010	Name: Stuart Fix Email: stufix@gmail.com Account Number: 8523-2693-9989

		Totals
Amazon Elastic Compute Cloud		
US East (Northern Virginia) Region		
Amazon EC2 running Linux/UNIX		
$0.085 per Small Instance (m1.small) instance-hour (or partial hour)	3 Hrs	0.26
$0.68 per High-CPU Extra Large Instance (c1.xlarge) instance-hour (or partial hour)	1,651 Hrs	1,122.68
Amazon EC2 EBS		
$0.10 per GB-month of provisioned storage	2,217.298 GB-Mo	221.73
$0.10 per 1 million I/O requests	194,593,524 IOs	19.46
$0.15 per GB-Month of snapshot data stored	34.491 GB-Mo	5.17
$0.01 per 10,000 gets (when loading a snapshot)	217,519 Requests	0.22
$0.01 per 1,000 puts (when saving a snapshot)	80,574 Requests	0.81
	»	1,370.33
Amazon Simple Storage Service		
US Standard Region		
$0.150 per GB - first 50 TB / month of storage used	0.600 GB-Mo	0.09
$0.01 per 1,000 PUT, COPY, POST, or LIST requests	137,422 Requests	1.37
$0.01 per 10,000 GET and all other requests	302 Requests	0.01
	»	1.47
Amazon Virtual Private Cloud		
	»	0.00
AWS Data Transfer (excluding Amazon CloudFront)		
$0.000 per GB - data transfer in (Until June 30, 2010)	0.367 GB	0.00
$0.000 per GB - first 1 GB / month data transfer out	1.000 GB	0.00
$0.150 per GB - up to 10 TB / month	4.283 GB	0.64

	data transfer out	4.285 GB	0.04
	$0.010 per GB - regional data transfer - in/out/between EC2 Avail Zones or when using public/elastic IP addresses or ELB	0.000672 GB	0.01
			0.65
Taxes			0.00
Total Charges due on June 1, 2010			$1,372.45
Payment received June 3, 2010 (Visa | Last 4 digits: 4576)			-1,372.45

amazon web services™

Amazon Web Services Billing Statement: June 1 - June 30, 2010 Date Printed: July 5, 2010	Name: Stuart Fix Email: stufix@gmail.com Account Number: 8523-2693-9989

		Totals
Amazon Elastic Compute Cloud		
US East (Northern Virginia) Region		
Amazon EC2 running Linux/UNIX		
$0.68 per High-CPU Extra Large Instance (c1.xlarge) instance-hour (or partial hour)	384 Hrs	261.12
Amazon EC2 EBS		
$0.10 per GB-month of provisioned storage	3,007.278 GB-Mo	300.73
$0.10 per 1 million I/O requests	77310094 IOs	7.73
$0.15 per GB-Month of snapshot data stored	211.604 GB-Mo	31.74
$0.01 per 10,000 gets (when loading a snapshot)	1866 Requests	0.01
$0.01 per 1,000 puts (when saving a snapshot)	98780 Requests	0.99
	»	602.32
Amazon Simple Storage Service		
US Standard Region		
$0.150 per GB - first 50 TB / month of storage used	4.359 GB-Mo	0.65
	»	0.65
Amazon Virtual Private Cloud		
	»	0.00
AWS Data Transfer (excluding Amazon CloudFront)		
$0.000 per GB - data transfer in (Until June 30, 2010)	3.617 GB	0.00
$0.000 per GB - first 1 GB / month data transfer out	1 GB	0.00
$0.150 per GB - up to 10 TB / month data transfer out	163.871 GB	24.58
		24.58
Taxes		0.00

Total Charges due on July 1, 2010	$627.55
Payment received July 3, 2010 (Visa | Last 4 digits: 4576)	-627.55

Appendix C - Python Code

<B> Denotes broken code line; must be repaired prior to execution.

CreateIDF.py

```
#!/usr/local/bin/python3

def IDFgenerator():
    """This function generates IDF files and executes then with EnergyPlus. Req's SubFunction.py"""

    import sys
    sys.path.append('/root/')

    from SubFunction import GeometryFunction

    # GeometryFunction has inputs of (NumStories, Basement, TotalArea, ShapeRatio, SouthWinWallRatio, EastWinWallRatio,
    # NorthWinWallRatio, WindowPerform)

    # Building Parameter Definition and Range:

    NumStories = [1,2,3]
    Basement = [0,1]                                                # 1 = basement, 0 = no basement
    TotalArea = [92.9,139.4,185.8,325.2,464.5]                      # Square Meters
    ShapeRatio = [0.75,1,1.25]                                      # South Facade Width = ShapeRatio*squareDim
    SouthWinWallRatio = [0.1,0.3,0.5,0.6]                           # %area window to wall
    EastWinWallRatio = [0.1,0.3,0.5]                                # %area window to wall
    NorthWinWallRatio = [0.1]                                       # %area window to wall
    WindowPerform = [101,102,103,104,105]                           # Construction names in IDF
    Infiltration = [0.667,0.334,0.167,0.067,0.01667]             # Levels at 1Pa pressure drop (10,5,2.5,1,0.25 @ 50Pa)
    ThermalMass = [0.00001,0.05,0.15,0.3]                           # Thickness of concrete in [m]

    RSIvalue = [2.5,5,7.5,10,12.5,15,17.5,20,22.5,25]               # [Km2/W]
    ThermConductivity = 0.035                                       # [W/mK]
    InsulThickness = [i*ThermConductivity for i in RSIvalue]       # Insulation thickness in [m], for dense polystyrene


    # Define Permutations():

    mm = (NumStories,Basement,TotalArea,ShapeRatio,SouthWinWallRatio,EastWinWallRatio,NorthWinWallRatio,WindowPerform,
        <B>Infiltration,InsulThickness,ThermalMass)
    n = 0
    numperm = 1

    # How many permutations are there?

    counter = list(range(len(mm)))

    for i in counter:
        counter[i] = len(mm[i])

    for s in counter:
        numperm = numperm*s

    print("number of permutations = {0}".format(numperm))

    # Generate permutations

    permutation = list(range(numperm))
    permtext = list(range(numperm))

    for a in list(range(len(mm[0]))):
        for b in list(range(len(mm[1]))):
            for c in list(range(len(mm[2]))):
                for d in list(range(len(mm[3]))):
                    for e in list(range(len(mm[4]))):
                        for f in list(range(len(mm[5]))):
                            for g in list(range(len(mm[6]))):
                                for h in list(range(len(mm[7]))):
                                    for i in list(range(len(mm[8]))):
                                        for j in list(range(len(mm[9]))):
                                            for k in list(range(len(mm[10]))):

                                                InsulationSlab = mm[9][j]*0.251
                                                #0.251:0.301:0.477:1 normalized OBC2006 slab:found:expwall:expceil
                                                InsulationFound = mm[9][j]*0.301
                                                InsulationWall = mm[9][j]*0.477
                                                InsulationCeiling = mm[9][j]

                                                permutation[n] = [str(n).zfill(7),mm[0][a],mm[1][b],mm[2][c],
                                                <B>mm[3][d], mm[4][e], mm[5][f], mm[6][g], mm[7][h], mm[8][i],
                                                <B>InsulationSlab, InsulationFound, InsulationWall, InsulationCeiling,
                                                <B>mm[10][k]]

                                                Geometry = GeometryFunction(mm[0][a], mm[1][b], mm[2][c], mm[3][d],
                                                <B>mm[4][e], mm[5][f],mm[6][g],mm[7][h])
```

```
#Create IDF's
                                                IDFText = """! File originally generated by DesignBuilder - 2.0.4.002

!- Thesis Simulation Trial #: {0}

Version,4.0;

RunPeriod,
    ,                        !- Name
    1,                       !- Begin Month
    1,                       !- Begin Day of Month
    12,                      !- End Month
    31,                      !- End Day of Month
    UseWeatherFile,          !- Day of Week for Start Day
    No,                      !- Use Weather File Holidays and Special Days
    No,                      !- Use Weather File Daylight Saving Period
    Yes,                     !- Apply Weekend Holiday Rule
    Yes,                     !- Use Weather File Rain Indicators
    Yes,                     !- Use Weather File Snow Indicators
    1;                       !- Number of Times Runperiod to be Repeated

RunPeriodControl:DaylightSavingTime,
    1st Sunday in April,     !- Start Date
    Last Sunday in October;  !- End Date

! Hourly weather file: CAN_ON_Toronto_CWEC.epw

Site:Location,
    Toronto,                 !- Name
    43.67,                   !- Latitude [deg]
    -79.63,                  !- Longitude [deg]
    -5,                      !- Time Zone [hr]
    173;                     !- Elevation [m]

Site:GroundTemperature:BuildingSurface,15,15,15,15,15,15,15,15,15,15,15,15;

 Site:GroundReflectance,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2;

Site:GroundReflectance:SnowModifier,
   1.0,                                         !- Ground Reflected Solar Modifier
   1.0;                                         !- Daylighting Ground Reflected Solar Modifier

SimulationControl,
   Yes,                                         !- Do the zone sizing calculation
   Yes,                                         !- Do the system sizing calculation
   No,                                          !- Do the plant sizing calculation
   Yes,                                         !- Do the design day calculation
   Yes;                                         !- Do the weather file calculation

SizingPeriod:DesignDay,
   Summer Design Day in Toronto,                !- Design Day Name
   30.6,                                        !- Max Dry-Bulb [C]
   10.6,                                        !- Daily Temp Range [C]
   21.9,                                        !- Wet-Bulb at Max [C]
   99263.9,                                     !- Barometric Pressure [N/M**2]
   0,                                           !- Wind Speed [m/s]
   0,                                           !- Wind Direction [Degrees N=0, S=180]
   0.98,                                        !- Clearness [0.0 to 1.1]
   0,                                           !- Rain [0-no,1-yes]
   0,                                           !- Snow on ground [0-no,1-yes]
   15,                                          !- Day of Month
   7,                                           !- Month
   SummerDesignDay,                             !- Day Type -- used for schedules
   1,                                           !- Daylight Savings Time Indicator
   WetBulb,                                     !- Type of humidity temperature Indicator
   ,                                            !- Relative Humidity Day Schedule(not used)
   ,                                            !- Dry-Bulb Temperature Range Modifier Type (not used)
   ;                                            !- Dry-Bulb Temperature Range Modifier Schedule (not used)

SizingPeriod:DesignDay,
   Winter Design Day in Toronto,                !- Design Day Name
   -19.4,                                       !- Max Dry-Bulb [C]
   0,                                           !- Daily Temp Range [C]
   -19.4,                                       !- Wet-Bulb at Max [C]
   99263.9,                                     !- Barometric Pressure [N/M**2]
   14.2,                                        !- Wind Speed [M/Sec]
   0,                                           !- Wind Direction [Degrees N=0, S=180]
   0,                                           !- Clearness [0.0 to 1.1] - gives no sun
   0,                                           !- Rain [0-no,1-yes]
   1,                                           !- Snow on ground [0-no,1-yes]
   15,                                          !- Day of Month
   1,                                           !- Month
   WinterDesignDay,                             !- Day Type -- used for schedules
   0,                                           !- Daylight Savings Time Indicator
   WetBulb,                                     !- Type of humidity temperature Indicator
   ,                                            !- Relative Humidity Day Schedule (not used)
   ,                                            !- Dry-Bulb Temperature Range Modifier Type (not used)
   ;                                            !- Dry-Bulb Temperature Range Modifier Schedule (not used)

Timestep, 4;                                    !- Timesteps/hour

ConvergenceLimits,
   1,                                           !- Minimum System Time Step (0=same as zone time step)
```

```
   20;                                          !- Maximum HVAC Iterations (1=min, 20=default)

ScheduleTypeLimits,
    Any Number;              !- Name

ScheduleTypeLimits,
    Fraction,                !- Name
    0.0,                     !- Lower Limit Value
    1.0,                     !- Upper Limit Value
    CONTINUOUS;              !- Numeric Type

ScheduleTypeLimits,
    Temperature,             !- Name
    -60,                     !- Lower Limit Value
    200,                     !- Upper Limit Value
    CONTINUOUS;              !- Numeric Type

ScheduleTypeLimits,
    Control Type,            !- Name
    0,                       !- Lower Limit Value
    4,                       !- Upper Limit Value
    DISCRETE;                !- Numeric Type

ScheduleTypeLimits,
    On/Off,                  !- Name
    0,                       !- Lower Limit Value
    1,                       !- Upper Limit Value
    DISCRETE;                !- Numeric Type

Schedule:Compact,
    On,                      !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,1;          !- Field 3

Schedule:Compact,
    Off,                     !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,0;          !- Field 3

Schedule:Compact,
    Work efficiency,         !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,0;          !- Field 3

Schedule:Compact,
    AirVelocitySchedule,     !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,0.137;      !- Field 3

! ------------------- Control type schedules (for heating & cooling) ---------------------

! Schedule: On
Schedule:Compact,
    2,                       !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,1;          !- Field 3

! Schedule: Off
Schedule:Compact,
    7,                       !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,0;          !- Field 3

! Schedule: Occupants
Schedule:Compact,
    2234,                    !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 Dec,         !- Field 1
    For: Weekdays SummerDesignDay WinterDesignDay, !- Field 2
    Until: 18:00,1,          !- Field 3
    Until: 22:00,1,          !- Field 5
    Until: 23:00,1,          !- Field 7
    Until: 24:00,1,          !- Field 9
    For: Weekends,           !- Field 11
    Until: 10:00,1,          !- Field 12
    Until: 17:00,1,          !- Field 14
    Until: 18:00,1,          !- Field 16
    Until: 23:00,1,          !- Field 18
    Until: 24:00,1,          !- Field 20
    For: Holidays,           !- Field 22
    Until: 24:00,0,          !- Field 23
    For:  AllOtherDays,      !- Field 25
    Until: 24:00,0;          !- Field 26
```

```
! Schedule: Lighting
Schedule:Compact,
    2235,                    !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 Dec,         !- Field 1
    For: Weekdays SummerDesignDay WinterDesignDay, !- Field 2
    Until: 08:00,1,          !- Field 3
    Until: 18:00,1,          !- Field 5
    Until: 24:00,1,          !- Field 7
    For: Weekends,           !- Field 9
    Until: 10:00,1,          !- Field 10
    Until: 24:00,1,          !- Field 12
    For: Holidays,           !- Field 14
    Until: 24:00,1,          !- Field 15
    For: AllOtherDays,       !- Field 17
    Until: 24:00,1;          !- Field 18

! Schedule: Equipment
Schedule:Compact,
    2236,                    !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 Dec,         !- Field 1
    For: Weekdays SummerDesignDay WinterDesignDay, !- Field 2
    Until: 18:00,1,          !- Field 3
    Until: 23:00,1,          !- Field 5
    Until: 24:00,1,          !- Field 7
    For: Weekends,           !- Field 9
    Until: 10:00,1,          !- Field 10
    Until: 24:00,1,          !- Field 12
    For: Holidays,           !- Field 14
    Until: 24:00,1,          !- Field 15
    For:  AllOtherDays,      !- Field 17
    Until: 24:00,1;          !- Field 18

WindowMaterial:Gas,
    1001,                    !- Name
    Air,                     !- Gas Type
    .006;                    !- Thickness [m]

WindowMaterial:Gas,
    Half thickness 1001,     !- Name
    Air,                     !- Gas Type
    .003;                    !- Thickness [m]

WindowMaterial:Gas,
    1020,                    !- Name
    Air,                     !- Gas Type
    .016;                    !- Thickness [m]

WindowMaterial:Gas,
    Half thickness 1020,     !- Name
    Air,                     !- Gas Type
    .008;                    !- Thickness [m]

WindowMaterial:Gas,
    1023,                    !- Name
    Krypton,                 !- Gas Type
    .016;                    !- Thickness [m]

WindowMaterial:Gas,
    Half thickness 1023,     !- Name
    Krypton,                 !- Gas Type
    .008;                    !- Thickness [m]

WindowMaterial:Glazing,
    2,                       !- Name
    SpectralAverage,         !- Optical Data Type
    ,                        !- Window Glass Spectral Data Set Name
    .003,                    !- Thickness [m]
    .837,                    !- Solar Transmittance at Normal Incidence
    .075,                    !- Front Side Solar Reflectance at Normal Incidence
    .075,                    !- Back Side Solar Reflectance at Normal Incidence
    .898,                    !- Visible Transmittance at Normal Incidence
    .081,                    !- Front Side Visible Reflectance at Normal Incidence
    .081,                    !- Back Side Visible Reflectance at Normal Incidence
    .0,                      !- Infrared Transmittance at Normal Incidence
    .84,                     !- Front Side Infrared Hemispherical Emissivity
    .84,                     !- Back Side Infrared Hemispherical Emissivity
    .9,                      !- Conductivity [W/m-K]
    1;                       !- Dirt Correction Factor for Solar and Visible Transmittance

WindowMaterial:Glazing,
    390,                     !- Name
    Spectral,                !- Optical Data Type
    AFG Industries Comfort ES LowE on Clear <ESN1.AFG>,  !- Window Glass Spectral Data Set Name
    .0056134,                !- Thickness [m]
    ,                        !- Solar Transmittance at Normal Incidence
    ,                        !- Front Side Solar Reflectance at Normal Incidence
    ,                        !- Back Side Solar Reflectance at Normal Incidence
    ,                        !- Visible Transmittance at Normal Incidence
    ,                        !- Front Side Visible Reflectance at Normal Incidence
    ,                        !- Back Side Visible Reflectance at Normal Incidence
    0,                       !- Infrared Transmittance at Normal Incidence
    0.09,                    !- Front Side Infrared Hemispherical Emissivity
```

```
    0.84,                    !- Back Side Infrared Hemispherical Emissivity
    1,                       !- Conductivity [W/m-K]
    1;                       !- Dirt Correction Factor for Solar and Visible Transmittance

MaterialProperty:GlazingSpectralData,
    AFG Industries Comfort ES LowE on Clear <ESN1.AFG>,  !- Name
    0.3,0,0.288,0.046,
    0.305,0,0.29,0.046,
    0.31,0,0.292,0.046,
    0.315,0.001,0.29,0.045,
    0.32,0.004,0.289,0.045,
    0.325,0.013,0.281,0.044,
    0.33,0.034,0.274,0.045,
    0.335,0.064,0.261,0.045,
    0.34,0.101,0.246,0.046,
    0.345,0.14,0.231,0.046,
    0.35,0.176,0.214,0.049,
    0.355,0.211,0.206,0.052,
    0.36,0.258,0.199,0.059,
    0.365,0.318,0.192,0.066,
    0.37,0.397,0.182,0.076,
    0.375,0.474,0.162,0.082,
    0.38,0.552,0.139,0.086,
    0.385,0.63,0.117,0.09,
    0.39,0.699,0.1,0.093,
    0.395,0.745,0.089,0.095,
    0.4,0.775,0.08,0.094,
    0.41,0.8,0.07,0.09,
    0.42,0.808,0.065,0.088,
    0.43,0.811,0.062,0.085,
    0.44,0.813,0.06,0.083,
    0.45,0.818,0.059,0.081,
    0.46,0.823,0.059,0.079,
    0.47,0.828,0.058,0.077,
    0.48,0.832,0.058,0.075,
    0.49,0.837,0.056,0.071,
    0.5,0.843,0.054,0.067,
    0.51,0.848,0.052,0.064,
    0.52,0.852,0.05,0.06,
    0.53,0.856,0.048,0.057,
    0.54,0.858,0.046,0.054,
    0.55,0.859,0.044,0.051,
    0.56,0.86,0.042,0.048,
    0.57,0.859,0.04,0.046,
    0.58,0.856,0.039,0.044,
    0.59,0.854,0.038,0.042,
    0.6,0.85,0.037,0.041,
    0.61,0.845,0.037,0.04,
    0.62,0.839,0.037,0.04,
    0.63,0.832,0.038,0.04,
    0.64,0.825,0.04,0.041,
    0.65,0.817,0.042,0.042,
    0.66,0.808,0.044,0.043,
    0.67,0.799,0.047,0.046,
    0.68,0.788,0.051,0.048,
    0.69,0.778,0.055,0.051,
    0.7,0.766,0.059,0.053,
    0.71,0.755,0.064,0.057,
    0.72,0.743,0.07,0.061,
    0.73,0.73,0.075,0.064,
    0.74,0.717,0.082,0.068,
    0.75,0.704,0.089,0.073,
    0.76,0.691,0.096,0.077,
    0.77,0.677,0.104,0.081,
    0.78,0.665,0.111,0.085,
    0.79,0.652,0.119,0.089,
    0.8,0.637,0.129,0.094,
    0.81,0.631,0.176,0.121,
    0.82,0.572,0.176,0.121,
    0.83,0.572,0.173,0.119,
    0.84,0.572,0.175,0.12,
    0.85,0.572,0.182,0.125,
    0.86,0.569,0.179,0.121,
    0.87,0.561,0.194,0.127,
    0.88,0.547,0.215,0.136,
    0.89,0.539,0.201,0.128,
    0.9,0.529,0.238,0.151,
    0.91,0.516,0.245,0.151,
    0.92,0.508,0.242,0.146,
    0.93,0.498,0.259,0.157,
    0.94,0.489,0.272,0.164,
    0.95,0.48,0.279,0.166,
    0.96,0.472,0.294,0.171,
    0.97,0.463,0.334,0.195,
    0.98,0.454,0.309,0.181,
    0.99,0.448,0.316,0.183,
    1,0.438,0.358,0.204,
    1.05,0.404,0.361,0.203,
    1.1,0.373,0.384,0.214,
    1.15,0.346,0.454,0.252,
    1.2,0.321,0.499,0.278,
    1.25,0.298,0.529,0.299,
    1.3,0.282,0.64,0.372,
    1.35,0.267,0.65,0.389,
    1.4,0.255,0.649,0.399,
```

```
    1.45,0.244,0.607,0.389,
    1.5,0.235,0.652,0.436,
    1.55,0.224,0.718,0.493,
    1.6,0.209,0.692,0.486,
    1.65,0.201,0.669,0.475,
    1.7,0.186,0.68,0.486,
    1.75,0.175,0.754,0.54,
    1.8,0.168,0.699,0.497,
    1.85,0.156,0.569,0.405,
    1.9,0.154,0.668,0.475,
    1.95,0.168,0.699,0.497,
    2,0.134,0.805,0.542,
    2.05,0.127,0.81,0.547,
    2.1,0.121,0.816,0.554,
    2.15,0.115,0.82,0.555,
    2.2,0.108,0.825,0.533,
    2.25,0.103,0.83,0.536,
    2.3,0.099,0.834,0.551,
    2.35,0.096,0.838,0.559,
    2.4,0.092,0.841,0.559,
    2.45,0.087,0.844,0.546,
    2.5,0.082,0.847,0.534,
    3,0.013,0.888,0.048,
    3.5,0.009,0.893,0.041,
    4,0.009,0.898,0.043;

WindowMaterial:Shade,
    20001,                  !- Name
    0.05,                   !- Solar Transmittance
    0.9,                    !- Solar Reflectance
    0.9,                    !- Visible Transmittance
    0.05,                   !- Visible Reflectance
    0.05,                   !- Thermal Hemispherical Emissivity
    0.9,                    !- Thermal Transmittance
    0.001,                  !- Thickness [m]
    10,                     !- Conductivity [W/m-K]
    0.020,                  !- Shade to Glass Distance [m]
    0,                      !- Top Opening Multiplier
    0,                      !- Bottom Opening Multiplier
    0,                      !- Left-Side Opening Multiplier
    0,                      !- Right-Side Opening Multiplier
    0.5;                    !- Airflow Permeability

! EPS Expanded Polystyrene (Heavyweight) - Slab thickness {2}
Material,
    1_1_85,                 !- Material name
    Rough,                  !- Roughness
    {2},                    !- Thickness [m]
    0.035,                  !- Conductivity [W/m-K]
    25,                     !- Density [kg/m3]
    1400,                   !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! EPS Expanded Polystyrene (Heavyweight) - Foundation thickness {3}
Material,
    1_1_86,                 !- Material name
    Rough,                  !- Roughness
    {3},                    !- Thickness [m]
    0.035,                  !- Conductivity [W/m-K]
    25,                     !- Density [kg/m3]
    1400,                   !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! EPS Expanded Polystyrene (Heavyweight) - Wall thickness {4}
Material,
    1_1_87,                 !- Material name
    Rough,                  !- Roughness
    {4},                    !- Thickness [m]
    0.035,                  !- Conductivity [W/m-K]
    25,                     !- Density [kg/m3]
    1400,                   !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! EPS Expanded Polystyrene (Heavyweight) - Ceiling thickness {5}
Material,
    1_1_88,                 !- Material name
    Rough,                  !- Roughness
    {5},                    !- Thickness [m]
    0.035,                  !- Conductivity [W/m-K]
    25,                     !- Density [kg/m3]
    1400,                   !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! Aerated Concrete Slab- thickness {6}
Material,
    1_1_1,                  !- Material name
    Rough,                  !- Roughness
```

```
    {6},                    !- Thickness [m]
    0.1600,                 !- Conductivity [w/m-K]
    500.00,                 !- Density [kg/m3]
    840.00,                 !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! Aerated Concrete Slab- thickness 0.05m
Material,
    1_1_2,                  !- Material name
    Rough,                  !- Roughness
    0.05,                   !- Thickness [m]
    0.1600,                 !- Conductivity [w/m-K]
    500.00,                 !- Density [kg/m3]
    840.00,                 !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! 'Slab Floor'
Construction,
    1,                      !- Name
    1_1_1,                        !- Aerated Concrete ({6}m)
    1_1_85;                 !- EPS Expanded Polystyrene (Heavyweight) ({2}m)

! 'Foundation Wall'
Construction,
    2,                      !- Name
    1_1_1,                        !- Aerated Concrete ({6}m)
    1_1_86;                 !- EPS Expanded Polystyrene (Heavyweight) ({3}m)

! 'Exposed Wall'
Construction,
    3,                      !- Name
    1_1_1,                      !- Aerated Concrete ({6}m)
    1_1_87;                 !- EPS Expanded Polystyrene (Heavyweight) ({4}m)

! 'Exposed Ceiling'
Construction,
    4,                      !- Name
    1_1_1,                        !- Aerated Concrete ({6}m)
    1_1_88;                 !- EPS Expanded Polystyrene (Heavyweight) ({5}m)

! <Previous reversed>
Construction,
    5,                      !- Name
    1_1_88,                 !- EPS Expanded Polystyrene (Heavyweight) ({5}m)
    1_1_1;                  !- Aerated Concrete ({6}m)

! 'Indoor Ceiling'
Construction,
    6,                      !- Name
    1_1_2;                        !- Aerated Concrete (0.05m)

! <Previous reversed>
Construction,
    7,                      !- Name
    1_1_2;                        !- Aerated Concrete (0.05m)

Construction,
    101,                    !- Thesis - Single Glaze
    2;                      !- Generic CLEAR 3MM

Construction,
    102,                    !- Thesis - Weak Double Glaze
    2,                      !- Generic CLEAR 3MM
    1001,                   !- AIR 6MM
    2;                      !- Generic CLEAR 3MM

Construction,
    103,                    !- Thesis - Good Double Glaze
    2,                      !- Generic CLEAR 3MM
    1020,                   !- AIR 16MM
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

Construction,
    104,                    !- Thesis - Triple Glaze
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

Construction,
    105,                    !- Thesis - Quad Glaze
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    390,                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>
    1023,                   !- KRYPTON 16MM
    390,                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>
    1023,                   !- KRYPTON 16MM
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

Construction,
```

```
    101S,                   !- Thesis - Single Glaze
    20001,                  !- Exterior Shading
    2;                      !- Generic CLEAR 3MM

Construction,
    102S,                   !- Thesis - Weak Double Glaze
    20001,                  !- Exterior Shading
    2,                      !- Generic CLEAR 3MM
    1001,                   !- AIR 6MM
    2;                      !- Generic CLEAR 3MM

Construction,
    103S,                   !- Thesis - Good Double Glaze
    20001,                  !- Exterior Shading
    2,                      !- Generic CLEAR 3MM
    1020,                   !- AIR 16MM
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

Construction,
    104S,                   !- Thesis - Triple Glaze
    20001,                  !- Exterior Shading
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

Construction,
    105S,                   !- Thesis - Quad Glaze
    20001,                  !- Exterior Shading
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    390,                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>
    1023,                   !- KRYPTON 16MM
    390,                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>
    1023,                   !- KRYPTON 16MM
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

WindowProperty:ShadingControl,
    1111,                       !- Name of shading control
    ExteriorShade,              !- Shading type
    {8}S,                       !- Name of glazed construction with shading
    OnIfHighZoneAirTemperature, !- Shading control type
    ,                           !- Schedule name
    24,                         !- Setpoint
    No,                         !- Shading control is scheduled
    No,                         !- Glare control is active
    ,                           !- Material name of shading device
    ,                           !- Type of slat angle control
    ,                           !- Slat angle schedule name
    ;                           !- Setpoint 2

HeatBalanceAlgorithm,ConductionTransferFunction,2000;

SurfaceConvectionAlgorithm:Inside,Detailed;

SurfaceConvectionAlgorithm:Outside,DOE-2;

ShadowCalculation,
    20,                     !- Calculation Frequency
    15000;                  !- Maximum Figures in Shadow Overlap Calculations

ZoneCapacitanceMultiplier,1.0;

Building,
    Building,               !- Building Name
    0,                      !- North Axis
    Suburbs,                !- Terrain
    .05,                    !- Loads Convergence Tolerance
    .4,                     !- Temperature Convergence Tolerance
    MinimalShadowing,       !- Solar Distribution
    25;                     !- Maximum number of warmup days


GlobalGeometryRules,
    LowerLeftCorner,        !- Starting Vertex Position
    CounterClockWise,       !- Vertex Entry Direction
    World;                  !- Coordinate System

! Linked Single Zone
Zone,
    208,                    !- Zone Name
    0,                      !- Relative North (to building)
    0,                      !- X Origin [m]
    0,                      !- Y Origin [m]
    0,                      !- Z Origin [m]
    1 ,                     !- Zone Type
    1,                      !- Zone multiplier
    ,                       !- Zone ceiling height
    autocalculate,          !- Zone volume
    Detailed;               !- Zone inside convection algorithm

PEOPLE,
    People 208,             !- Name
    208,                    !- Zone Name
```

```
    2234,                   !- Number of People SCHEDULE Name
    People,                 !- Number of People
    3,                      !- Number of People
    ,                       !- People per Zone Area
    ,                       !- Zone Area per Person
    .5,                     !- radiant fraction
    AUTOCALCULATE,          !- User Specified Sensible Fraction
    Activity Schedule 208,  !- Activity level SCHEDULE Name (units W/person, real)
    No,                     !- Enable ASHRAE 55 comfort warnings
    ZoneAveraged,           !- MRT Calculation Type
    ,                       !- no particular surface is weighted
    Work efficiency,        !- Work Efficiency SCHEDULE Name (0.0-1.0,real)
    Clothing Schedule 208,  !- Clothing Insulation SCHEDULE Name (real)
    AirVelocitySchedule;    !- Air Velocity SCHEDULE Name (units m/s, real)

Schedule:Compact,
    Activity Schedule 208,  !- Name
    Any Number,             !- Schedule Type Limits Name
    Through: 12/31,         !- Field 1
    For: AllDays,           !- Field 2
    Until: 24:00,120;       !- Field 3

Schedule:Compact,
    Clothing Schedule 208,  !- Name
    Any Number,             !- Schedule Type Limits Name
    Through: 4/1,           !- Field 1
    For: AllDays,           !- Field 2
    Until: 24:00,1,         !- Field 3
    Through: 9/30,          !- Field 5
    For: AllDays,           !- Field 6
    Until: 24:00,.5,        !- Field 7
    Through: 12/31,         !- Field 9
    For: AllDays,           !- Field 10
    Until: 24:00,1;         !- Field 11

Lights,
    208 General lighting,   !- Name
    208,                    !- Zone Name
    2235,                   !- Schedule Name
    Watts/Area,             !- Design Level Calculation Method
    ,                       !- Lighting Level [W]
    1.55,                   !- Watts per Zone Floor Area [W/m2]
    ,                       !- Watts per Person [W/person]
    0,                      !- Return Air Fraction
    .42,                    !- Fraction Radiant
    .18,                    !- Fraction Visible
    0,                      !- Fraction Replaceable
    208GeneralLights;       !- End-Use Subcategory

ElectricEquipment,
    208 Equipment 1,        !- Name
    208,                    !- Zone Name
    2236,                   !- Schedule Name
    Watts/Area,             !- Design Level Calculation Method
    ,                       !- Design Level [W]
    3.73,                   !- Watts per Zone Floor Area [W/m2]
    ,                       !- Watts per Person [W/person]
    0,                      !- Fraction Latent
    .2,                     !- Fraction Radiant
    0,                      !- Fraction Lost
    208Appliances;          !- End-Use Subcategory

WaterUse:Equipment,
    DHW 208,                    !- Name
    208DHW,                     !- End-Use Subcategory
    3.04E-06,                   !- Peak Flow Rate [m3/s]
    2234,                       !- Flow Rate Fraction Schedule Name
    DHW Supply Temperature 208, !- Target Temperature Schedule Name
    DHW Supply Temperature 208, !- Hot Water Supply Temperature Schedule Name
    DHW Mains Temperature 208,  !- Cold Water Supply Temperature Schedule Name
    208,                        !- Zone Name
    ,                           !- Sensible Fraction Schedule Name
    ;                           !- Latent Fraction Schedule Name

Schedule:Compact,
    DHW Supply Temperature 208, !- Name
    Temperature,                !- Schedule Type Limits Name
    Through: 12/31,             !- Field 1
    For: AllDays,               !- Field 2
    Until: 24:00,60;            !- Field 3

Schedule:Compact,
    DHW Mains Temperature 208,  !- Name
    Temperature,                !- Schedule Type Limits Name
    Through: 12/31,             !- Field 1
    For: AllDays,               !- Field 2
    Until: 24:00,10;            !- Field 3

ZoneInfiltration:DesignFlowRate,
    208 Infiltration,           !- Name
    208,                        !- Zone Name
    On,                         !- Infiltration SCHEDULE Name
    AirChanges/Hour,            !- Design Volume Flow Rate calculation method
    ,                           !- Design Volume Flow Rate [m3/s]
    ,                           !- Flow per Zone Floor Area [m3/s/m2]
```

```
    ,                           !- Flow per Exterior Surface Area [m3/s/m2]
    {1},                        !- Air Changes Per Hour
    1,                          !- Constant Term Coefficient
    0,                          !- Temperature Term Coefficient
    0,                          !- Velocity Term Coefficient
    0;                          !- Velocity Squared Term Coefficient

ZoneVentilation,
    208 Ventilation,        !- Name
    208,                    !- Zone Name
    On,                     !- Schedule Name
    Flow/Area,              !- Design Flow Rate Calculation Method
    ,                       !- Design Flow Rate [m3/s]
    3.55E-04,               !- Flow Rate per Zone Floor Area [m3/s-m2]
    ,                       !- Flow Rate per Person [m3/s-person]
    ,                       !- Air Changes per Hour
    Natural,                !- Ventilation Type
    ,                       !- Fan Pressure Rise [Pa]
    ,                       !- Fan Total Efficiency
    1,                      !- Constant Term Coefficient
    0,                      !- Temperature Term Coefficient
    0,                      !- Velocity Term Coefficient
    0,                      !- Velocity Squared Term Coefficient
    0,                      !- Minimum Indoor Temperature [C]
    ,                       !- Minimum Indoor Temperature Schedule Name
    40,                     !- Maximum Indoor Temperature [C]
    ,                       !- Maximum Indoor Temperature Schedule Name
    2,                      !- Delta Temperature [deltaC]
    ,                       !- Delta Temperature Schedule Name
    -100,                   !- Minimum Outdoor Temperature [C]
    ,                       !- Minimum Outdoor Temperature Schedule Name
    40,                     !- Maximum Outdoor Temperature [C]
    ,                       !- Maximum Outdoor Temperature Schedule Name
    40;                     !- Maximum Wind Speed [m/s]


   {7}


! - Basement Surfaces Output
Output:Variable, S_208_0_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_208_2_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_208_3_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_208_4_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_208_5_0_0, Opaque Surface Inside Face Conduction, monthly;

! - First Floor Surfaces Output
Output:Variable, C_220_1_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_220_2_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_220_2_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_220_2_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_220_2_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_220_3_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_220_3_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_220_3_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_220_3_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_220_4_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_220_4_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_220_4_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_220_4_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_220_5_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_220_5_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_220_5_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_220_5_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, F_208_0_0_10001, Opaque Surface Inside Face Conduction, monthly;

! - Second Floor Surfaces Output
Output:Variable, C_171_1_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_171_2_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_171_2_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_171_2_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_171_2_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_171_3_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_171_3_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_171_3_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_171_3_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_171_4_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_171_4_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_171_4_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_171_4_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_171_5_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_171_5_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_171_5_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_171_5_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, F_208_0_0_10002, Opaque Surface Inside Face Conduction, monthly;

! - Third Floor Surfaces Output
Output:Variable, C_280_1_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_280_2_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_280_2_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_280_2_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_280_2_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_280_3_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_280_3_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_280_3_0_0_0_0_Win, Window Heat Loss, monthly;
```

```
Output:Variable, W_280_3_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_280_4_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_280_4_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_280_4_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_280_4_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_280_5_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_280_5_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_280_5_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_280_5_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, F_265_8_0_10003, Opaque Surface Inside Face Conduction, monthly;

! - Roof Surfaces Output
Output:Variable, F_265_8_0_10003, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_265_0_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_265_1_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_265_2_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_265_3_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, R_265_4_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, R_265_5_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, R_265_6_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, R_265_7_0_0, Opaque Surface Inside Face Conduction, monthly;

Output:Variable, *, Outdoor Dry Bulb, monthly;
Output:Variable, 208, Zone Mean Air Temperature, monthly, On;
Output:Variable, 208, Zone Mean Radiant Temperature, monthly, On;
Output:Variable, 208, Zone Air Relative Humidity, monthly, On;
Output:Variable, 208, Zone Infiltration Air Change Rate, monthly;
Output:Variable, 208, Zone Ventilation Total Heat Loss, monthly;
Output:Variable, 208, Zone Ventilation Total Heat Gain, monthy;
Output:Variable, 208, Zone/Sys Sensible Heating Rate, monthly;
Output:Variable, 208, Zone/Sys Sensible Cooling Rate, monthly;
Output:Variable, 208, Zone People Sensible Heat Gain, monthly;
Output:Variable, 208, Zone Transmitted Solar, monthly;
Output:Variable, 208, Zone Infiltration Sensible Heat Loss, monthly;
Output:Variable, 208, Zone Infiltration Sensible Heat Gain, monthly;

Output:Meter, 208GeneralLights*, monthly;
Output:Meter, 208Appliances*, monthly;
Output:Meter, 208DHW*, monthly;

Output:Surfaces:Drawing, DXF, Triangulate3DFace;
Output:Surfaces:List,Details;
Output:Constructions,Constructions;
Output:VariableDictionary, regular;
Output:Diagnostics, DisplayAdvancedReportVariables, DisplayExtraWarnings;

!
! ---------------------------------------------------------------
! HVAC Definition
! ---------------------------------------------------------------
!

ScheduleTypeLimits,
    HVACTemplate Any Number;        !- Name

Schedule:Compact,
    HVACTemplate-Always 4,          !- Name
    HVACTemplate Any Number,        !- Type
    Through: 12/31,                 !- Field
    For: AllDays,                   !- Field
    Until: 24:00,                   !- Field
    4;                              !- Field

Schedule:Compact,
    HVACTemplate-Always 1,          !- Name
    HVACTemplate Any Number,        !- Type
    Through: 12/31,                 !- Field
    For: AllDays,                   !- Field
    Until: 24:00,                   !- Field
    1;                              !- Field

ThermostatSetpoint:DualSetpoint,
    Zone 208 Thermostat Dual SP Control,    !- Name
    Zone 208 Heating SP Sch,                !- Heating Setpoint Temperature Schedule Name
    Zone 208 Cooling SP Sch;                !- Cooling Setpoint Temperature Schedule Name

ZoneControl:Thermostat,
    208 Thermostat,                         !- Thermostat Name
    208,                                    !- Zone Name
    HVACTemplate-Always 4,                  !- Control Type Schedule Name
    ThermostatSetpoint:DualSetpoint,        !- Control Type
    Zone 208 Thermostat Dual SP Control;    !- Control Type Name

Sizing:Zone,
    208,                            !- Zone Name
    14,                             !- Zone cooling design supply air temperature [C]
    50,                             !- Zone heating design supply air temperature [C]
    0.008,                          !- Zone cooling design supply air humidity ratio [kg-H20/kg-air]
    0.008,                          !- Zone heating design supply air humidity ratio [kg-H2O/kg-air]
    Flow/Area,                      !- Outdoor Air Method
    ,                               !- outside air flow per person [m3/s]
    3.55E-04,                       !- outside air flow per zone area [m3/s-m2]
    ,                               !- outside air flow per zone [m3/s]
    ,                               !- Zone Sizing Factor
    DesignDay,                      !- Cooling Design Air Flow Method
```

```
    ,                               !- cooling design air flow rate [m3/s]
    ,                               !- cooling min air flow per zone area [m3/s-m2]
    ,                               !- cooling min air flow [m3/s]
    ,                               !- cooling min air flow fraction []
    DesignDay,                      !- Heating Design Air Flow Method
    ,                               !- heating design air flow rate [m3/s]
    ,                               !- heating min air flow per zone area [m3/s-m2]
    ,                               !- heating min air flow [m3/s]
    ;                               !- heating min air flow fraction []

ZoneHVAC:EquipmentConnections,
    208,                            !- Zone Name
    208Equipment,                   !- Zone Conditioning Equipment List Name
    208 HVAC Delivery,              !- List Name: Zone Air Inlet Nodes
    ,                               !- List Name: Zone Air Exhaust Nodes
    208 Zone Air,                   !- Zone Air Node Name
    208 Zone Return;                !- Zone Return Air Node Name (HVAC to zone)

ZoneHVAC:EquipmentList,
    208Equipment,                   !- Name
    ZoneHVAC:IdealLoadsAirSystem,   !- Zone Equipment 1 Object Type
    208 IdealHVAC,                  !- Zone Equipment 1 Name
    1,                              !- CoolingPriority
    1;                              !- HeatingPriority

ZoneHVAC:IdealLoadsAirSystem,
    208 IdealHVAC,                  !- Air system name
    208 HVAC Delivery,              !- Zone Supply Air Node (HVAC delivery)
    50,                             !- Heating Supply Air Temp
    14,                             !- Cooling Supply Air Temp
    0.008,                          !- Heating Supply Air Humidity Ratio
    0.008,                          !- Cooling Supply Air Humidity Ratio
    NoLimit,                        !- Heating Limit
    ,                               !- Max Heating Flow
    NoLimit,                        !- Cooling Limit
    ,                               !- Max Cooling Flow
    NoOutdoorAir,                   !- Outdoor air
    ,                               !- Outdoor air flow rate
    208 Heating Availability Sch,   !- Heating Avail Sch
    208 Cooling Availability Sch;   !- Cooling Avail Sch

! Modified schedule: Heating Setback
Schedule:Compact,
    Zone 208 Heating SP Sch, !- Name
    Temperature,             !- Schedule Type Limits Name
    Through: 31 May,         !- Field 1
    For: AllDays,            !- Field 2
    Until: 05:00,20,         !- Field 3
    Until: 09:00,20,         !- Field 5
    Until: 17:00,20,         !- Field 7
    Until: 24:00,20,         !- Field 9
    Through: 30 September,   !- Field 11
    For: AllDays,            !- Field 12
    Until: 05:00,0,          !- Field 13
    Until: 09:00,0,          !- Field 15
    Until: 17:00,0,          !- Field 17
    Until: 24:00,0,          !- Field 19
    Through: 31 December,    !- Field 21
    For: AllDays,            !- Field 22
    Until: 05:00,20,         !- Field 23
    Until: 09:00,20,         !- Field 25
    Until: 17:00,20,         !- Field 27
    Until: 24:00,20;         !- Field 29

! Modified schedule: Heating Availability
Schedule:Compact,
    208 Heating Availability Sch,  !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 May,         !- Field 1
    For: AllDays,            !- Field 2
    Until: 05:00,1,          !- Field 3
    Until: 09:00,1,          !- Field 5
    Until: 17:00,1,          !- Field 7
    Until: 24:00,1,          !- Field 9
    Through: 30 September,   !- Field 11
    For: AllDays,            !- Field 12
    Until: 05:00,0,          !- Field 13
    Until: 09:00,0,          !- Field 15
    Until: 17:00,0,          !- Field 17
    Until: 24:00,0,          !- Field 19
    Through: 31 December,    !- Field 21
    For: AllDays,            !- Field 22
    Until: 05:00,1,          !- Field 23
    Until: 09:00,1,          !- Field 25
    Until: 17:00,1,          !- Field 27
    Until: 24:00,1;          !- Field 29

! Modified schedule: Cooling Setback
Schedule:Compact,
    Zone 208 Cooling SP Sch, !- Name
    Temperature,             !- Schedule Type Limits Name
    Through: 31 May,         !- Field 1
    For: AllDays,            !- Field 2
    Until: 05:00,100,        !- Field 3
    Until: 09:00,100,        !- Field 5
```

```
    Until: 17:00,100,        !- Field 7
    Until: 24:00,100,        !- Field 9
    Through: 30 September,   !- Field 11
    For: AllDays,            !- Field 12
    Until: 05:00,25,         !- Field 13
    Until: 09:00,25,         !- Field 15
    Until: 17:00,25,         !- Field 17
    Until: 24:00,25,         !- Field 19
    Through: 31 December,    !- Field 21
    For: AllDays,            !- Field 22
    Until: 05:00,100,        !- Field 23
    Until: 09:00,100,        !- Field 25
    Until: 17:00,100,        !- Field 27
    Until: 24:00,100;        !- Field 29

! Modified schedule: Cooling Availability
Schedule:Compact,
    208 Cooling Availability Sch,  !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 May,         !- Field 1
    For: AllDays,            !- Field 2
    Until: 05:00,0,          !- Field 3
    Until: 09:00,0,          !- Field 5
    Until: 17:00,0,          !- Field 7
    Until: 24:00,0,          !- Field 9
    Through: 30 September,   !- Field 11
    For: AllDays,            !- Field 12
    Until: 05:00,1,          !- Field 13
    Until: 09:00,1,          !- Field 15
    Until: 17:00,1,          !- Field 17
    Until: 24:00,1,          !- Field 19
    Through: 31 December,    !- Field 21
    For: AllDays,            !- Field 22
    Until: 05:00,0,          !- Field 23
    Until: 09:00,0,          !- Field 25
    Until: 17:00,0,          !- Field 27
    Until: 24:00,0;          !- Field 29 """.format(permutation[n],permutation[n][9],permutation[n][10],
                                                    <B>permutation[n][11],permutation[n][12],permutation[n][13],
                                                    <B>permutation[n][14],Geometry,permutation[n][8])

                                                print('making IDF #{0}'.format(n))
                                                #Create new IDF file
                                                currentIDF = '{0}_{1}_{2}_{3:.1f}_{4:.2f}_{5:.1f}_{6:.1f}_{7:.1f}'
                                                <B>'_{8}_{9:.5f}_{10:.3f}_{11:.3f}_{12:.3f}_{13:.3f}_{14:.5f}.idf'
                                                <B>.format(permutation[n][0],permutation[n][1],permutation[n][2],
                                                <B>permutation[n][3], permutation[n][4], permutation[n][5],
                                                <B>permutation[n][6], permutation[n][7], permutation[n][8],
                                                <B>permutation[n][9],permutation[n][10], permutation[n][11],
                                                <B>permutation[n][12],permutation[n][13],permutation[n][14],)

                                                permtext[n] = currentIDF
                                                notf = open('/thesis/runsR1/{0}'.format(currentIDF), 'w')
                                                notf.write(IDFText)
                                                notf.close()
                                                n = n + 1


    #Randomize the complete permutation array (for balanced processing time groups)
    #and write it out to a globally available file

    import random
    random.shuffle(permtext, None, int)
    count = list(range(numperm))

    a = open('/thesis/run1/randarray', 'w')
    for elem in count:
        a.write('{0} '.format(permtext[elem]))
    a.close()
    print('done rand 1')

    b = open('/thesis/run2/randarray', 'w')
    for elem in count:
        b.write('{0} '.format(permtext[elem]))
    b.close()
    print('done rand 2')

    c = open('/thesis/run3/randarray', 'w')
    for elem in count:
        c.write('{0} '.format(permtext[elem]))
    c.close()
    print('done rand 3')

    d = open('/thesis/run4/randarray', 'w')
    for elem in count:
        d.write('{0} '.format(permtext[elem]))
    d.close()
    print('done rand 4')

    e = open('/thesis/run5/randarray', 'w')
    for elem in count:
        e.write('{0} '.format(permtext[elem]))
    e.close()
    print('done rand 5')

    f = open('/thesis/run6/randarray', 'w')
```

```
    for elem in count:
        f.write('{0} '.format(permtext[elem]))
    f.close()
    print('done rand 6')

    g = open('/thesis/run7/randarray', 'w')
    for elem in count:
        g.write('{0} '.format(permtext[elem]))
    g.close()
    print('done rand 7')

    h = open('/thesis/run8/randarray', 'w')
    for elem in count:
        h.write('{0} '.format(permtext[elem]))
    h.close()
    print('done rand 8')

IDFgenerator()
```

SubFunction.py

```
def GeometryFunction(NumStories, Basement, TotalArea, ShapeRatio, SouthWinWallRatio,EastWinWallRatio,
        <B>NorthWinWallRatio, WindowPerform):
    """This function generates the geometry dependent Zone information for your IDF"""


    import math

    FloorArea = 1

    if Basement == 1:

        FloorArea = TotalArea/(NumStories + 1)

    if Basement == 0:

        FloorArea = TotalArea/NumStories

    SquareDim = math.sqrt(FloorArea)
    Width = SquareDim*ShapeRatio
    Length = SquareDim/ShapeRatio
    OverHang = 0.75
    OverWidth = Width + OverHang
    OverLength = Length + OverHang
    HalfWidth = Width/2
    HalfLength = Length/2
    Height = 3                   #only number defined in this function
    SecondHeight = 2*Height
    ThirdHeight = 3*Height

    if NumStories == 1:
        PeakHeight = Height + 4.5
        RoofHeight = Height + 0.350

    if NumStories == 2:
        PeakHeight = SecondHeight + 4.5
        RoofHeight = SecondHeight + 0.350

    if NumStories == 3:
        PeakHeight = ThirdHeight + 4.5
        RoofHeight = ThirdHeight + 0.350

    WinHeight = 0.75*Height
    WinVertOffset = 0.125*Height

    FirstFlrShortDim = WinVertOffset
    FirstFlrTallDim = FirstFlrShortDim + WinHeight
    SecondFlrShortDim = Height + WinVertOffset
    SecondFlrTallDim = WinHeight + SecondFlrShortDim
    ThirdFlrShortDim = 2*Height + WinVertOffset
    ThirdFlrTallDim = WinHeight + ThirdFlrShortDim

    SouthWinArea = SouthWinWallRatio*Width*Height
    SouthWinWidth = SouthWinArea/WinHeight
    SouthWinShortDim = (Width-SouthWinWidth)/2
    SouthWinLongDim = SouthWinShortDim + SouthWinWidth

    EastWinArea = EastWinWallRatio*Length*Height
    EastWinLength = EastWinArea/WinHeight
    EastWinShortDim = (Length-EastWinLength)/2
    EastWinLongDim = EastWinShortDim + EastWinLength

    NorthWinArea = NorthWinWallRatio*Width*Height
    NorthWinWidth = NorthWinArea/WinHeight
    NorthWinShortDim = (Width-NorthWinWidth)/2
    NorthWinLongDim = NorthWinShortDim + NorthWinWidth

    NorthWindowArea = Width

    if Basement == 1:

        BasementIDF = """   ! Basement, Basement, Ground floor

   BuildingSurface:Detailed, S_208_0_0_0,         !- Surface name

      Floor, 1,                                   !- Class and Construction Name
      208,                                        !- Zone Name
      Ground, ,                                   !- Outside Face Environment
      NoSun,                                      !- Sun Exposure
      NoWind,                                     !- Wind Exposure
      1,                                          !- View Factor to Ground
      4,                                          !- Number vertices
       {0},0,-{2},              !- Vertex 1
       0,0,-{2},                !- Vertex 2
       0,{1},-{2},              !- Vertex 3
       {0},{1},-{2};            !- Vertex 4


   ! Basement, Basement, East Wall
```

```
BuildingSurface:Detailed, W_208_2_0_0,         !- Surface name

   Wall, 2,                                    !- Class and Construction Name
   208,                                        !- Zone Name
   Ground, ,                                   !- Outside Face Environment
   NoSun,                                      !- Sun Exposure
   NoWind,                                     !- Wind Exposure
   .5,                                         !- View Factor to Ground
   4,                                          !- Number vertices
    {0},0,-{2},                !- Vertex 1
    {0},{1},-{2},              !- Vertex 2
    {0},{1},0,                 !- Vertex 3
    {0},0,0;                   !- Vertex 4

! Basement, Basement, North Wall

BuildingSurface:Detailed, W_208_3_0_0,         !- Surface name

   Wall, 2,                                    !- Class and Construction Name
   208,                                        !- Zone Name
   Ground, ,                                   !- Outside Face Environment
   NoSun,                                      !- Sun Exposure
   NoWind,                                     !- Wind Exposure
   .5,                                         !- View Factor to Ground
   4,                                          !- Number vertices
    {0},{1},-{2},              !- Vertex 1
    0,{1},-{2},                !- Vertex 2
    0,{1},0,                   !- Vertex 3
    {0},{1},0;                 !- Vertex 4

! Basement, Basement, West Wall

BuildingSurface:Detailed, W_208_4_0_0,         !- Surface name

   Wall, 2,                                    !- Class and Construction Name
   208,                                        !- Zone Name
   Ground, ,                                   !- Outside Face Environment
   NoSun,                                      !- Sun Exposure
   NoWind,                                     !- Wind Exposure
   .5,                                         !- View Factor to Ground
   4,                                          !- Number vertices
    0,{1},-{2},                !- Vertex 1
    0,0,-{2},                  !- Vertex 2
    0,0,0,                     !- Vertex 3
    0,{1},0;                   !- Vertex 4

! Basement, Basement, South Wall

BuildingSurface:Detailed, W_208_5_0_0,         !- Surface name

   Wall, 2,                                    !- Class and Construction Name
   208,                                        !- Zone Name
   Ground, ,                                   !- Outside Face Environment
   NoSun,                                      !- Sun Exposure
   NoWind,                                     !- Wind Exposure
   .5,                                         !- View Factor to Ground
   4,                                          !- Number vertices
    0,0,-{2},                  !- Vertex 1
    {0},0,-{2},                !- Vertex 2
    {0},0,0,                   !- Vertex 3
    0,0,0;                     !- Vertex 4""".format(Width, Length, Height)


 else: BasementIDF = """   ! 1st Floor, 1st Floor, Ground floor

BuildingSurface:Detailed, S_208_0_0_0,         !- Surface name

   Floor, 1,                                   !- Class and Construction Name
   208,                                        !- Zone Name
   Ground, ,                                   !- Outside Face Environment
   NoSun,                                      !- Sun Exposure
   NoWind,                                     !- Wind Exposure
   1,                                          !- View Factor to Ground
   4,                                          !- Number vertices
    {0},0,0,                   !- Vertex 1
    0,0,0,                     !- Vertex 2
    0,{1},0,                   !- Vertex 3
    {0},{1},0;                 !- Vertex 4""".format(Width, Length, Height)


 if NumStories == 1:

     UpperIDF = """! 1st Floor, 1st Floor, Ceiling

BuildingSurface:Detailed, C_220_1_0_0,         !- Surface name

   Ceiling, 4,                                 !- Class and Construction Name
   208,                                        !- Zone Name
   Surface, F_265_8_0_10003,                   !- Outside Face Environment
   NoSun,                                      !- Sun Exposure
   NoWind,                                     !- Wind Exposure
   0,                                          !- View Factor to Ground
   4,                                          !- Number vertices
    0,0,{2},                   !- Vertex 1
```

```
     {0},0,{2},               !- Vertex 2
     {0},{1},{2},             !- Vertex 3
     0,{1},{2};               !- Vertex 4


  ! 1st Floor, 1st Floor, Ceiling

  BuildingSurface:Detailed, F_265_8_0_10003,     !- Surface name - reverse definition

    Floor, 5,                                    !- Class and Construction Name
    265,                                         !- Zone Name
    Surface, C_220_1_0_0,                        !- Outside Face Environment
    NoSun,                                       !- Sun Exposure
    NoWind,                                      !- Wind Exposure
    0,                                           !- View Factor to Ground
    4,                                           !- Number vertices
     {0},0,{2},               !- Vertex 1
     0,0,{2},                 !- Vertex 2
     0,{1},{2},               !- Vertex 3
     {0},{1},{2};             !- Vertex 4


  ! 1st Floor, 1st Floor, East Wall

  BuildingSurface:Detailed, W_220_2_0_0,         !- Surface name

    Wall, 3,                                     !- Class and Construction Name
    208,                                         !- Zone Name
    Outdoors, ,                                  !- Outside Face Environment
    SunExposed,                                  !- Sun Exposure
    WindExposed,                                 !- Wind Exposure
    .5,                                          !- View Factor to Ground
    4,                                           !- Number vertices
     {0},0,0,                 !- Vertex 1
     {0},{1},0,               !- Vertex 2
     {0},{1},{2},             !- Vertex 3
     {0},0,{2};               !- Vertex 4


    ! East Window

    FenestrationSurface:Detailed, W_220_2_0_0_0_Win,  !- Window name

      Window,                                    !- Class
      {3},                                       !- Construction Name
      W_220_2_0_0,                               !- Base surface
      ,                                          !- corresponding other window subsurface
      .5,                                        !- View Factor to Ground
      1111,                                      !- Window shading control
      ,                                          !- Frame divider name
      1,                                         !- Multiplier
      4,                                         !- Number vertices
       {0},{6},{10},              !- Vertex 1
       {0},{7},{10},              !- Vertex 2
       {0},{7},{11},            !- Vertex 3
       {0},{6},{11};              !- Vertex 4


  ! 1st Floor, 1st Floor, North Wall

  BuildingSurface:Detailed, W_220_3_0_0,         !- Surface name

    Wall, 3,                                     !- Class and Construction Name
    208,                                         !- Zone Name
    Outdoors, ,                                  !- Outside Face Environment
    SunExposed,                                  !- Sun Exposure
    WindExposed,                                 !- Wind Exposure
    .5,                                          !- View Factor to Ground
    4,                                           !- Number vertices
     {0},{1},0,               !- Vertex 1
     0,{1},0,                 !- Vertex 2
     0,{1},{2},               !- Vertex 3
     {0},{1},{2};             !- Vertex 4

    ! North Window

    FenestrationSurface:Detailed, W_220_3_0_0_0_Win,  !- Window name

      Window,                                    !- Class
      {3},                                       !- Construction Name
      W_220_3_0_0,                               !- Base surface
      ,                                          !- corresponding other window subsurface
      .5,                                        !- View Factor to Ground
      1111,                                      !- Window shading control
      ,                                          !- Frame divider name
      1,                                         !- Multiplier
      4,                                         !- Number vertices
       {9}, {1}, {10},          !- Vertex 1
       {8}, {1}, {10},          !- Vertex 2
       {8}, {1}, {11},          !- Vertex 3
       {9}, {1}, {11};          !- Vertex 4


  ! 1st Floor, 1st Floor, West Wall
```

```
   BuildingSurface:Detailed, W_220_4_0_0,         !- Surface name

      Wall, 3,                                    !- Class and Construction Name
      208,                                        !- Zone Name
      Outdoors, ,                                 !- Outside Face Environment
      SunExposed,                                 !- Sun Exposure
      WindExposed,                                !- Wind Exposure
      .5,                                         !- View Factor to Ground
      4,                                          !- Number vertices
       0,{1},0,                 !- Vertex 1
       0,0,0,                   !- Vertex 2
       0,0,{2},                 !- Vertex 3
       0,{1},{2};               !- Vertex 4

      ! West Window

      FenestrationSurface:Detailed, W_220_4_0_0_0_0_Win,  !- Window name

         Window,                                  !- Class
         {3},                                     !- Construction Name
         W_220_4_0_0,                             !- Base surface
         ,                                        !- corresponding other window subsurface
         .5,                                      !- View Factor to Ground
         1111,                                    !- Window shading control
         ,                                        !- Frame divider name
         1,                                       !- Multiplier
         4,                                       !- Number vertices
          0,{7},{10},               !- Vertex 1
          0,{6},{10},               !- Vertex 2
          0,{6},{11},               !- Vertex 3
          0,{7},{11};               !- Vertex 4


   ! 1st Floor, 1st Floor, South Wall

   BuildingSurface:Detailed, W_220_5_0_0,         !- Surface name

      Wall, 3,                                    !- Class and Construction Name
      208,                                        !- Zone Name
      Outdoors, ,                                 !- Outside Face Environment
      SunExposed,                                 !- Sun Exposure
      WindExposed,                                !- Wind Exposure
      .5,                                         !- View Factor to Ground
      4,                                          !- Number vertices
       0,0,0,                   !- Vertex 1
       {0},0,0,                 !- Vertex 2
       {0},0,{2},               !- Vertex 3
       0,0,{2};                 !- Vertex 4

      ! South Window

      FenestrationSurface:Detailed, W_220_5_0_0_0_0_Win,  !- Window name

         Window,                                  !- Class
         {3},                                    !- Construction Name
         W_220_5_0_0,                             !- Base surface
         ,                                        !- corresponding other window subsurface
         .5,                                      !- View Factor to Ground
         1111,                                    !- Window shading control
         ,                                        !- Frame divider name
         1,                                       !- Multiplier
         4,                                       !- Number vertices
          {4},0,{10},               !- Vertex 1
          {5},0,{10},               !- Vertex 2
          {5},0,{11},               !- Vertex 3
          {4},0,{11};               !- Vertex 4


Shading:Building:Detailed, Pitched roof overhang West,  , 4,  !- site shading

   -{18},{20},{2},                 !- Vertex 1
   -{18},-{18},{2},                !- Vertex 2
    0,0,{2},                       !- Vertex 3
    0,{1},{2};                     !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang North,  , 4,  !- site shading

    0,{1},{2},                     !- Vertex 1
    {0},{1},{2},                   !- Vertex 2
    {19},{20},{2},                 !- Vertex 3
   -{18},{20},{2};                 !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang East,  , 4,  !- site shading

    {19},-{18},{2},                 !- Vertex 1
    {19},{20},{2},                 !- Vertex 2
    {0},{1},{2},                   !- Vertex 3
    {0},0,{2};                     !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang South,  , 4,  !- site shading

   -{18},-{18},{2},                !- Vertex 1
    {19},-{18},{2},                !- Vertex 2
    {0},0,{2},                     !- Vertex 3
    0,0,{2};                       !- Vertex 4
```

```
! Roof 1 - Roof

Zone, 265,                                      !- Zone Name

   0,                                           !- Relative North (to building)
   0,                                           !- X Origin [m]
   0,                                           !- Y Origin [m]
   0,                                           !- Z Origin [m]
   1 ,                                          !- Zone Type
   1,                                           !- Zone multiplier
   ,                                            !- Zone ceiling height - Let EnergyPlus work it out
   autocalculate,                               !- Zone volume
   Detailed;                                    !- Zone inside convection algorithm

   PEOPLE, People 265,                          !- Name

      265,                                      !- Zone Name
      7,                                        !- Number of People SCHEDULE Name
      People,                                   !- Number of People
       0,                                       !- Number of People
      ,                                         !- People per Zone Area
      ,                                         !- Zone Area per Person
       .5,                                      !- radiant fraction
      AUTOCALCULATE,                            !- User Specified Sensible Fraction
      Activity Schedule 265,                    !- Activity level SCHEDULE Name (units W/person, real)
      No,                                       !- Enable ASHRAE 55 comfort warnings
      ZoneAveraged,                             !- MRT Calculation Type
      ,                                         !- no particular surface is weighted
      Work efficiency,                          !- Work Efficiency SCHEDULE Name (0.0-1.0,real)
      Clothing Schedule 265,                    !- Clothing Insulation SCHEDULE Name (real)
      AirVelocitySchedule;                      !- Air Velocity SCHEDULE Name (units m/s, real)

   Schedule:Compact, Activity Schedule 265,     !- activity schedule W/person

      Any Number,                               !- Type
      Through: 12/31,                           !- Type
      For: AllDays,                             !- All days in year
      Until: 24:00,  117;                       !- Constant value

   Schedule:Compact, Clothing Schedule 265,     !- Clothing schedule clo

      Any Number,                               !- Type
      Through: 4/1,                             !- Type
      For: AllDays,                             !- All days in year
      Until: 24:00,  1,                         !- Constant value
      Through: 9/30,                            !- Type
      For: AllDays,                             !- All days in year
      Until: 24:00,  .5,                        !- Constant value
      Through: 12/31,                           !- Type
      For: AllDays,                             !- All days in year
      Until: 24:00,  1;                         !- Constant value


   ZoneInfiltration:DesignFlowRate, 265 Infiltration,  !- Name

      265,                                      !- Zone Name
      On,                                       !- Infiltration SCHEDULE Name
      AirChanges/Hour,                          !- Design Volume Flow Rate calculation method
      ,                                         !- Design Volume Flow Rate [m3/s]
      ,                                         !- Flow per Zone Floor Area [m3/s/m2]
      ,                                         !- Flow per Exterior Surface Area [m3/s/m2]
      0.5,                                      !- Air Changes Per Hour
      1,                                        !- Constant Term Coefficient
      0,                                        !- Temperature Term Coefficient
      0,                                        !- Velocity Term Coefficient
      0;                                        !- Velocity Squared Term Coefficient

   ! Roof 1, Roof, East Wall

   BuildingSurface:Detailed, W_265_0_0_0,       !- Surface name

      Wall, 6,                                  !- Class and Construction Name
      265,                                      !- Zone Name
      Outdoors, ,                               !- Outside Face Environment
      SunExposed,                               !- Sun Exposure
      WindExposed,                              !- Wind Exposure
      .5,                                       !- View Factor to Ground
      4,                                        !- Number vertices
       {0},0,{2},                  !- Vertex 1
       {0},{1},{2},                !- Vertex 2
       {0},{1},{21},               !- Vertex 3
       {0},0,{21};                 !- Vertex 4


   ! Roof 1, Roof, North Wall

   BuildingSurface:Detailed, W_265_1_0_0,       !- Surface name

      Wall, 6,                                  !- Class and Construction Name
      265,                                      !- Zone Name
      Outdoors, ,                               !- Outside Face Environment
      SunExposed,                               !- Sun Exposure
      WindExposed,                              !- Wind Exposure
```

```
    .5,                                    !- View Factor to Ground
    4,                                     !- Number vertices
     {0},{1},{2},                 !- Vertex 1
     0,{1},{2},                   !- Vertex 2
     0,{1},{21},                  !- Vertex 3
     {0},{1},{21};                !- Vertex 4


 ! Roof 1, Roof, West Wall

 BuildingSurface:Detailed, W_265_2_0_0,       !- Surface name

    Wall, 6,                               !- Class and Construction Name
    265,                                   !- Zone Name
    Outdoors, ,                            !- Outside Face Environment
    SunExposed,                            !- Sun Exposure
    WindExposed,                           !- Wind Exposure
    .5,                                    !- View Factor to Ground
    4,                                     !- Number vertices
     0,{1},{2},                   !- Vertex 1
     0,0,{2},                     !- Vertex 2
     0,0,{21},                    !- Vertex 3
     0,{1},{21};                  !- Vertex 4


 ! Roof 1, Roof, South Wall

 BuildingSurface:Detailed, W_265_3_0_0,       !- Surface name

    Wall, 6,                               !- Class and Construction Name
    265,                                   !- Zone Name
    Outdoors, ,                            !- Outside Face Environment
    SunExposed,                            !- Sun Exposure
    WindExposed,                           !- Wind Exposure
    .5,                                    !- View Factor to Ground
    4,                                     !- Number vertices
     0,0,{2},                     !- Vertex 1
     {0},0,{2},                   !- Vertex 2
     {0},0,{21},                  !- Vertex 3
     0,0,{21};                    !- Vertex 4


 ! Roof 1, Roof, North External roof

 BuildingSurface:Detailed, R_265_4_0_0,       !- Surface name

    Roof, 6,                               !- Class and Construction Name
    265,                                   !- Zone Name
    Outdoors, ,                            !- Outside Face Environment
    SunExposed,                            !- Sun Exposure
    WindExposed,                           !- Wind Exposure
    .067,                                  !- View Factor to Ground
    3,                                     !- Number vertices
     {0},{1},{21},                !- Vertex 1
     0,{1},{21},                  !- Vertex 2
     {23},{24},{22};              !- Vertex 3

 ! Roof 1, Roof, East External roof

 BuildingSurface:Detailed, R_265_5_0_0,       !- Surface name

    Roof, 6,                               !- Class and Construction Name
    265,                                   !- Zone Name
    Outdoors, ,                            !- Outside Face Environment
    SunExposed,                            !- Sun Exposure
    WindExposed,                           !- Wind Exposure
    .067,                                  !- View Factor to Ground
    3,                                     !- Number vertices
     {0},0,{21},                  !- Vertex 1
     {0},{1},{21},                !- Vertex 2
     {23},{24},{22};              !- Vertex 3

 ! Roof 1, Roof, South External roof

 BuildingSurface:Detailed, R_265_6_0_0,       !- Surface name

    Roof, 6,                               !- Class and Construction Name
    265,                                   !- Zone Name
    Outdoors, ,                            !- Outside Face Environment
    SunExposed,                            !- Sun Exposure
    WindExposed,                           !- Wind Exposure
    .067,                                  !- View Factor to Ground
    3,                                     !- Number vertices
     0,0,{21},                    !- Vertex 1
     {0},0,{21},                  !- Vertex 2
     {23},{24},{22};              !- Vertex 3

 ! Roof 1, Roof, West External roof

 BuildingSurface:Detailed, R_265_7_0_0,       !- Surface name

    Roof, 6,                               !- Class and Construction Name
    265,                                   !- Zone Name
    Outdoors, ,                            !- Outside Face Environment
    SunExposed,                            !- Sun Exposure
```

```
      WindExposed,                              !- Wind Exposure
      .067,                                     !- View Factor to Ground
      3,                                        !- Number vertices
       0,{1},{21},                 !- Vertex 1
       0,0,{21},                   !- Vertex 2
       {23},{24},{22};                  !- Vertex 3""".format(Width, Length, Height, WindowPerform, SouthWinShortDim,
SouthWinLongDim, EastWinShortDim, EastWinLongDim, NorthWinShortDim, NorthWinLongDim, FirstFlrShortDim, FirstFlrTallDim,
SecondFlrShortDim, SecondFlrTallDim, ThirdFlrShortDim, ThirdFlrTallDim, SecondHeight, ThirdHeight, OverHang, OverWidth,
OverLength, RoofHeight, PeakHeight, HalfWidth, HalfLength)


    if NumStories == 2:

        UpperIDF = """! 1st Floor, 1st Floor, East Wall
   BuildingSurface:Detailed, W_220_2_0_0,         !- Surface name
      Wall, 3,                                  !- Class and Construction Name
      208,                                      !- Zone Name
      Outdoors, ,                               !- Outside Face Environment
      SunExposed,                               !- Sun Exposure
      WindExposed,                              !- Wind Exposure
      .5,                                       !- View Factor to Ground
      4,                                        !- Number vertices
       {0},0,0,                 !- Vertex 1
       {0},{1},0,               !- Vertex 2
       {0},{1},{2},             !- Vertex 3
       {0},0,{2};               !- Vertex 4

      ! East Window
      FenestrationSurface:Detailed, W_220_2_0_0_0_Win,  !- Window name
         Window,                                !- Class
         {3},                                   !- Construction Name
         W_220_2_0_0,                           !- Base surface
         ,                                      !- corresponding other window subsurface
         .5,                                    !- View Factor to Ground
         1111,                                  !- Window shading control
         ,                                      !- Frame divider name
         1,                                     !- Multiplier
         4,                                     !- Number vertices
          {0},{6},{10},          !- Vertex 1
          {0},{7},{10},          !- Vertex 2
          {0},{7},{11},        !- Vertex 3
          {0},{6},{11};          !- Vertex 4

   ! 1st Floor, 1st Floor, North Wall
   BuildingSurface:Detailed, W_220_3_0_0,         !- Surface name
      Wall, 3,                                  !- Class and Construction Name
      208,                                      !- Zone Name
      Outdoors, ,                               !- Outside Face Environment
      SunExposed,                               !- Sun Exposure
      WindExposed,                              !- Wind Exposure
      .5,                                       !- View Factor to Ground
      4,                                        !- Number vertices
       {0},{1},0,                 !- Vertex 1
       0,{1},0,                   !- Vertex 2
       0,{1},{2},                 !- Vertex 3
       {0},{1},{2};               !- Vertex 4

      ! North Window
      FenestrationSurface:Detailed, W_220_3_0_0_0_Win,  !- Window name
         Window,                                !- Class
         {3},                                   !- Construction Name
         W_220_3_0_0,                           !- Base surface
         ,                                      !- corresponding other window subsurface
         .5,                                    !- View Factor to Ground
         1111,                                  !- Window shading control
         ,                                      !- Frame divider name
         1,                                     !- Multiplier
         4,                                     !- Number vertices
          {9}, {1}, {10},          !- Vertex 1
          {8}, {1}, {10},          !- Vertex 2
          {8}, {1}, {11},          !- Vertex 3
          {9}, {1}, {11};          !- Vertex 4

   ! 1st Floor, 1st Floor, West Wall
   BuildingSurface:Detailed, W_220_4_0_0,         !- Surface name
      Wall, 3,                                  !- Class and Construction Name
      208,                                      !- Zone Name
      Outdoors, ,                               !- Outside Face Environment
      SunExposed,                               !- Sun Exposure
      WindExposed,                              !- Wind Exposure
      .5,                                       !- View Factor to Ground
      4,                                        !- Number vertices
       0,{1},0,                   !- Vertex 1
       0,0,0,                     !- Vertex 2
       0,0,{2},                   !- Vertex 3
       0,{1},{2};                 !- Vertex 4

      ! West Window
      FenestrationSurface:Detailed, W_220_4_0_0_0_Win,  !- Window name
         Window,                                !- Class
         {3},                                   !- Construction Name
         W_220_4_0_0,                           !- Base surface
         ,                                      !- corresponding other window subsurface
         .5,                                    !- View Factor to Ground
         1111,                                  !- Window shading control
```

```
      ,                                       !- Frame divider name
      1,                                      !- Multiplier
      4,                                      !- Number vertices
       0,{7},{10},              !- Vertex 4
       0,{6},{10},              !- Vertex 3
       0,{6},{11},              !- Vertex 2
       0,{7},{11};              !- Vertex 1


! 1st Floor, 1st Floor, South Wall
BuildingSurface:Detailed, W_220_5_0_0,        !- Surface name
   Wall, 3,                                   !- Class and Construction Name
   208,                                       !- Zone Name
   Outdoors, ,                                !- Outside Face Environment
   SunExposed,                                !- Sun Exposure
   WindExposed,                               !- Wind Exposure
   .5,                                        !- View Factor to Ground
   4,                                         !- Number vertices
    0,0,0,                    !- Vertex 1
    {0},0,0,                  !- Vertex 2
    {0},0,{2},                !- Vertex 3
    0,0,{2};                  !- Vertex 4

   ! South Window
   FenestrationSurface:Detailed, W_220_5_0_0_0_0_Win,  !- Window name
      Window,                                 !- Class
      {3},                                   !- Construction Name
      W_220_5_0_0,                            !- Base surface
      ,                                       !- corresponding other window subsurface
      .5,                                     !- View Factor to Ground
      1111,                                   !- Window shading control
      ,                                       !- Frame divider name
      1,                                      !- Multiplier
      4,                                      !- Number vertices
       {4},0,{10},              !- Vertex 1
       {5},0,{10},              !- Vertex 2
       {5},0,{11},              !- Vertex 3
       {4},0,{11};              !- Vertex 4


! 2nd Floor, 2nd Floor, Ceiling
BuildingSurface:Detailed, C_171_1_0_0,        !- Surface name
   Ceiling, 4,                                !- Class and Construction Name
   208,                                       !- Zone Name
   Surface, F_265_8_0_10003,                  !- Outside Face Environment
   NoSun,                                     !- Sun Exposure
   NoWind,                                    !- Wind Exposure
   0,                                         !- View Factor to Ground
   4,                                         !- Number vertices
    0,0,{16},               !- Vertex 1
    {0},0,{16},             !- Vertex 2
    {0},{1},{16},           !- Vertex 3
    0,{1},{16};             !- Vertex 4


! 2nd Floor, 2nd Floor
BuildingSurface:Detailed, F_265_8_0_10003,    !- Surface name - reverse definition
   Floor, 5,                                  !- Class and Construction Name
   265,                                       !- Zone Name
   Surface, C_171_1_0_0,                      !- Outside Face Environment
   NoSun,                                     !- Sun Exposure
   NoWind,                                    !- Wind Exposure
   0,                                         !- View Factor to Ground
   4,                                         !- Number vertices
    {0},0,{16},             !- Vertex 1
    0,0,{16},               !- Vertex 2
    0,{1},{16},             !- Vertex 3
    {0},{1},{16};           !- Vertex 4


! 2nd Floor, 2nd Floor, East Wall
BuildingSurface:Detailed, W_171_2_0_0,        !- Surface name
   Wall, 3,                                   !- Class and Construction Name
   208,                                       !- Zone Name
   Outdoors, ,                                !- Outside Face Environment
   SunExposed,                                !- Sun Exposure
   WindExposed,                               !- Wind Exposure
   .5,                                        !- View Factor to Ground
   4,                                         !- Number vertices
    {0},0,{2},              !- Vertex 1
    {0},{1},{2},            !- Vertex 2
    {0},{1},{16},           !- Vertex 3
    {0},0,{16};             !- Vertex 4

   ! East Window
   FenestrationSurface:Detailed, W_171_2_0_0_0_0_Win,  !- Window name
      Window,                                 !- Class
      {3},                                    !- Construction Name
      W_171_2_0_0,                            !- Base surface
      ,                                       !- corresponding other window subsurface
      .5,                                     !- View Factor to Ground
      1111,                                   !- Window shading control
      ,                                       !- Frame divider name
      1,                                      !- Multiplier
      4,                                      !- Number vertices
```

```
        {0},{6},{12},             !- Vertex 1
        {0},{7},{12},             !- Vertex 2
        {0},{7},{13},             !- Vertex 3
        {0},{6},{13};             !- Vertex 4


 ! 2nd Floor, 2nd Floor, North Wall
 BuildingSurface:Detailed, W_171_3_0_0,        !- Surface name
    Wall, 3,                                   !- Class and Construction Name
    208,                                       !- Zone Name
    Outdoors, ,                                !- Outside Face Environment
    SunExposed,                                !- Sun Exposure
    WindExposed,                               !- Wind Exposure
    .5,                                        !- View Factor to Ground
    4,                                         !- Number vertices
     {0},{1},{2},             !- Vertex 1
     0,{1},{2},               !- Vertex 2
     0,{1},{16},              !- Vertex 3
     {0},{1},{16};            !- Vertex 4

    ! North Window
    FenestrationSurface:Detailed, W_171_3_0_0_0_0_Win,  !- Window name
       Window,                                 !- Class
       {3},                                   !- Construction Name
       W_171_3_0_0,                            !- Base surface
       ,                                       !- corresponding other window subsurface
       .5,                                     !- View Factor to Ground
       1111,                                   !- Window shading control
       ,                                       !- Frame divider name
       1,                                      !- Multiplier
       4,                                      !- Number vertices
        {9},{1},{12},             !- Vertex 1
        {8},{1},{12},             !- Vertex 2
        {8},{1},{13},             !- Vertex 3
        {9},{1},{13};             !- Vertex 4


 ! 2nd Floor, 2nd Floor, West Wall
 BuildingSurface:Detailed, W_171_4_0_0,        !- Surface name
    Wall, 3,                                   !- Class and Construction Name
    208,                                       !- Zone Name
    Outdoors, ,                                !- Outside Face Environment
    SunExposed,                                !- Sun Exposure
    WindExposed,                               !- Wind Exposure
    .5,                                        !- View Factor to Ground
    4,                                         !- Number vertices
     0,{1},{2},               !- Vertex 1
     0,0,{2},                 !- Vertex 2
     0,0,{16},                !- Vertex 3
     0,{1},{16};              !- Vertex 4

    ! West Window
    FenestrationSurface:Detailed, W_171_4_0_0_0_0_Win,  !- Window name
       Window,                                 !- Class
       {3},                                    !- Construction Name
       W_171_4_0_0,                            !- Base surface
       ,                                       !- corresponding other window subsurface
       .5,                                     !- View Factor to Ground
       1111,                                   !- Window shading control
       ,                                       !- Frame divider name
       1,                                      !- Multiplier
       4,                                      !- Number vertices
        0,{7},{12},               !- Vertex 1
        0,{6},{12},               !- Vertex 2
        0,{6},{13},               !- Vertex 3
        0,{7},{13};               !- Vertex 4


 ! 2nd Floor, 2nd Floor, South Wall
 BuildingSurface:Detailed, W_171_5_0_0,        !- Surface name
    Wall, 3,                                   !- Class and Construction Name
    208,                                       !- Zone Name
    Outdoors, ,                                !- Outside Face Environment
    SunExposed,                                !- Sun Exposure
    WindExposed,                               !- Wind Exposure
    .5,                                        !- View Factor to Ground
    4,                                         !- Number vertices
     0,0,{2},                 !- Vertex 1
     {0},0,{2},               !- Vertex 2
     {0},0,{16},              !- Vertex 3
     0,0,{16};                !- Vertex 4

    ! South Window
    FenestrationSurface:Detailed, W_171_5_0_0_0_0_Win,  !- Window name
       Window,                                 !- Class
       {3},                                    !- Construction Name
       W_171_5_0_0,                            !- Base surface
       ,                                       !- corresponding other window subsurface
       .5,                                     !- View Factor to Ground
       1111,                                   !- Window shading control
       ,                                       !- Frame divider name
       1,                                      !- Multiplier
       4,                                      !- Number vertices
        {4},0,{12},           !- Vertex 1
        {5},0,{12},           !- Vertex 2
```

```
          {5},0,{13},            !- Vertex 3
          {4},0,{13};            !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang West,  , 4,  !- site shading
   -{18},{20},{16},                 !- Vertex 1
   -{18},-{18},{16},                !- Vertex 2
    0,0,{16},                       !- Vertex 3
    0,{1},{16};                     !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang North,  , 4,  !- site shading
    0,{1},{16},                     !- Vertex 1
    {0},{1},{16},                   !- Vertex 2
    {19},{20},{16},                 !- Vertex 3
   -{18},{20},{16};                 !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang East,  , 4,  !- site shading
    {19},-{18},{16},                 !- Vertex 1
    {19},{20},{16},                 !- Vertex 2
    {0},{1},{16},                   !- Vertex 3
    {0},0,{16};                     !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang South,  , 4,  !- site shading
   -{18},-{18},{16},                !- Vertex 1
    {19},-{18},{16},                !- Vertex 2
    {0},0,{16},                     !- Vertex 3
    0,0,{16};                       !- Vertex 4


! Roof 1 - Roof
Zone, 265,                                    !- Zone Name
   0,                                         !- Relative North (to building)
   0,                                         !- X Origin [m]
   0,                                         !- Y Origin [m]
   0,                                         !- Z Origin [m]
   1 ,                                        !- Zone Type
   1,                                         !- Zone multiplier
   ,                                          !- Zone ceiling height - Let EnergyPlus work it out
   autocalculate,                             !- Zone volume
   Detailed;                                  !- Zone inside convection algorithm

   PEOPLE, People 265,                        !- Name
      265,                                    !- Zone Name
      7,                                      !- Number of People SCHEDULE Name
      People,                                 !- Number of People
       0,                                     !- Number of People
      ,                                       !- People per Zone Area
      ,                                       !- Zone Area per Person
       .5,                                    !- radiant fraction
      AUTOCALCULATE,                          !- User Specified Sensible Fraction
      Activity Schedule 265,                  !- Activity level SCHEDULE Name (units W/person, real)
      No,                                     !- Enable ASHRAE 55 comfort warnings
      ZoneAveraged,                           !- MRT Calculation Type
      ,                                       !- no particular surface is weighted
      Work efficiency,                        !- Work Efficiency SCHEDULE Name (0.0-1.0,real)
      Clothing Schedule 265,                  !- Clothing Insulation SCHEDULE Name (real)
      AirVelocitySchedule;                    !- Air Velocity SCHEDULE Name (units m/s, real)

   Schedule:Compact, Activity Schedule 265,   !- activity schedule W/person
      Any Number,                             !- Type
      Through: 12/31,                         !- Type
      For: AllDays,                           !- All days in year
      Until: 24:00,  117;                     !- Constant value

   Schedule:Compact, Clothing Schedule 265,   !- Clothing schedule clo
      Any Number,                             !- Type
      Through: 4/1,                           !- Type
      For: AllDays,                           !- All days in year
      Until: 24:00,  1,                       !- Constant value
      Through: 9/30,                          !- Type
      For: AllDays,                           !- All days in year
      Until: 24:00,  .5,                      !- Constant value
      Through: 12/31,                         !- Type
      For: AllDays,                           !- All days in year
      Until: 24:00,  1;                       !- Constant value

   ZoneInfiltration:DesignFlowRate, 265 Infiltration,  !- Name
      265,                                    !- Zone Name
      On,                                     !- Infiltration SCHEDULE Name
      AirChanges/Hour,                        !- Design Volume Flow Rate calculation method
      ,                                       !- Design Volume Flow Rate [m3/s]
      ,                                       !- Flow per Zone Floor Area [m3/s/m2]
      ,                                       !- Flow per Exterior Surface Area [m3/s/m2]
      0.5,                                    !- Air Changes Per Hour
      1,                                      !- Constant Term Coefficient
      0,                                      !- Temperature Term Coefficient
      0,                                      !- Velocity Term Coefficient
      0;                                      !- Velocity Squared Term Coefficient

   ! Roof 1, Roof, East Wall
   BuildingSurface:Detailed, W_265_0_0_0,     !- Surface name
      Wall, 6,                                !- Class and Construction Name
      265,                                    !- Zone Name
      Outdoors, ,                             !- Outside Face Environment
      SunExposed,                             !- Sun Exposure
      WindExposed,                            !- Wind Exposure
```

```
    .5,                                         !- View Factor to Ground
    4,                                          !- Number vertices
     {0},0,{16},                  !- Vertex 1
     {0},{1},{16},                !- Vertex 2
     {0},{1},{21},                !- Vertex 3
     {0},0,{21};                  !- Vertex 4

 ! Roof 1, Roof, North Wall
 BuildingSurface:Detailed, W_265_1_0_0,         !- Surface name
    Wall, 6,                                    !- Class and Construction Name
    265,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .5,                                         !- View Factor to Ground
    4,                                          !- Number vertices
     {0},{1},{16},                !- Vertex 1
     0,{1},{16},                  !- Vertex 2
     0,{1},{21},                  !- Vertex 3
     {0},{1},{21};                !- Vertex 4

 ! Roof 1, Roof, West Wall
 BuildingSurface:Detailed, W_265_2_0_0,         !- Surface name
    Wall, 6,                                    !- Class and Construction Name
    265,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .5,                                         !- View Factor to Ground
    4,                                          !- Number vertices
     0,{1},{16},                  !- Vertex 1
     0,0,{16},                    !- Vertex 2
     0,0,{21},                    !- Vertex 3
     0,{1},{21};                  !- Vertex 4

 ! Roof 1, Roof, South Wall
 BuildingSurface:Detailed, W_265_3_0_0,         !- Surface name
    Wall, 6,                                    !- Class and Construction Name
    265,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .5,                                         !- View Factor to Ground
    4,                                          !- Number vertices
     0,0,{16},                    !- Vertex 1
     {0},0,{16},                  !- Vertex 2
     {0},0,{21},                  !- Vertex 3
     0,0,{21};                    !- Vertex 4

 ! Roof 1, Roof, North External roof
 BuildingSurface:Detailed, R_265_4_0_0,         !- Surface name
    Roof, 6,                                    !- Class and Construction Name
    265,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .067,                                       !- View Factor to Ground
    3,                                          !- Number vertices
     {0},{1},{21},                !- Vertex 1
     0,{1},{21},                  !- Vertex 2
     {23},{24},{22};              !- Vertex 3

 ! Roof 1, Roof, East External roof
 BuildingSurface:Detailed, R_265_5_0_0,         !- Surface name
    Roof, 6,                                    !- Class and Construction Name
    265,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .067,                                       !- View Factor to Ground
    3,                                          !- Number vertices
     {0},0,{21},                  !- Vertex 1
     {0},{1},{21},                !- Vertex 2
     {23},{24},{22};              !- Vertex 3

 ! Roof 1, Roof, South External roof
 BuildingSurface:Detailed, R_265_6_0_0,         !- Surface name
    Roof, 6,                                    !- Class and Construction Name
    265,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .067,                                       !- View Factor to Ground
    3,                                          !- Number vertices
     0,0,{21},                    !- Vertex 1
     {0},0,{21},                  !- Vertex 2
     {23},{24},{22};              !- Vertex 3

 ! Roof 1, Roof, West External roof
 BuildingSurface:Detailed, R_265_7_0_0,         !- Surface name
    Roof, 6,                                    !- Class and Construction Name
    265,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
```

```
    .067,                                    !- View Factor to Ground
    3,                                       !- Number vertices
     0,{1},{21},                 !- Vertex 1
     0,0,{21},                   !- Vertex 2
     {23},{24},{22};                  !- Vertex 3""".format(Width, Length, Height, WindowPerform, SouthWinShortDim,
       <B>SouthWinLongDim,  EastWinShortDim,  EastWinLongDim,  NorthWinShortDim,  NorthWinLongDim,  FirstFlrShortDim,
       <B>FirstFlrTallDim,  SecondFlrShortDim,  SecondFlrTallDim,  ThirdFlrShortDim,  ThirdFlrTallDim,  SecondHeight,
       <B>ThirdHeight, OverHang, OverWidth, OverLength, RoofHeight, PeakHeight, HalfWidth, HalfLength)


  if NumStories == 3:

      UpperIDF = """! 1st Floor, 1st Floor, East Wall
 BuildingSurface:Detailed, W_220_2_0_0,         !- Surface name
    Wall, 3,                                 !- Class and Construction Name
    208,                                     !- Zone Name
    Outdoors, ,                              !- Outside Face Environment
    SunExposed,                              !- Sun Exposure
    WindExposed,                             !- Wind Exposure
    .5,                                      !- View Factor to Ground
    4,                                       !- Number vertices
     {0},0,0,                  !- Vertex 1
     {0},{1},0,                !- Vertex 2
     {0},{1},{2},              !- Vertex 3
     {0},0,{2};                !- Vertex 4

    ! East Window
    FenestrationSurface:Detailed, W_220_2_0_0_0_0_Win,  !- Window name
       Window,                               !- Class
       {3},                                  !- Construction Name
       W_220_2_0_0,                          !- Base surface
       ,                                     !- corresponding other window subsurface
       .5,                                   !- View Factor to Ground
       1111,                                 !- Window shading control
       ,                                     !- Frame divider name
       1,                                    !- Multiplier
       4,                                    !- Number vertices
        {0},{6},{10},             !- Vertex 1
        {0},{7},{10},             !- Vertex 2
        {0},{7},{11},           !- Vertex 3
        {0},{6},{11};             !- Vertex 4

 ! 1st Floor, 1st Floor, North Wall
 BuildingSurface:Detailed, W_220_3_0_0,         !- Surface name
    Wall, 3,                                 !- Class and Construction Name
    208,                                     !- Zone Name
    Outdoors, ,                              !- Outside Face Environment
    SunExposed,                              !- Sun Exposure
    WindExposed,                             !- Wind Exposure
    .5,                                      !- View Factor to Ground
    4,                                       !- Number vertices
     {0},{1},0,                !- Vertex 1
     0,{1},0,                  !- Vertex 2
     0,{1},{2},                !- Vertex 3
     {0},{1},{2};              !- Vertex 4

    ! North Window
    FenestrationSurface:Detailed, W_220_3_0_0_0_0_Win,  !- Window name
       Window,                               !- Class
       {3},                                  !- Construction Name
       W_220_3_0_0,                          !- Base surface
       ,                                     !- corresponding other window subsurface
       .5,                                   !- View Factor to Ground
       1111,                                 !- Window shading control
       ,                                     !- Frame divider name
       1,                                    !- Multiplier
       4,                                    !- Number vertices
        {9}, {1}, {10},           !- Vertex 1
        {8}, {1}, {10},           !- Vertex 2
        {8}, {1}, {11},           !- Vertex 3
        {9}, {1}, {11};           !- Vertex 4

 ! 1st Floor, 1st Floor, West Wall
 BuildingSurface:Detailed, W_220_4_0_0,         !- Surface name
    Wall, 3,                                 !- Class and Construction Name
    208,                                     !- Zone Name
    Outdoors, ,                              !- Outside Face Environment
    SunExposed,                              !- Sun Exposure
    WindExposed,                             !- Wind Exposure
    .5,                                      !- View Factor to Ground
    4,                                       !- Number vertices
     0,{1},0,                  !- Vertex 1
     0,0,0,                    !- Vertex 2
     0,0,{2},                  !- Vertex 3
     0,{1},{2};                !- Vertex 4

    ! West Window
    FenestrationSurface:Detailed, W_220_4_0_0_0_0_Win,  !- Window name
       Window,                               !- Class
       {3},                                  !- Construction Name
       W_220_4_0_0,                          !- Base surface
       ,                                     !- corresponding other window subsurface
       .5,                                   !- View Factor to Ground
       1111,                                 !- Window shading control
       ,                                     !- Frame divider name
```

```
      1,                                   !- Multiplier
      4,                                   !- Number vertices
       0,{7},{10},              !- Vertex 1
       0,{6},{10},              !- Vertex 2
       0,{6},{11},              !- Vertex 3
       0,{7},{11};              !- Vertex 4

  ! 1st Floor, 1st Floor, South Wall
  BuildingSurface:Detailed, W_220_5_0_0,         !- Surface name
     Wall, 3,                                    !- Class and Construction Name
     208,                                        !- Zone Name
     Outdoors, ,                                 !- Outside Face Environment
     SunExposed,                                 !- Sun Exposure
     WindExposed,                                !- Wind Exposure
     .5,                                         !- View Factor to Ground
     4,                                          !- Number vertices
      0,0,0,                    !- Vertex 1
      {0},0,0,                  !- Vertex 2
      {0},0,{2},                !- Vertex 3
      0,0,{2};                  !- Vertex 4

     ! South Window
     FenestrationSurface:Detailed, W_220_5_0_0_0_0_Win,  !- Window name
        Window,                                  !- Class
        {3},                                    !- Construction Name
        W_220_5_0_0,                             !- Base surface
        ,                                        !- corresponding other window subsurface
        .5,                                      !- View Factor to Ground
        1111,                                    !- Window shading control
        ,                                        !- Frame divider name
        1,                                       !- Multiplier
        4,                                       !- Number vertices
         {4},0,{10},            !- Vertex 1
         {5},0,{10},            !- Vertex 2
         {5},0,{11},            !- Vertex 3
         {4},0,{11};            !- Vertex 4

  ! 2nd Floor, 2nd Floor, East Wall
  BuildingSurface:Detailed, W_171_2_0_0,         !- Surface name
     Wall, 3,                                    !- Class and Construction Name
     208,                                        !- Zone Name
     Outdoors, ,                                 !- Outside Face Environment
     SunExposed,                                 !- Sun Exposure
     WindExposed,                                !- Wind Exposure
     .5,                                         !- View Factor to Ground
     4,                                          !- Number vertices
      {0},0,{2},                !- Vertex 1
      {0},{1},{2},              !- Vertex 2
      {0},{1},{16},             !- Vertex 3
      {0},0,{16};               !- Vertex 4

     ! East Window
     FenestrationSurface:Detailed, W_171_2_0_0_0_0_Win,  !- Window name
        Window,                                  !- Class
        {3},                                     !- Construction Name
        W_171_2_0_0,                             !- Base surface
        ,                                        !- corresponding other window subsurface
        .5,                                      !- View Factor to Ground
        1111,                                    !- Window shading control
        ,                                        !- Frame divider name
        1,                                       !- Multiplier
        4,                                       !- Number vertices
         {0},{6},{12},          !- Vertex 1
         {0},{7},{12},          !- Vertex 2
         {0},{7},{13},          !- Vertex 3
         {0},{6},{13};          !- Vertex 4

  ! 2nd Floor, 2nd Floor, North Wall
  BuildingSurface:Detailed, W_171_3_0_0,         !- Surface name
     Wall, 3,                                    !- Class and Construction Name
     208,                                        !- Zone Name
     Outdoors, ,                                 !- Outside Face Environment
     SunExposed,                                 !- Sun Exposure
     WindExposed,                                !- Wind Exposure
     .5,                                         !- View Factor to Ground
     4,                                          !- Number vertices
      {0},{1},{2},              !- Vertex 1
      0,{1},{2},                !- Vertex 2
      0,{1},{16},               !- Vertex 3
      {0},{1},{16};             !- Vertex 4

     ! North Window
     FenestrationSurface:Detailed, W_171_3_0_0_0_0_Win,  !- Window name
        Window,                                  !- Class
        {3},                                    !- Construction Name
        W_171_3_0_0,                             !- Base surface
        ,                                        !- corresponding other window subsurface
        .5,                                      !- View Factor to Ground
        1111,                                    !- Window shading control
        ,                                        !- Frame divider name
        1,                                       !- Multiplier
        4,                                       !- Number vertices
         {9},{1},{12},         !- Vertex 1
         {8},{1},{12},         !- Vertex 2
         {8},{1},{13},         !- Vertex 3
```

```
      {9},{1},{13};           !- Vertex 4

  ! 2nd Floor, 2nd Floor, West Wall
  BuildingSurface:Detailed, W_171_4_0_0,        !- Surface name
     Wall, 3,                                   !- Class and Construction Name
     208,                                       !- Zone Name
     Outdoors, ,                                !- Outside Face Environment
     SunExposed,                                !- Sun Exposure
     WindExposed,                               !- Wind Exposure
     .5,                                        !- View Factor to Ground
     4,                                         !- Number vertices
      0,{1},{2},              !- Vertex 1
      0,0,{2},                !- Vertex 2
      0,0,{16},               !- Vertex 3
      0,{1},{16};             !- Vertex 4

     ! West Window
     FenestrationSurface:Detailed, W_171_4_0_0_0_0_Win,  !- Window name
        Window,                                 !- Class
        {3},                                    !- Construction Name
        W_171_4_0_0,                            !- Base surface
        ,                                       !- corresponding other window subsurface
        .5,                                     !- View Factor to Ground
        1111,                                   !- Window shading control
        ,                                       !- Frame divider name
        1,                                      !- Multiplier
        4,                                      !- Number vertices
         0,{7},{12},         !- Vertex 1
         0,{6},{12},          !- Vertex 2
         0,{6},{13},          !- Vertex 3
         0,{7},{13};         !- Vertex 4

  ! 2nd Floor, 2nd Floor, South Wall
  BuildingSurface:Detailed, W_171_5_0_0,        !- Surface name
     Wall, 3,                                   !- Class and Construction Name
     208,                                       !- Zone Name
     Outdoors, ,                                !- Outside Face Environment
     SunExposed,                                !- Sun Exposure
     WindExposed,                               !- Wind Exposure
     .5,                                        !- View Factor to Ground
     4,                                         !- Number vertices
      0,0,{2},                !- Vertex 1
      {0},0,{2},              !- Vertex 2
      {0},0,{16},             !- Vertex 3
      0,0,{16};               !- Vertex 4

     ! South Window
     FenestrationSurface:Detailed, W_171_5_0_0_0_0_Win,  !- Window name
        Window,                                 !- Class
        {3},                                    !- Construction Name
        W_171_5_0_0,                            !- Base surface
        ,                                       !- corresponding other window subsurface
        .5,                                     !- View Factor to Ground
        1111,                                   !- Window shading control
        ,                                       !- Frame divider name
        1,                                      !- Multiplier
        4,                                      !- Number vertices
         {4},0,{12},          !- Vertex 1
         {5},0,{12},          !- Vertex 2
         {5},0,{13},          !- Vertex 3
         {4},0,{13};          !- Vertex 4

  ! 3rd Floor, 3rd Floor, Ceiling

  BuildingSurface:Detailed, C_280_1_0_0,        !- Surface name
     Ceiling, 4,                                !- Class and Construction Name
     208,                                       !- Zone Name
     Surface, F_265_8_0_10003,                  !- Outside Face Environment
     NoSun,                                     !- Sun Exposure
     NoWind,                                    !- Wind Exposure
     0,                                         !- View Factor to Ground
     4,                                         !- Number vertices
      0,0,{17},               !- Vertex 1
      {0},0,{17},             !- Vertex 2
      {0},{1},{17},           !- Vertex 3
      0,{1},{17};             !- Vertex 4

  ! 3rd Floor, 3rd Floor, Ceiling
  BuildingSurface:Detailed, F_265_8_0_10003,    !- Surface name - reverse definition
     Floor, 5,                                  !- Class and Construction Name
     265,                                       !- Zone Name
     Surface, C_280_1_0_0,                      !- Outside Face Environment
     NoSun,                                     !- Sun Exposure
     NoWind,                                    !- Wind Exposure
     0,                                         !- View Factor to Ground
     4,                                         !- Number vertices
      {0},0,{17},             !- Vertex 1
      0,0,{17},               !- Vertex 2
      0,{1},{17},             !- Vertex 3
      {0},{1},{17};           !- Vertex 4

  ! 3rd Floor, 3rd Floor, East Wall
  BuildingSurface:Detailed, W_280_2_0_0,        !- Surface name
     Wall, 3,                                   !- Class and Construction Name
     208,                                       !- Zone Name
```

```
   Outdoors, ,                                  !- Outside Face Environment
   SunExposed,                                  !- Sun Exposure
   WindExposed,                                 !- Wind Exposure
   .5,                                          !- View Factor to Ground
   4,                                           !- Number vertices
    {0},0,{16},              !- Vertex 1
    {0},{1},{16},            !- Vertex 2
    {0},{1},{17},            !- Vertex 3
    {0},0,{17};              !- Vertex 4

   ! East Window
   FenestrationSurface:Detailed, W_280_2_0_0_0_0_Win,  !- Window name
      Window,                                   !- Class
      {3},                                      !- Construction Name
      W_280_2_0_0,                              !- Base surface
      ,                                         !- corresponding other window subsurface
      .5,                                       !- View Factor to Ground
      1111,                                     !- Window shading control
      ,                                         !- Frame divider name
      1,                                        !- Multiplier
      4,                                        !- Number vertices
       {0},{6},{14},             !- Vertex 1
       {0},{7},{14},             !- Vertex 2
       {0},{7},{15},             !- Vertex 3
       {0},{6},{15};             !- Vertex 4

! 3rd Floor, 3rd Floor, North Wall
BuildingSurface:Detailed, W_280_3_0_0,         !- Surface name
   Wall, 3,                                     !- Class and Construction Name
   208,                                         !- Zone Name
   Outdoors, ,                                  !- Outside Face Environment
   SunExposed,                                  !- Sun Exposure
   WindExposed,                                 !- Wind Exposure
   .5,                                          !- View Factor to Ground
   4,                                           !- Number vertices
    {0},{1},{16},            !- Vertex 1
    0,{1},{16},              !- Vertex 2
    0,{1},{17},              !- Vertex 3
    {0},{1},{17};            !- Vertex 4

   ! North Window
   FenestrationSurface:Detailed, W_280_3_0_0_0_0_Win,  !- Window name
      Window,                                   !- Class
      {3},                                      !- Construction Name
      W_280_3_0_0,                              !- Base surface
      ,                                         !- corresponding other window subsurface
      .5,                                       !- View Factor to Ground
      1111,                                     !- Window shading control
      ,                                         !- Frame divider name
      1,                                        !- Multiplier
      4,                                        !- Number vertices
       {9},{1},{14},              !- Vertex 1
       {8},{1},{14},              !- Vertex 2
       {8},{1},{15},              !- Vertex 3
       {9},{1},{15};              !- Vertex 4

! 3rd Floor, 3rd Floor, West Wall
BuildingSurface:Detailed, W_280_4_0_0,         !- Surface name
   Wall, 3,                                     !- Class and Construction Name
   208,                                         !- Zone Name
   Outdoors, ,                                  !- Outside Face Environment
   SunExposed,                                  !- Sun Exposure
   WindExposed,                                 !- Wind Exposure
   .5,                                          !- View Factor to Ground
   4,                                           !- Number vertices
    0,{1},{16},              !- Vertex 1
    0,0,{16},                !- Vertex 2
    0,0,{17},                !- Vertex 3
    0,{1},{17};              !- Vertex 4

   ! West Window
   FenestrationSurface:Detailed, W_280_4_0_0_0_0_Win,  !- Window name
      Window,                                   !- Class
      {3},                                      !- Construction Name
      W_280_4_0_0,                              !- Base surface
      ,                                         !- corresponding other window subsurface
      .5,                                       !- View Factor to Ground
      1111,                                     !- Window shading control
      ,                                         !- Frame divider name
      1,                                        !- Multiplier
      4,                                        !- Number vertices
       0,{7},{14},               !- Vertex 1
       0,{6},{14},               !- Vertex 2
       0,{6},{15},               !- Vertex 3
       0,{7},{15};               !- Vertex 4

! 3rd Floor, 3rd Floor, South Wall
BuildingSurface:Detailed, W_280_5_0_0,         !- Surface name
   Wall, 3,                                     !- Class and Construction Name
   208,                                         !- Zone Name
   Outdoors, ,                                  !- Outside Face Environment
   SunExposed,                                  !- Sun Exposure
   WindExposed,                                 !- Wind Exposure
   .5,                                          !- View Factor to Ground
   4,                                           !- Number vertices
```

```
       0,0,{16},                !- Vertex 1
       {0},0,{16},              !- Vertex 2
       {0},0,{17},              !- Vertex 3
       0,0,{17};                !- Vertex 4

      ! South Window
      FenestrationSurface:Detailed, W_280_5_0_0_0_0_Win,  !- Window name
         Window,                                 !- Class
         {3},                                    !- Construction Name
         W_280_5_0_0,                            !- Base surface
         ,                                       !- corresponding other window subsurface
         .5,                                     !- View Factor to Ground
         1111,                                   !- Window shading control
         ,                                       !- Frame divider name
         1,                                      !- Multiplier
         4,                                      !- Number vertices
          {4},0,{14},               !- Vertex 1
          {5},0,{14},               !- Vertex 2
          {5},0,{15},               !- Vertex 3
          {4},0,{15};               !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang West,  , 4,  !- site shading
   -{18},{20},{17},                 !- Vertex 1
   -{18},-{18},{17},                !- Vertex 2
    0,0,{17},                       !- Vertex 3
    0,{1},{17};                     !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang North,  , 4,  !- site shading
    0,{1},{17},                     !- Vertex 1
    {0},{1},{17},                   !- Vertex 2
    {19},{20},{17},                 !- Vertex 3
   -{18},{20},{17};                 !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang East,  , 4,  !- site shading
    {19},-{18},{17},                 !- Vertex 1
    {19},{20},{17},                 !- Vertex 2
    {0},{1},{17},                   !- Vertex 3
    {0},0,{17};                     !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang South,  , 4,  !- site shading
   -{18},-{18},{17},                !- Vertex 1
    {19},-{18},{17},                !- Vertex 2
    {0},0,{17},                     !- Vertex 3
    0,0,{17};                       !- Vertex 4


! Roof 1 - Roof
Zone, 265,                                       !- Zone Name
   0,                                            !- Relative North (to building)
   0,                                            !- X Origin [m]
   0,                                            !- Y Origin [m]
   0,                                            !- Z Origin [m]
   1 ,                                           !- Zone Type
   1,                                            !- Zone multiplier
   ,                                             !- Zone ceiling height - Let EnergyPlus work it out
   autocalculate,                                !- Zone volume
   Detailed;                                     !- Zone inside convection algorithm

   PEOPLE, People 265,                           !- Name
      265,                                       !- Zone Name
      7,                                         !- Number of People SCHEDULE Name
      People,                                    !- Number of People
       0,                                        !- Number of People
      ,                                          !- People per Zone Area
      ,                                          !- Zone Area per Person
       .5,                                       !- radiant fraction
      AUTOCALCULATE,                             !- User Specified Sensible Fraction
      Activity Schedule 265,                     !- Activity level SCHEDULE Name (units W/person, real)
      No,                                        !- Enable ASHRAE 55 comfort warnings
      ZoneAveraged,                              !- MRT Calculation Type
      ,                                          !- no particular surface is weighted
      Work efficiency,                           !- Work Efficiency SCHEDULE Name (0.0-1.0,real)
      Clothing Schedule 265,                     !- Clothing Insulation SCHEDULE Name (real)
      AirVelocitySchedule;                       !- Air Velocity SCHEDULE Name (units m/s, real)

   Schedule:Compact, Activity Schedule 265,      !- activity schedule W/person
      Any Number,                                !- Type
      Through: 12/31,                            !- Type
      For: AllDays,                              !- All days in year
      Until: 24:00,  117;                        !- Constant value

   Schedule:Compact, Clothing Schedule 265,      !- Clothing schedule clo
      Any Number,                                !- Type
      Through: 4/1,                              !- Type
      For: AllDays,                              !- All days in year
      Until: 24:00,  1,                          !- Constant value
      Through: 9/30,                             !- Type
      For: AllDays,                              !- All days in year
      Until: 24:00,  .5,                         !- Constant value
      Through: 12/31,                            !- Type
      For: AllDays,                              !- All days in year
      Until: 24:00,  1;                          !- Constant value

   ZoneInfiltration:DesignFlowRate, 265 Infiltration,  !- Name
      265,                                       !- Zone Name
```

```
    On,                                          !- Infiltration SCHEDULE Name
    AirChanges/Hour,                             !- Design Volume Flow Rate calculation method
    ,                                            !- Design Volume Flow Rate [m3/s]
    ,                                            !- Flow per Zone Floor Area [m3/s/m2]
    ,                                            !- Flow per Exterior Surface Area [m3/s/m2]
    0.5,                                         !- Air Changes Per Hour
    1,                                           !- Constant Term Coefficient
    0,                                           !- Temperature Term Coefficient
    0,                                           !- Velocity Term Coefficient
    0;                                           !- Velocity Squared Term Coefficient

 ! Roof 1, Roof, East Wall
 BuildingSurface:Detailed, W_265_0_0_0,          !- Surface name
    Wall, 6,                                     !- Class and Construction Name
    265,                                         !- Zone Name
    Outdoors, ,                                  !- Outside Face Environment
    SunExposed,                                  !- Sun Exposure
    WindExposed,                                 !- Wind Exposure
    .5,                                          !- View Factor to Ground
    4,                                           !- Number vertices
     {0},0,{17},                   !- Vertex 1
     {0},{1},{17},                 !- Vertex 2
     {0},{1},{21},                 !- Vertex 3
     {0},0,{21};                   !- Vertex 4

 ! Roof 1, Roof, North Wall
 BuildingSurface:Detailed, W_265_1_0_0,          !- Surface name
    Wall, 6,                                     !- Class and Construction Name
    265,                                         !- Zone Name
    Outdoors, ,                                  !- Outside Face Environment
    SunExposed,                                  !- Sun Exposure
    WindExposed,                                 !- Wind Exposure
    .5,                                          !- View Factor to Ground
    4,                                           !- Number vertices
     {0},{1},{17},                 !- Vertex 1
     0,{1},{17},                   !- Vertex 2
     0,{1},{21},                   !- Vertex 3
     {0},{1},{21};                 !- Vertex 4

 ! Roof 1, Roof, West Wall
 BuildingSurface:Detailed, W_265_2_0_0,          !- Surface name
    Wall, 6,                                     !- Class and Construction Name
    265,                                         !- Zone Name
    Outdoors, ,                                  !- Outside Face Environment
    SunExposed,                                  !- Sun Exposure
    WindExposed,                                 !- Wind Exposure
    .5,                                          !- View Factor to Ground
    4,                                           !- Number vertices
     0,{1},{17},                   !- Vertex 1
     0,0,{17},                     !- Vertex 2
     0,0,{21},                     !- Vertex 3
     0,{1},{21};                   !- Vertex 4

 ! Roof 1, Roof, South Wall
 BuildingSurface:Detailed, W_265_3_0_0,          !- Surface name
    Wall, 6,                                     !- Class and Construction Name
    265,                                         !- Zone Name
    Outdoors, ,                                  !- Outside Face Environment
    SunExposed,                                  !- Sun Exposure
    WindExposed,                                 !- Wind Exposure
    .5,                                          !- View Factor to Ground
    4,                                           !- Number vertices
     0,0,{17},                     !- Vertex 1
     {0},0,{17},                   !- Vertex 2
     {0},0,{21},                   !- Vertex 3
     0,0,{21};                     !- Vertex 4

 ! Roof 1, Roof, North External roof
 BuildingSurface:Detailed, R_265_4_0_0,          !- Surface name
    Roof, 6,                                     !- Class and Construction Name
    265,                                         !- Zone Name
    Outdoors, ,                                  !- Outside Face Environment
    SunExposed,                                  !- Sun Exposure
    WindExposed,                                 !- Wind Exposure
    .067,                                        !- View Factor to Ground
    3,                                           !- Number vertices
     {0},{1},{21},                 !- Vertex 1
     0,{1},{21},                   !- Vertex 2
     {23},{24},{22};               !- Vertex 3

 ! Roof 1, Roof, East External roof
 BuildingSurface:Detailed, R_265_5_0_0,          !- Surface name
    Roof, 6,                                     !- Class and Construction Name
    265,                                         !- Zone Name
    Outdoors, ,                                  !- Outside Face Environment
    SunExposed,                                  !- Sun Exposure
    WindExposed,                                 !- Wind Exposure
    .067,                                        !- View Factor to Ground
    3,                                           !- Number vertices
     {0},0,{21},                   !- Vertex 1
     {0},{1},{21},                 !- Vertex 2
     {23},{24},{22};               !- Vertex 3

 ! Roof 1, Roof, South External roof
 BuildingSurface:Detailed, R_265_6_0_0,          !- Surface name
```

```
   Roof, 6,                                    !- Class and Construction Name
   265,                                        !- Zone Name
   Outdoors, ,                                 !- Outside Face Environment
   SunExposed,                                 !- Sun Exposure
   WindExposed,                                !- Wind Exposure
   .067,                                       !- View Factor to Ground
   3,                                          !- Number vertices
    0,0,{21},                    !- Vertex 1
    {0},0,{21},                  !- Vertex 2
    {23},{24},{22};              !- Vertex 3

! Roof 1, Roof, West External roof
BuildingSurface:Detailed, R_265_7_0_0,         !- Surface name
   Roof, 6,                                    !- Class and Construction Name
   265,                                        !- Zone Name
   Outdoors, ,                                 !- Outside Face Environment
   SunExposed,                                 !- Sun Exposure
   WindExposed,                                !- Wind Exposure
   .067,                                       !- View Factor to Ground
   3,                                          !- Number vertices
    0,{1},{21},                  !- Vertex 1
    0,0,{21},                    !- Vertex 2
    {23},{24},{22};                   !- Vertex 3""".format(Width, Length, Height, WindowPerform, SouthWinShortDim,
       <B>SouthWinLongDim,  EastWinShortDim,  EastWinLongDim,  NorthWinShortDim,  NorthWinLongDim,  FirstFlrShortDim,
       <B>FirstFlrTallDim,  SecondFlrShortDim,  SecondFlrTallDim,  ThirdFlrShortDim,  ThirdFlrTallDim,  SecondHeight,
       <B>ThirdHeight, OverHang, OverWidth, OverLength, RoofHeight, PeakHeight, HalfWidth, HalfLength)

 return "{0} \n\n\n {1}".format(BasementIDF, UpperIDF)
```

Run1.py

```
#!/usr/local/bin/python3.1

def IDFexecutor():
    """This function executes a subset of randomized IDF files with EnergyPlus. Req's
       SubFunction.py"""

    numperm = 1080000
    randarray = list(range(numperm))

    import sys
    import shutil
    import re
    from subprocess import Popen

    #Open up the randomized permutation array and read in the data
    f = open('/thesis/run1/randarray','r')
    pulldata = f.read()
    randarray = re.split(' ',pulldata)
    f.close()

    #Split permutations into 1 of 8 randomized groupings, and execute independently
    count = list(range(numperm))
    weatherfile = 'CAN_ON_Toronto_CWEC'

    count1 = count[000000:045000]
    for elem in count1:

        currentIDF = randarray[elem]

        try:
            shutil.move('/thesis/runs/{0}'.format(currentIDF), '/thesis/run1/')
            Popen( "/usr/local/bin/runenergyplus     '/thesis/run1/{0}' '{1}'
             ".format(currentIDF, weatherfile,) , shell=True).wait()

        except (IOError):
            print('{0} doesnt exist'.format(currentIDF))

        except (shutil.Error):
            print('{0} is done already'.format(currentIDF))


IDFexecutor()
```

Run2.py

```
#!/usr/local/bin/python3.1

def IDFexecutor():
    """This function executes a subset of randomized IDF files with EnergyPlus. Req's
SubFunction.py"""

    numperm = 1080000
    randarray = list(range(numperm))

    import sys
    import shutil
    import re
    from subprocess import Popen

    #Open up the randomized permutation array and read in the data
    f = open('/thesis/run2/randarray','r')
    pulldata = f.read()
    randarray = re.split(' ',pulldata)
    f.close()

    #Split permutations into 2nd of 8 randomized groupings, and execute independently
    count = list(range(numperm))
    weatherfile = 'CAN_ON_Toronto_CWEC'

    count2 = count[045000:090000]
    for elem in count2:

        currentIDF = randarray[elem]

        try:
            shutil.move('/thesis/runs/{0}'.format(currentIDF), '/thesis/run2/')
            Popen( "/usr/local/bin/runenergyplus     '/thesis/run2/{0}' '{1}'
             ".format(currentIDF, weatherfile,) , shell=True).wait()

        except (IOError):
            print('{0} doesnt exist'.format(currentIDF))

        except (shutil.Error):
            print('{0} is done already'.format(currentIDF))


IDFexecutor()
```

Run3.py

```
#!/usr/local/bin/python3.1

def IDFexecutor():
    """This function executes a subset of randomized IDF files with EnergyPlus. Req's
SubFunction.py"""

    numperm = 1080000
    randarray = list(range(numperm))

    import sys
    import shutil
    import re
    from subprocess import Popen

    #Open up the randomized permutation array and read in the data
    f = open('/thesis/run2/randarray','r')
    pulldata = f.read()
    randarray = re.split(' ',pulldata)
    f.close()

    #Split permutations into 2nd of 8 randomized groupings, and execute independently
    count = list(range(numperm))
    weatherfile = 'CAN_ON_Toronto_CWEC'

    count3 = count[090000:135000]
    for elem in count3:

        currentIDF = randarray[elem]

        try:
            shutil.move('/thesis/runs/{0}'.format(currentIDF), '/thesis/run3/')
            Popen( "/usr/local/bin/runenergyplus    '/thesis/run3/{0}' '{1}'
           ".format(currentIDF, weatherfile,) , shell=True).wait()

        except (IOError):
            print('{0} doesnt exist'.format(currentIDF))

        except (shutil.Error):
            print('{0} is done already'.format(currentIDF))


IDFexecutor()
```

Run4.py

```
#!/usr/local/bin/python3.1

def IDFexecutor():
    """This function executes a subset of randomized IDF files with EnergyPlus. Req's
       SubFunction.py"""

    numperm = 1080000
    randarray = list(range(numperm))

    import sys
    import shutil
    import re
    from subprocess import Popen

    #Open up the randomized permutation array and read in the data
    f = open('/thesis/run4/randarray','r')
    pulldata = f.read()
    randarray = re.split(' ',pulldata)
    f.close()

    #Split permutations into 4th of 8 randomized groupings, and execute independently
    count = list(range(numperm))
    weatherfile = 'CAN_ON_Toronto_CWEC'

    count4 = count[135000:180000]
    for elem in count4:


        currentIDF = randarray[elem]
        try:
            shutil.move('/thesis/runsR1/{0}'.format(currentIDF), '/thesis/run4/')
            Popen( "/usr/local/bin/runenergyplus     '/thesis/run4/{0}' '{1}'
             ".format(currentIDF, weatherfile,) , shell=True).wait()

        except (IOError):
            print('{0} doesnt exist'.format(currentIDF))

        except (shutil.Error):
            print('{0} is done already'.format(currentIDF))

IDFexecutor()
```

Run5.py

```
#!/usr/local/bin/python3.1

def IDFexecutor():
    """This function executes a subset of randomized IDF files with EnergyPlus. Req's
       SubFunction.py"""

    numperm = 1080000
    randarray = list(range(numperm))

    import sys
    import shutil
    import re
    from subprocess import Popen

    #Open up the randomized permutation array and read in the data
    f = open('/thesis/run5/randarray','r')
    pulldata = f.read()
    randarray = re.split(' ',pulldata)
    f.close()

    #Split permutations into 5th of 8 randomized groupings, and execute independently
    count = list(range(numperm))
    weatherfile = 'CAN_ON_Toronto_CWEC'

    count5 = count[180000:225000]
    for elem in count5:

        currentIDF = randarray[elem]
        try:
            shutil.move('/thesis/runs/{0}'.format(currentIDF), '/thesis/run5/')
            Popen( "/usr/local/bin/runenergyplus        '/thesis/run5/{0}' '{1}'
             ".format(currentIDF, weatherfile,) , shell=True).wait()

        except (IOError):
            print('{0} doesnt exist'.format(currentIDF))

        except (shutil.Error):
            print('{0} is done already'.format(currentIDF))


IDFexecutor()
```

Run6.py

```
#!/usr/local/bin/python3.1

def IDFexecutor():
    """This function executes a subset of randomized IDF files with EnergyPlus. Req's
       SubFunction.py"""

    numperm = 1080000
    randarray = list(range(numperm))

    import sys
    import shutil
    import re
    from subprocess import Popen

    #Open up the randomized permutation array and read in the data
    f = open('/thesis/run6/randarray','r')
    pulldata = f.read()
    randarray = re.split(' ',pulldata)
    f.close()

    #Split permutations into 6th of 8 randomized groupings, and execute independently
    count = list(range(numperm))
    weatherfile = 'CAN_ON_Toronto_CWEC'

    count6 = count[225000:270000]
    for elem in count6:

        currentIDF = randarray[elem]

        try:
            shutil.move('/thesis/runs/{0}'.format(currentIDF), '/thesis/run6/')
            Popen( "/usr/local/bin/runenergyplus     '/thesis/run6/{0}' '{1}'
             ".format(currentIDF, weatherfile,) , shell=True).wait()

        except (IOError):
            print('{0} doesnt exist'.format(currentIDF))

        except (shutil.Error):
            print('{0} is done already'.format(currentIDF))

IDFexecutor()
```

Run7.py

```
#!/usr/local/bin/python3.1

def IDFexecutor():
    """This function executes a subset of randomized IDF files with EnergyPlus. Req's
       SubFunction.py"""

    numperm = 1080000
    randarray = list(range(numperm))

    import sys
    import shutil
    import re
    from subprocess import Popen

    #Open up the randomized permutation array and read in the data
    f = open('/thesis/run7/randarray','r')
    pulldata = f.read()
    randarray = re.split(' ',pulldata)
    f.close()

    #Split permutations into 7th of 8 randomized groupings, and execute independently
    count = list(range(numperm))
    weatherfile = 'CAN_ON_Toronto_CWEC'

    count7 = count[270000:315000]
    for elem in count7:

        currentIDF = randarray[elem]

        try:
            shutil.move('/thesis/runs/{0}'.format(currentIDF), '/thesis/run7/')
            Popen( "/usr/local/bin/runenergyplus     '/thesis/run7/{0}' '{1}'
             ".format(currentIDF, weatherfile,) , shell=True).wait()

        except (IOError):
            print('{0} doesnt exist'.format(currentIDF))

        except (shutil.Error):
            print('{0} is done already'.format(currentIDF))

IDFexecutor()
```

Run8.py

```
#!/usr/local/bin/python3.1

def IDFexecutor():
    """This function executes a subset of randomized IDF files with EnergyPlus. Req's
       SubFunction.py"""

    numperm = 1080000
    randarray = list(range(numperm))

    import sys
    import shutil
    import re
    from subprocess import Popen

    #Open up the randomized permutation array and read in the data
    f = open('/thesis/run8/randarray','r')
    pulldata = f.read()
    randarray = re.split(' ',pulldata)
    f.close()

    #Split permutations into 8th of 8 randomized groupings, and execute independently
    count = list(range(numperm))
    weatherfile = 'CAN_ON_Toronto_CWEC'

    count8 = count[315000:360000]
    for elem in count8:

        currentIDF = randarray[elem]

        try:
            shutil.move('/thesis/runs/{0}'.format(currentIDF), '/thesis/run8/')
            Popen( "/usr/local/bin/runenergyplus     '/thesis/run8/{0}' '{1}'
             ".format(currentIDF, weatherfile,) , shell=True).wait()

        except (IOError):
            print('{0} doesnt exist'.format(currentIDF))

        except (shutil.Error):
            print('{0} is done already'.format(currentIDF))

IDFexecutor()
```

Database.py

```
#!/usr/bin/python

def DatabaseBuilder():
    """This function collects all the database parameters and outputs them to a tab delimited text file"""

    import csv
    import math


#List of Input Parameters & Embodied Energy Data

    NumStories = [1,2,3]
    Basement = [0,1]                                            # 1 = basement, 0 = no basement
    TotalArea = [92.9,139.4,185.8,325.2,464.5]                  # Square Meters
    ShapeRatio = [0.75,1,1.25]                                  # South Facade Width = ShapeRatio*squareDim
    SouthWinWallRatio = [0.1,0.3,0.5,0.6]                       # %area window to wall
    EastWinWallRatio = [0.1,0.3,0.5]                            # %area window to wall
    NorthWinWallRatio = [0.1]                                   # %area window to wall
    WindowPerform = [101,102,103,104,105]                       # Construction names in IDF
    Infiltration = [0.667,0.334,0.167,0.067,0.01667]        # Levels at 1Pa pressure drop (10,5,2.5,1,0.25 @ 50Pa)
    ThermalMass = [0.00001,0.05,0.15,0.3]                       # Thickness of concrete in [m]

    RSIvalue = [2.5,5,7.5,10,12.5,15,17.5,20,22.5,25]           # [Km2/W]
    ThermConductivity = 0.035                                   # [W/mK]
    InsulThickness = [i*ThermConductivity for i in RSIvalue]  # Insulation thickness in [m], for dense polystyrene

    CelluloseCond = 0.042                                       # [W/mK] (ASHRAE)
    EPSCond = 0.037
    FibreGlassCond = 0.040
    PolyISOCond = 0.020
    RockWoolCond = 0.039
    XPSCond = 0.029

    CelluloseEmbRate = 23.57                                    # [KWH/m3]
    EPSEmbRate = 405.29
    FibreGlassEmbRate = 169.45
    PolyISOEmbRate = 653.65
    RockWoolEmbRate = 287.31
    XPSEmbRate = 810.02

#Set up Field Names in Database Text File

    notf = open('/Volumes/DigLib1/database/thesis.txt', 'w')

notf.write('SimNumber\tNumStories\tBasement\tTotalArea\tShapeRatio\tSouthWinWallRatio\tEast/WestWinWallRatio\tNorthWinW
allRatio\tWindowPerform\tInfiltration\tRSIvalue\tThermalMass\tHeatingDD\tCoolingDD\tYearlyHeating\tYearlyCooling\tTotal
WindowArea\tTotalFrameLength\tEmbodiedCell\tEmbodiedEPS\tEmbodiedFibreGlass\tEmbodiedPolyISO\tEmbodiedRockWool\tEmbodie
dXPS\n')
    notf.close()

#Regenerate the results file names .csv

    mm  =  (NumStories,  Basement,  TotalArea,  ShapeRatio,  SouthWinWallRatio,  EastWinWallRatio,  NorthWinWallRatio,
          <B>WindowPerform, Infiltration, InsulThickness, ThermalMass)
    n = 0
    heaterror = 0
    coolerror = 0
    heatdderror = 0
    cooldderror = 0
    numperm = 1

    counter = list(range(len(mm)))

    for i in counter:
        counter[i] = len(mm[i])

    for s in counter:
        numperm = numperm*s

    print("number of permutations = {0}".format(numperm))

    permutation = list(range(numperm))
    permtext = list(range(numperm))

    for a in list(range(len(mm[0]))):
        for b in list(range(len(mm[1]))):
            for c in list(range(len(mm[2]))):
                for d in list(range(len(mm[3]))):
                    for e in list(range(len(mm[4]))):
                        for f in list(range(len(mm[5]))):
                            for g in list(range(len(mm[6]))):
                                for h in list(range(len(mm[7]))):
                                    for i in list(range(len(mm[8]))):
                                        for j in list(range(len(mm[9]))):
                                            for k in list(range(len(mm[10]))):

                                                InsulationSlab = mm[9][j]*0.251
                                        # 0.251:0.301:0.477:1 normalized OBC 2006 slab:found:expwall:expceiling
                                                InsulationFound = mm[9][j]*0.301
                                                InsulationWall = mm[9][j]*0.477
```

```
InsulationCeiling = mm[9][j]

permutation[n] = [str(n).zfill(7), mm[0][a] ,mm[1][b] ,mm[2][c],
  <B>mm[3][d], mm[4][e], mm[5][f], mm[6][g], mm[7][h], mm[8][i],
  <B>InsulationSlab, InsulationFound, InsulationWall,
  <B>InsulationCeiling, mm[10][k]]

currentCSV = '{0}_{1}_{2}_{3:.1f}_{4:.2f}_{5:.1f}_{6:.1f}_{7:.1f}_{8}_
  <B>{9:.5f}_{10:.3f}_{11:.3f}_{12:.3f}_{13:.3f}_{14:.5f}
  <B>.csv'.format(permutation[n][0], permutation[n][1],
  <B>permutation[n][2], permutation[n][3], permutation[n][4],
  <B>permutation[n][5], permutation[n][6], permutation[n][7],
  <B>permutation[n][8], permutation[n][9], permutation[n][10],
  <B>permutation[n][11], permutation[n][12], permutation[n][13],
  <B>permutation[n][14],)

# Pull Data out of the current CSV

print('Reading CSV#{0}'.format(permutation[n][0]))
reader = csv.reader(open('/Volumes/DigLib1
  <B>/stu/results/{0}'.format(currentCSV), "rb"))

results = []
for row in reader:
    results.append(row)

if permutation[n][2] == 0:

    if permutation[n][1] == 1:

        try:
            HeatingDD = float(results[2][38])
        except IndexError:
            heatdderror = heatdderror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('heatdderror in {0}'.format(currentCSV))
            notf.close()

        try:
            CoolingDD = float(results[1][39])
        except IndexError:
            cooldderror = cooldderror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('cooldderror in {0}'.format(currentCSV))
            notf.close()

        try:
            YearlyHeating = float(results[3][38])*31*24 +
            <B>float(results[4][38])*28*24 +
            <B>float(results[5][38])*31*24 +
            <B>float(results[6][38])*30*24 +
            <B>float(results[7][38])*31*24 +
            <B>float(results[8][38])*30*24 +
            <B>float(results[9][38])*31*24 +
            <B>float(results[10][38])*31*24 +
            <B>float(results[11][38])*30*24 +
            <B>float(results[12][38])*31*24 +
            <B>float(results[13][38])*30*24 +
            <B>float(results[14][38])*31*24

         except IndexError:
            heaterror = heaterror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('heaterror in {0}'.format(currentCSV))
            notf.close()

        try:
            YearlyCooling = float(results[8][39])*30*24 +
            <B>float(results[9][39])*31*24 +
            <B>float(results[10][39])*31*24 +
            <B>float(results[11][39])*30*24

        except IndexError:
            coolerror = coolerror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('coolerror in {0}'.format(currentCSV))

    if permutation[n][1] == 2:

        try:
            HeatingDD = float(results[2][54])
        except IndexError:
            heatdderror = heatdderror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('heatdderror in {0}'.format(currentCSV))
            notf.close()

        try:
            CoolingDD = float(results[1][55])
        except IndexError:
            cooldderror = cooldderror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('cooldderror in {0}'.format(currentCSV))
            notf.close()
```

```
        try:
            YearlyHeating = float(results[3][54])*31*24 +
            <B>float(results[4][54])*28*24 +
            <B>float(results[5][54])*31*24 +
            <B>float(results[6][54])*30*24 +
            <B>float(results[7][54])*31*24 +
            <B>float(results[8][54])*30*24 +
            <B>float(results[9][54])*31*24 +
            <B>float(results[10][54])*31*24 +
            <B>float(results[11][54])*30*24 +
            <B>float(results[12][54])*31*24 +
            <B>float(results[13][54])*30*24 +
            <B>float(results[14][54])*31*24

        except IndexError:
            heaterror = heaterror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('heaterror in {0}'.format(currentCSV))
            notf.close()

        try:
            YearlyCooling = float(results[8][55])*30*24 +
            <B>float(results[9][55])*31*24 +
            <B>float(results[10][55])*31*24 +
            <B>float(results[11][55])*30*24

        except IndexError:
            coolerror = coolerror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('coolerror in {0}'.format(currentCSV))

    if permutation[n][1] == 3:

        try:
            HeatingDD = float(results[2][70])
        except IndexError:
            heatdderror = heatdderror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('heatdderror in {0}'.format(currentCSV))
            notf.close()

        try:
            CoolingDD = float(results[1][71])
        except IndexError:
            cooldderror = cooldderror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('cooldderror in {0}'.format(currentCSV))
            notf.close()

        try:
            YearlyHeating = float(results[3][70])*31*24 +
            <B>float(results[4][70])*28*24 +
            <B>float(results[5][70])*31*24 +
            <B>float(results[6][70])*30*24 +
            <B>float(results[7][70])*31*24 +
            <B>float(results[8][70])*30*24 +
            <B>float(results[9][70])*31*24 +
            <B>float(results[10][70])*31*24 +
            <B>float(results[11][70])*30*24 +
            <B>float(results[12][70])*31*24 +
            <B>float(results[13][70])*30*24 +
            <B>float(results[14][70])*31*24

        except IndexError:
            heaterror = heaterror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('heaterror in {0}'.format(currentCSV))
            notf.close()

        try:
            YearlyCooling = float(results[8][71])*30*24 +
            <B>float(results[9][71])*31*24 +
            <B>float(results[10][71])*31*24 +
            <B>float(results[11][71])*30*24

        except IndexError:
            coolerror = coolerror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('coolerror in {0}'.format(currentCSV))


if permutation[n][2] == 1:

    if permutation[n][1] == 1:

        try:
            HeatingDD = float(results[2][42])
        except IndexError:
            heatdderror = heatdderror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('heatdderror in {0}'.format(currentCSV))
            notf.close()

        try:
            CoolingDD = float(results[1][43])
```

```
        except IndexError:
            cooldderror = cooldderror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('cooldderror in {0}'.format(currentCSV))
            notf.close()

        try:
            YearlyHeating = float(results[3][42])*31*24 +
            <B>float(results[4][42])*28*24 +
            <B>float(results[5][42])*31*24 +
            <B>float(results[6][42])*30*24 +
            <B>float(results[7][42])*31*24 +
            <B>float(results[8][42])*30*24 +
            <B>float(results[9][42])*31*24 +
            <B>float(results[10][42])*31*24 +
            <B>float(results[11][42])*30*24 +
            <B>float(results[12][42])*31*24 +
            <B>float(results[13][42])*30*24 +
            <B>float(results[14][42])*31*24

        except IndexError:
            heaterror = heaterror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('heaterror in {0}'.format(currentCSV))
            notf.close()

        try:
            YearlyCooling = float(results[8][43])*30*24 +
            <B>float(results[9][43])*31*24 +
            <B>float(results[10][43])*31*24 +
            <B>float(results[11][43])*30*24

        except IndexError:
            coolerror = coolerror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('coolerror in {0}'.format(currentCSV))

    if permutation[n][1] == 2:

        try:
            HeatingDD = float(results[2][58])
        except IndexError:
            heatdderror = heatdderror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('heatdderror in {0}'.format(currentCSV))
            notf.close()

        try:
            CoolingDD = float(results[1][59])
        except IndexError:
            cooldderror = cooldderror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('cooldderror in {0}'.format(currentCSV))
            notf.close()

        try:
            YearlyHeating = float(results[3][58])*31*24 +
            <B>float(results[4][58])*28*24 +
            <B>float(results[5][58])*31*24 +
            <B>float(results[6][58])*30*24 +
            <B>float(results[7][58])*31*24 +
            <B>float(results[8][58])*30*24 +
            <B>float(results[9][58])*31*24 +
            <B>float(results[10][58])*31*24 +
            <B>float(results[11][58])*30*24 +
            <B>float(results[12][58])*31*24 +
            <B>float(results[13][58])*30*24 +
            <B>float(results[14][58])*31*24

        except IndexError:
            heaterror = heaterror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('heaterror in {0}'.format(currentCSV))
            notf.close()

        try:
            YearlyCooling = float(results[8][59])*30*24 +
            <B>float(results[9][59])*31*24 +
            <B>float(results[10][59])*31*24 +
            <B>float(results[11][59])*30*24

        except IndexError:
            coolerror = coolerror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('coolerror in {0}'.format(currentCSV))

    if permutation[n][1] == 3:

        try:
            HeatingDD = float(results[2][74])
        except IndexError:
            heatdderror = heatdderror + 1
            notf = open('/Volumes/DigLib1/database/error.txt', 'a')
            notf.write('heatdderror in {0}'.format(currentCSV))
            notf.close()
```

```
try:
    CoolingDD = float(results[1][75])
except IndexError:
    cooldderror = cooldderror + 1
    notf = open('/Volumes/DigLib1/database/error.txt', 'a')
    notf.write('cooldderror in {0}'.format(currentCSV))
    notf.close()

try:
    YearlyHeating = float(results[3][74])*31*24 +
    <B>float(results[4][74])*28*24 +
    <B>float(results[5][74])*31*24 +
    <B>float(results[6][74])*30*24 +
    <B>float(results[7][74])*31*24 +
    <B>float(results[8][74])*30*24 +
    <B>float(results[9][74])*31*24 +
    <B>float(results[10][74])*31*24 +
    <B>float(results[11][74])*30*24 +
    <B>float(results[12][74])*31*24 +
    <B>float(results[13][74])*30*24 +
    <B>float(results[14][74])*31*24

except IndexError:
    heaterror = heaterror + 1
    notf = open('/Volumes/DigLib1/database/error.txt', 'a')
    notf.write('heaterror in {0}'.format(currentCSV))
    notf.close()

try:
    YearlyCooling = float(results[8][75])*30*24 +
    <B>float(results[9][75])*31*24 +
    <B>float(results[10][75])*31*24 +
    <B>float(results[11][75])*30*24
except IndexError:
    coolerror = coolerror + 1
    notf = open('/Volumes/DigLib1/database/error.txt', 'a')
    notf.write('coolerror in {0}'.format(currentCSV))
```

```
# Calculate Insulation Volume for Embodied Energy

print('Calculating Embodied Energy')
FloorArea = 1
if permutation[n][2] == 1:
    FloorArea = permutation[n][3]/(permutation[n][1] + 1)
if permutation[n][2] == 0:
    FloorArea = permutation[n][3]/permutation[n][1]

SquareDim = math.sqrt(FloorArea)
Width = SquareDim*permutation[n][4]
Length = SquareDim/permutation[n][4]
Height = 3
WinHeight = 0.75*Height
SouthWinArea = permutation[n][5]*Width*Height
SouthWinWidth = SouthWinArea/WinHeight
EastWinArea = permutation[n][6]*Length*Height
EastWinLength = EastWinArea/WinHeight
NorthWinArea = permutation[n][7]*Width*Height
NorthWinWidth = NorthWinArea/WinHeight

TotalWindowArea = SouthWinArea + 2*EastWinArea + NorthWinArea
TotalFrameLength = (WinHeight*8 + SouthWinWidth + 2*EastWinLength +
  <B>NorthWinWidth)*permutation[n][1]

if permutation[n][2] == 1:
    FoundationVolRSI =
  <B>Height*(2*Width+2*Length)*InsulationFound/ThermConductivity
if permutation[n][2] == 0:
    FoundationVolRSI = 0

WallVolRSI = permutation[n][1]*(Height*(2*Width+2*Length)-
  <B>TotalWindowArea)*InsulationWall/ThermConductivity

InsulationVolumeRSI = FloorArea*(InsulationSlab/ThermConductivity +
  <B>InsulationCeiling/ThermConductivity) + FoundationVolRSI +
  <B>WallVolRSI

VolCellulose = InsulationVolumeRSI*CelluloseCond
VolEPS = InsulationVolumeRSI*EPSCond
VolFibreGlass = InsulationVolumeRSI*FibreGlassCond
VolPolyISO = InsulationVolumeRSI*PolyISOCond
VolRockWool = InsulationVolumeRSI*RockWoolCond
VolXPS = InsulationVolumeRSI*XPSCond

EmbodiedCell = VolCellulose*CelluloseEmbRate
EmbodiedEPS = VolEPS*EPSEmbRate
EmbodiedFibreGlass = VolFibreGlass*FibreGlassEmbRate
EmbodiedPolyISO = VolPolyISO*PolyISOEmbRate
EmbodiedRockWool = VolRockWool*RockWoolEmbRate
EmbodiedXPS = VolXPS*XPSEmbRate
```

```
# Open Database file & Append Data
                                                  print('Writing to Database file')
                                                  noth = open('/Volumes/DigLib1/database/thesis.txt', 'a')
                                                  noth.write('{0}\t{1}\t{2}\t{3:.1f}\t{4:.2f}\t{5:.1f}\t{6:.1f}
                                                    <B>\t{7:.1f}\t{8}\t{9:.5f}\t{10:.1f}\t{11:.5f}\t{12:.2f}\t{13:.2f}
                                                    <B>\t{14:.2f}\t{15:.2f}\t{16:.2f}\t{17:.2f}\t{18:.2f}\t{19:.2f}
                                                    <B>\t{20:.2f}\t{21:.2f}\t{22:.2f}\t{23:.2f}\n'
                                                    <B>.format(permutation[n][0], permutation[n][1], permutation[n][2],
                                                    <B>permutation[n][3], permutation[n][4], permutation[n][5],
                                                    <B>permutation[n][6], permutation[n][7], permutation[n][8],
                                                    <B>permutation[n][9], permutation[n][13]/ThermConductivity,
                                                    <B>permutation[n][14], HeatingDD,CoolingDD, YearlyHeating,
                                                    <B>YearlyCooling, TotalWindowArea, TotalFrameLength, EmbodiedCell,
                                                    <B>EmbodiedEPS,EmbodiedFibreGlass ,EmbodiedPolyISO ,EmbodiedRockWool
                                                    <B>,EmbodiedXPS))

                                                  noth.close()

                                                  n = n + 1

    print('#Heat Errors = {0}, #Cool Errors = {1}, #HeatDD Errors = {2}, #CoolDD Errors =
          <B>{3}'.format(heaterror,coolerror, heatdderror, cooldderror))

DatabaseBuilder()
```

Mover.py

```
#!/usr/bin/python

def IDFexecutor():
    """This function moves results CSV’s using the IDF name master array"""

    numperm = 1080000
    randarray = list(range(numperm))

    import sys
    import shutil
    import re
    from subprocess import Popen
    import os.path

    #Open up the randomized permutation array and read in the data
    f = open('/Volumes/DigLib1/stu/Instance2/run3/randarray','r')
    pulldata = f.read()
    randarray = re.split(' ',pulldata)
    f.close()

    #Split permutations into 3rd of 8 randomized groupings, and execute independently
    count = list(range(numperm))
    weatherfile = 'CAN_ON_Toronto_CWEC'
    test = 'test'

    count3 = count[990000:1035000]
    for elem in count3:

        currentIDF = randarray[elem]

        try:

shutil.move('/Volumes/DigLib1/stu/Instance3/run7/Output/{0}.csv'.format(str.rstrip(curren
       <B>tIDF,'.idf')), '/Volumes/DigLib1/stu/results/')

        except (IOError):
            print('{0} doesnt exist'.format(currentIDF))

        except (shutil.Error):
            print('{0} is done already'.format(currentIDF))


IDFexecutor()
```

Appendix D - Sample IDF # 0029163

```
! File originally generated by DesignBuilder - 2.0.4.002

!- Thesis Simulation Trial #: ['0029163', 1, 0, 92.9, 1.25, 0.3, 0.5, 0.1, 101, 0.01667, 0.021962500000000003, 0.026337500000000003, 0.041737500000000004, 0.08750000000000001, 0.3]

Version,4.0;

RunPeriod,
    ,                        !- Name
    1,                       !- Begin Month
    1,                       !- Begin Day of Month
    12,                      !- End Month
    31,                      !- End Day of Month
    UseWeatherFile,          !- Day of Week for Start Day
    No,                      !- Use Weather File Holidays and Special Days
    No,                      !- Use Weather File Daylight Saving Period
    Yes,                     !- Apply Weekend Holiday Rule
    Yes,                     !- Use Weather File Rain Indicators
    Yes,                     !- Use Weather File Snow Indicators
    1;                       !- Number of Times Runperiod to be Repeated

RunPeriodControl:DaylightSavingTime,
    1st Sunday in April,     !- Start Date
    Last Sunday in October;  !- End Date

! Hourly weather file: CAN_ON_Toronto_CWEC.epw

Site:Location,
    Toronto,                 !- Name
    43.67,                   !- Latitude [deg]
    -79.63,                  !- Longitude [deg]
    -5,                      !- Time Zone [hr]
    173;                     !- Elevation [m]

Site:GroundTemperature:BuildingSurface,15,15,15,15,15,15,15,15,15,15,15,15;

 Site:GroundReflectance,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2;

Site:GroundReflectance:SnowModifier,
   1.0,                                         !- Ground Reflected Solar Modifier
   1.0;                                         !- Daylighting Ground Reflected Solar Modifier

SimulationControl,
   Yes,                                         !- Do the zone sizing calculation
   Yes,                                         !- Do the system sizing calculation
   No,                                          !- Do the plant sizing calculation
   Yes,                                         !- Do the design day calculation
   Yes;                                         !- Do the weather file calculation

SizingPeriod:DesignDay,
   Summer Design Day in Toronto,                !- Design Day Name
   30.6,                                        !- Max Dry-Bulb [C]
   10.6,                                        !- Daily Temp Range [C]
   21.9,                                        !- Wet-Bulb at Max [C]
   99263.9,                                     !- Barometric Pressure [N/M**2]
   0,                                           !- Wind Speed [m/s]
   0,                                           !- Wind Direction [Degrees N=0, S=180]
   0.98,                                        !- Clearness [0.0 to 1.1]
   0,                                           !- Rain [0-no,1-yes]
   0,                                           !- Snow on ground [0-no,1-yes]
   15,                                          !- Day of Month
   7,                                           !- Month
   SummerDesignDay,                             !- Day Type -- used for schedules
   1,                                           !- Daylight Savings Time Indicator
   WetBulb,                                     !- Type of humidity temperature Indicator
   ,                                            !- Relative Humidity Day Schedule(not used)
   ,                                            !- Dry-Bulb Temperature Range Modifier Type (not used)
   ;                                            !- Dry-Bulb Temperature Range Modifier Schedule (not used)

SizingPeriod:DesignDay,
   Winter Design Day in Toronto,                !- Design Day Name
   -19.4,                                       !- Max Dry-Bulb [C]
   0,                                           !- Daily Temp Range [C]
   -19.4,                                       !- Wet-Bulb at Max [C]
   99263.9,                                     !- Barometric Pressure [N/M**2]
   14.2,                                        !- Wind Speed [M/Sec]
   0,                                           !- Wind Direction [Degrees N=0, S=180]
   0,                                             !- Clearness [0.0 to 1.1] - gives no sun (but does include long wave radiant heat exchange with sky)
   0,                                           !- Rain [0-no,1-yes]
   1,                                           !- Snow on ground [0-no,1-yes]
   15,                                          !- Day of Month
   1,                                           !- Month
   WinterDesignDay,                             !- Day Type -- used for schedules
   0,                                           !- Daylight Savings Time Indicator
   WetBulb,                                     !- Type of humidity temperature Indicator
   ,                                            !- Relative Humidity Day Schedule (not used)
   ,                                            !- Dry-Bulb Temperature Range Modifier Type (not used)
   ;                                            !- Dry-Bulb Temperature Range Modifier Schedule (not used)

Timestep, 4;                                    !- Timesteps/hour
```

```
ConvergenceLimits,
   1,                                            !- Minimum System Time Step (0=same as zone time step)
   20;                                           !- Maximum HVAC Iterations (1=min, 20=default)

ScheduleTypeLimits,
    Any Number;              !- Name

ScheduleTypeLimits,
    Fraction,                !- Name
    0.0,                     !- Lower Limit Value
    1.0,                     !- Upper Limit Value
    CONTINUOUS;              !- Numeric Type

ScheduleTypeLimits,
    Temperature,             !- Name
    -60,                     !- Lower Limit Value
    200,                     !- Upper Limit Value
    CONTINUOUS;              !- Numeric Type

ScheduleTypeLimits,
    Control Type,            !- Name
    0,                       !- Lower Limit Value
    4,                       !- Upper Limit Value
    DISCRETE;                !- Numeric Type

ScheduleTypeLimits,
    On/Off,                  !- Name
    0,                       !- Lower Limit Value
    1,                       !- Upper Limit Value
    DISCRETE;                !- Numeric Type

Schedule:Compact,
    On,                      !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,1;          !- Field 3

Schedule:Compact,
    Off,                     !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,0;          !- Field 3

Schedule:Compact,
    Work efficiency,         !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,0;          !- Field 3

Schedule:Compact,
    AirVelocitySchedule,     !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,0.137;      !- Field 3

! ------------------- Control type schedules (for heating & cooling) ---------------------

! Schedule: On
Schedule:Compact,
    2,                       !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,1;          !- Field 3

! Schedule: Off
Schedule:Compact,
    7,                       !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,0;          !- Field 3

! Schedule: Occupants
Schedule:Compact,
    2234,                    !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 Dec,         !- Field 1
    For: Weekdays SummerDesignDay WinterDesignDay, !- Field 2
    Until: 18:00,1,          !- Field 3
    Until: 22:00,1,          !- Field 5
    Until: 23:00,1,          !- Field 7
    Until: 24:00,1,          !- Field 9
    For: Weekends,           !- Field 11
    Until: 10:00,1,          !- Field 12
    Until: 17:00,1,          !- Field 14
    Until: 18:00,1,          !- Field 16
    Until: 23:00,1,          !- Field 18
    Until: 24:00,1,          !- Field 20
    For: Holidays,           !- Field 22
```

```
    Until: 24:00,0,          !- Field 23
    For:  AllOtherDays,      !- Field 25
    Until: 24:00,0;          !- Field 26

! Schedule: Lighting
Schedule:Compact,
    2235,                    !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 Dec,         !- Field 1
    For: Weekdays SummerDesignDay WinterDesignDay, !- Field 2
    Until: 08:00,1,          !- Field 3
    Until: 18:00,1,          !- Field 5
    Until: 24:00,1,          !- Field 7
    For: Weekends,           !- Field 9
    Until: 10:00,1,          !- Field 10
    Until: 24:00,1,          !- Field 12
    For: Holidays,           !- Field 14
    Until: 24:00,1,          !- Field 15
    For: AllOtherDays,       !- Field 17
    Until: 24:00,1;          !- Field 18

! Schedule: Equipment
Schedule:Compact,
    2236,                    !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 Dec,         !- Field 1
    For: Weekdays SummerDesignDay WinterDesignDay, !- Field 2
    Until: 18:00,1,          !- Field 3
    Until: 23:00,1,          !- Field 5
    Until: 24:00,1,          !- Field 7
    For: Weekends,           !- Field 9
    Until: 10:00,1,          !- Field 10
    Until: 24:00,1,          !- Field 12
    For: Holidays,           !- Field 14
    Until: 24:00,1,          !- Field 15
    For:  AllOtherDays,      !- Field 17
    Until: 24:00,1;          !- Field 18

WindowMaterial:Gas,
    1001,                    !- Name
    Air,                     !- Gas Type
    .006;                    !- Thickness [m]

WindowMaterial:Gas,
    Half thickness 1001,     !- Name
    Air,                     !- Gas Type
    .003;                    !- Thickness [m]

WindowMaterial:Gas,
    1020,                    !- Name
    Air,                     !- Gas Type
    .016;                    !- Thickness [m]

WindowMaterial:Gas,
    Half thickness 1020,     !- Name
    Air,                     !- Gas Type
    .008;                    !- Thickness [m]

WindowMaterial:Gas,
    1023,                    !- Name
    Krypton,                 !- Gas Type
    .016;                    !- Thickness [m]

WindowMaterial:Gas,
    Half thickness 1023,     !- Name
    Krypton,                 !- Gas Type
    .008;                    !- Thickness [m]

WindowMaterial:Glazing,
    2,                       !- Name
    SpectralAverage,         !- Optical Data Type
    ,                        !- Window Glass Spectral Data Set Name
    .003,                    !- Thickness [m]
    .837,                    !- Solar Transmittance at Normal Incidence
    .075,                    !- Front Side Solar Reflectance at Normal Incidence
    .075,                    !- Back Side Solar Reflectance at Normal Incidence
    .898,                    !- Visible Transmittance at Normal Incidence
    .081,                    !- Front Side Visible Reflectance at Normal Incidence
    .081,                    !- Back Side Visible Reflectance at Normal Incidence
    .0,                      !- Infrared Transmittance at Normal Incidence
    .84,                     !- Front Side Infrared Hemispherical Emissivity
    .84,                     !- Back Side Infrared Hemispherical Emissivity
    .9,                      !- Conductivity [W/m-K]
    1;                       !- Dirt Correction Factor for Solar and Visible Transmittance

WindowMaterial:Glazing,
    390,                     !- Name
    Spectral,                !- Optical Data Type
    AFG Industries Comfort ES LowE on Clear <ESN1.AFG>,  !- Window Glass Spectral Data Set Name
    .0056134,                !- Thickness [m]
    ,                        !- Solar Transmittance at Normal Incidence
    ,                        !- Front Side Solar Reflectance at Normal Incidence
    ,                        !- Back Side Solar Reflectance at Normal Incidence
    ,                        !- Visible Transmittance at Normal Incidence
    ,                        !- Front Side Visible Reflectance at Normal Incidence
```

```
    ,                        !- Back Side Visible Reflectance at Normal Incidence
    0,                       !- Infrared Transmittance at Normal Incidence
    0.09,                    !- Front Side Infrared Hemispherical Emissivity
    0.84,                    !- Back Side Infrared Hemispherical Emissivity
    1,                       !- Conductivity [W/m-K]
    1;                       !- Dirt Correction Factor for Solar and Visible Transmittance

MaterialProperty:GlazingSpectralData,
    AFG Industries Comfort ES LowE on Clear <ESN1.AFG>,  !- Name
    0.3,0,0.288,0.046,
    0.305,0,0.29,0.046,
    0.31,0,0.292,0.046,
    0.315,0.001,0.29,0.045,
    0.32,0.004,0.289,0.045,
    0.325,0.013,0.281,0.044,
    0.33,0.034,0.274,0.045,
    0.335,0.064,0.261,0.045,
    0.34,0.101,0.246,0.046,
    0.345,0.14,0.231,0.046,
    0.35,0.176,0.214,0.049,
    0.355,0.211,0.206,0.052,
    0.36,0.258,0.199,0.059,
    0.365,0.318,0.192,0.066,
    0.37,0.397,0.182,0.076,
    0.375,0.474,0.162,0.082,
    0.38,0.552,0.139,0.086,
    0.385,0.63,0.117,0.09,
    0.39,0.699,0.1,0.093,
    0.395,0.745,0.089,0.095,
    0.4,0.775,0.08,0.094,
    0.41,0.8,0.07,0.09,
    0.42,0.808,0.065,0.088,
    0.43,0.811,0.062,0.085,
    0.44,0.813,0.06,0.083,
    0.45,0.818,0.059,0.081,
    0.46,0.823,0.059,0.079,
    0.47,0.828,0.058,0.077,
    0.48,0.832,0.058,0.075,
    0.49,0.837,0.056,0.071,
    0.5,0.843,0.054,0.067,
    0.51,0.848,0.052,0.064,
    0.52,0.852,0.05,0.06,
    0.53,0.856,0.048,0.057,
    0.54,0.858,0.046,0.054,
    0.55,0.859,0.044,0.051,
    0.56,0.86,0.042,0.048,
    0.57,0.859,0.04,0.046,
    0.58,0.856,0.039,0.044,
    0.59,0.854,0.038,0.042,
    0.6,0.85,0.037,0.041,
    0.61,0.845,0.037,0.04,
    0.62,0.839,0.037,0.04,
    0.63,0.832,0.038,0.04,
    0.64,0.825,0.04,0.041,
    0.65,0.817,0.042,0.042,
    0.66,0.808,0.044,0.043,
    0.67,0.799,0.047,0.046,
    0.68,0.788,0.051,0.048,
    0.69,0.778,0.055,0.051,
    0.7,0.766,0.059,0.053,
    0.71,0.755,0.064,0.057,
    0.72,0.743,0.07,0.061,
    0.73,0.73,0.075,0.064,
    0.74,0.717,0.082,0.068,
    0.75,0.704,0.089,0.073,
    0.76,0.691,0.096,0.077,
    0.77,0.677,0.104,0.081,
    0.78,0.665,0.111,0.085,
    0.79,0.652,0.119,0.089,
    0.8,0.637,0.129,0.094,
    0.81,0.631,0.176,0.121,
    0.82,0.572,0.176,0.121,
    0.83,0.572,0.173,0.119,
    0.84,0.572,0.175,0.12,
    0.85,0.572,0.182,0.125,
    0.86,0.569,0.179,0.121,
    0.87,0.561,0.194,0.127,
    0.88,0.547,0.215,0.136,
    0.89,0.539,0.201,0.128,
    0.9,0.529,0.238,0.151,
    0.91,0.516,0.245,0.151,
    0.92,0.508,0.242,0.146,
    0.93,0.498,0.259,0.157,
    0.94,0.489,0.272,0.164,
    0.95,0.48,0.279,0.166,
    0.96,0.472,0.294,0.171,
    0.97,0.463,0.334,0.195,
    0.98,0.454,0.309,0.181,
    0.99,0.448,0.316,0.183,
    1,0.438,0.358,0.204,
    1.05,0.404,0.361,0.203,
    1.1,0.373,0.384,0.214,
    1.15,0.346,0.454,0.252,
    1.2,0.321,0.499,0.278,
    1.25,0.298,0.529,0.299,
```

```
    1.3,0.282,0.64,0.372,
    1.35,0.267,0.65,0.389,
    1.4,0.255,0.649,0.399,
    1.45,0.244,0.607,0.389,
    1.5,0.235,0.652,0.436,
    1.55,0.224,0.718,0.493,
    1.6,0.209,0.692,0.486,
    1.65,0.201,0.669,0.475,
    1.7,0.186,0.68,0.486,
    1.75,0.175,0.754,0.54,
    1.8,0.168,0.699,0.497,
    1.85,0.156,0.569,0.405,
    1.9,0.154,0.668,0.475,
    1.95,0.168,0.699,0.497,
    2,0.134,0.805,0.542,
    2.05,0.127,0.81,0.547,
    2.1,0.121,0.816,0.554,
    2.15,0.115,0.82,0.555,
    2.2,0.108,0.825,0.533,
    2.25,0.103,0.83,0.536,
    2.3,0.099,0.834,0.551,
    2.35,0.096,0.838,0.559,
    2.4,0.092,0.841,0.559,
    2.45,0.087,0.844,0.546,
    2.5,0.082,0.847,0.534,
    3,0.013,0.888,0.048,
    3.5,0.009,0.893,0.041,
    4,0.009,0.898,0.043;

WindowMaterial:Shade,
    20001,                  !- Name
    0.05,                   !- Solar Transmittance
    0.9,                    !- Solar Reflectance
    0.9,                    !- Visible Transmittance
    0.05,                   !- Visible Reflectance
    0.05,                   !- Thermal Hemispherical Emissivity
    0.9,                    !- Thermal Transmittance
    0.001,                  !- Thickness [m]
    10,                     !- Conductivity [W/m-K]
    0.020,                  !- Shade to Glass Distance [m]
    0,                      !- Top Opening Multiplier
    0,                      !- Bottom Opening Multiplier
    0,                      !- Left-Side Opening Multiplier
    0,                      !- Right-Side Opening Multiplier
    0.5;                    !- Airflow Permeability

! EPS Expanded Polystyrene (Heavyweight) - Slab thickness 0.0219625
Material,
    1_1_85,                 !- Material name
    Rough,                  !- Roughness
    0.0219625,                    !- Thickness [m]
    0.035,                  !- Conductivity [W/m-K]
    25,                     !- Density [kg/m3]
    1400,                   !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! EPS Expanded Polystyrene (Heavyweight) - Foundation thickness 0.0263375
Material,
    1_1_86,                 !- Material name
    Rough,                  !- Roughness
    0.0263375,                    !- Thickness [m]
    0.035,                  !- Conductivity [W/m-K]
    25,                     !- Density [kg/m3]
    1400,                   !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! EPS Expanded Polystyrene (Heavyweight) - Wall thickness 0.0417375
Material,
    1_1_87,                 !- Material name
    Rough,                  !- Roughness
    0.0417375,                    !- Thickness [m]
    0.035,                  !- Conductivity [W/m-K]
    25,                     !- Density [kg/m3]
    1400,                   !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! EPS Expanded Polystyrene (Heavyweight) - Ceiling thickness 0.0875
Material,
    1_1_88,                 !- Material name
    Rough,                  !- Roughness
    0.0875,                    !- Thickness [m]
    0.035,                  !- Conductivity [W/m-K]
    25,                     !- Density [kg/m3]
    1400,                   !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! Aerated Concrete Slab- thickness 0.3
```

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Material,
    1_1_1,                  !- Material name
    Rough,                  !- Roughness
    0.3,                    !- Thickness [m]
    0.1600,                 !- Conductivity [w/m-K]
    500.00,                 !- Density [kg/m3]
    840.00,                 !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! Aerated Concrete Slab- thickness 0.05m
Material,
    1_1_2,                  !- Material name
    Rough,                  !- Roughness
    0.05,                   !- Thickness [m]
    0.1600,                 !- Conductivity [w/m-K]
    500.00,                 !- Density [kg/m3]
    840.00,                 !- Specific Heat [J/kg-K]
    0.9,                    !- Thermal Emittance
    0.6,                    !- Solar Absorptance
    0.6;                    !- Visible Absorptance

! 'Slab Floor'
Construction,
    1,                      !- Name
    1_1_1,                        !- Aerated Concrete (0.3m)
    1_1_85;                 !- EPS Expanded Polystyrene (Heavyweight) (0.0219625m)

! 'Foundation Wall'
Construction,
    2,                      !- Name
    1_1_1,                        !- Aerated Concrete (0.3m)
    1_1_86;                 !- EPS Expanded Polystyrene (Heavyweight) (0.0263375m)

! 'Exposed Wall'
Construction,
    3,                      !- Name
    1_1_1,                      !- Aerated Concrete (0.3m)
    1_1_87;                 !- EPS Expanded Polystyrene (Heavyweight) (0.0417375m)

! 'Exposed Ceiling'
Construction,
    4,                      !- Name
    1_1_1,                        !- Aerated Concrete (0.3m)
    1_1_88;                 !- EPS Expanded Polystyrene (Heavyweight) (0.0875m)

! <Previous reversed>
Construction,
    5,                      !- Name
    1_1_88,                 !- EPS Expanded Polystyrene (Heavyweight) (0.0875m)
    1_1_1;                  !- Aerated Concrete (0.3m)

! 'Indoor Ceiling'
Construction,
    6,                      !- Name
    1_1_2;                        !- Aerated Concrete (0.05m)

! <Previous reversed>
Construction,
    7,                      !- Name
    1_1_2;                        !- Aerated Concrete (0.05m)

Construction,
    101,                    !- Thesis - Single Glaze
    2;                      !- Generic CLEAR 3MM

Construction,
    102,                    !- Thesis - Weak Double Glaze
    2,                      !- Generic CLEAR 3MM
    1001,                   !- AIR 6MM
    2;                      !- Generic CLEAR 3MM

Construction,
    103,                    !- Thesis - Good Double Glaze
    2,                      !- Generic CLEAR 3MM
    1020,                   !- AIR 16MM
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

Construction,
    104,                    !- Thesis - Triple Glaze
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

Construction,
    105,                    !- Thesis - Quad Glaze
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    390,                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>
    1023,                   !- KRYPTON 16MM
    390,                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>
    1023,                   !- KRYPTON 16MM
```

```
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

Construction,
    101S,                   !- Thesis - Single Glaze
    20001,                  !- Exterior Shading
    2;                      !- Generic CLEAR 3MM

Construction,
    102S,                   !- Thesis - Weak Double Glaze
    20001,                  !- Exterior Shading
    2,                      !- Generic CLEAR 3MM
    1001,                   !- AIR 6MM
    2;                      !- Generic CLEAR 3MM

Construction,
    103S,                   !- Thesis - Good Double Glaze
    20001,                  !- Exterior Shading
    2,                      !- Generic CLEAR 3MM
    1020,                   !- AIR 16MM
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

Construction,
    104S,                   !- Thesis - Triple Glaze
    20001,                  !- Exterior Shading
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

Construction,
    105S,                   !- Thesis - Quad Glaze
    20001,                  !- Exterior Shading
    2,                      !- Generic CLEAR 3MM
    1023,                   !- KRYPTON 16MM
    390,                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>
    1023,                   !- KRYPTON 16MM
    390,                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>
    1023,                   !- KRYPTON 16MM
    390;                    !- AFG Industries Comfort ES LowE on Clear <ESN1.AFG>

WindowProperty:ShadingControl,
    1111,                       !- Name of shading control
    ExteriorShade,              !- Shading type
    101S,                       !- Name of glazed construction with shading
    OnIfHighZoneAirTemperature, !- Shading control type
    ,                           !- Schedule name
    24,                         !- Setpoint
    No,                         !- Shading control is scheduled
    No,                         !- Glare control is active
    ,                           !- Material name of shading device
    ,                           !- Type of slat angle control
    ,                           !- Slat angle schedule name
    ;                           !- Setpoint 2

HeatBalanceAlgorithm,ConductionTransferFunction,2000;

SurfaceConvectionAlgorithm:Inside,Detailed;

SurfaceConvectionAlgorithm:Outside,DOE-2;

ShadowCalculation,
    20,                     !- Calculation Frequency
    15000;                  !- Maximum Figures in Shadow Overlap Calculations

ZoneCapacitanceMultiplier,1.0;

Building,
    Building,               !- Building Name
    0,                      !- North Axis
    Suburbs,                !- Terrain
    .05,                    !- Loads Convergence Tolerance
    .4,                     !- Temperature Convergence Tolerance
    MinimalShadowing,       !- Solar Distribution
    25;                     !- Maximum number of warmup days


GlobalGeometryRules,
    LowerLeftCorner,        !- Starting Vertex Position
    CounterClockWise,       !- Vertex Entry Direction
    World;                  !- Coordinate System

! Linked Single Zone
Zone,
    208,                    !- Zone Name
    0,                      !- Relative North (to building)
    0,                      !- X Origin [m]
    0,                      !- Y Origin [m]
    0,                      !- Z Origin [m]
    1 ,                     !- Zone Type
    1,                      !- Zone multiplier
    ,                       !- Zone ceiling height
    autocalculate,          !- Zone volume
    Detailed;               !- Zone inside convection algorithm
```

```
PEOPLE,
    People 208,             !- Name
    208,                    !- Zone Name
    2234,                   !- Number of People SCHEDULE Name
    People,                 !- Number of People
    3,                      !- Number of People
    ,                       !- People per Zone Area
    ,                       !- Zone Area per Person
    .5,                     !- radiant fraction
    AUTOCALCULATE,          !- User Specified Sensible Fraction
    Activity Schedule 208,  !- Activity level SCHEDULE Name (units W/person, real)
    No,                     !- Enable ASHRAE 55 comfort warnings
    ZoneAveraged,           !- MRT Calculation Type
    ,                       !- no particular surface is weighted
    Work efficiency,        !- Work Efficiency SCHEDULE Name (0.0-1.0,real)
    Clothing Schedule 208,  !- Clothing Insulation SCHEDULE Name (real)
    AirVelocitySchedule;    !- Air Velocity SCHEDULE Name (units m/s, real)

Schedule:Compact,
    Activity Schedule 208,  !- Name
    Any Number,             !- Schedule Type Limits Name
    Through: 12/31,         !- Field 1
    For: AllDays,           !- Field 2
    Until: 24:00,120;       !- Field 3

Schedule:Compact,
    Clothing Schedule 208,  !- Name
    Any Number,             !- Schedule Type Limits Name
    Through: 4/1,           !- Field 1
    For: AllDays,           !- Field 2
    Until: 24:00,1,         !- Field 3
    Through: 9/30,          !- Field 5
    For: AllDays,           !- Field 6
    Until: 24:00,.5,        !- Field 7
    Through: 12/31,         !- Field 9
    For: AllDays,           !- Field 10
    Until: 24:00,1;         !- Field 11

Lights,
    208 General lighting,   !- Name
    208,                    !- Zone Name
    2235,                   !- Schedule Name
    Watts/Area,             !- Design Level Calculation Method
    ,                       !- Lighting Level [W]
    1.55,                   !- Watts per Zone Floor Area [W/m2]
    ,                       !- Watts per Person [W/person]
    0,                      !- Return Air Fraction
    .42,                    !- Fraction Radiant
    .18,                    !- Fraction Visible
    0,                      !- Fraction Replaceable
    208GeneralLights;       !- End-Use Subcategory

ElectricEquipment,
    208 Equipment 1,        !- Name
    208,                    !- Zone Name
    2236,                   !- Schedule Name
    Watts/Area,             !- Design Level Calculation Method
    ,                       !- Design Level [W]
    3.73,                   !- Watts per Zone Floor Area [W/m2]
    ,                       !- Watts per Person [W/person]
    0,                      !- Fraction Latent
    .2,                     !- Fraction Radiant
    0,                      !- Fraction Lost
    208Appliances;          !- End-Use Subcategory

WaterUse:Equipment,
    DHW 208,                    !- Name
    208DHW,                     !- End-Use Subcategory
    3.04E-06,                   !- Peak Flow Rate [m3/s]
    2234,                       !- Flow Rate Fraction Schedule Name
    DHW Supply Temperature 208, !- Target Temperature Schedule Name
    DHW Supply Temperature 208, !- Hot Water Supply Temperature Schedule Name
    DHW Mains Temperature 208,  !- Cold Water Supply Temperature Schedule Name
    208,                        !- Zone Name
    ,                           !- Sensible Fraction Schedule Name
    ;                           !- Latent Fraction Schedule Name

Schedule:Compact,
    DHW Supply Temperature 208, !- Name
    Temperature,                !- Schedule Type Limits Name
    Through: 12/31,             !- Field 1
    For: AllDays,               !- Field 2
    Until: 24:00,60;            !- Field 3

Schedule:Compact,
    DHW Mains Temperature 208,  !- Name
    Temperature,                !- Schedule Type Limits Name
    Through: 12/31,             !- Field 1
    For: AllDays,               !- Field 2
    Until: 24:00,10;            !- Field 3

ZoneInfiltration:DesignFlowRate,
    208 Infiltration,           !- Name
    208,                        !- Zone Name
    On,                         !- Infiltration SCHEDULE Name
```

```
    AirChanges/Hour,            !- Design Volume Flow Rate calculation method
    ,                           !- Design Volume Flow Rate [m3/s]
    ,                           !- Flow per Zone Floor Area [m3/s/m2]
    ,                           !- Flow per Exterior Surface Area [m3/s/m2]
    0.01667,                        !- Air Changes Per Hour
    1,                          !- Constant Term Coefficient
    0,                          !- Temperature Term Coefficient
    0,                          !- Velocity Term Coefficient
    0;                          !- Velocity Squared Term Coefficient

ZoneVentilation,
    208 Ventilation,        !- Name
    208,                    !- Zone Name
    On,                     !- Schedule Name
    Flow/Area,              !- Design Flow Rate Calculation Method
    ,                       !- Design Flow Rate [m3/s]
    3.55E-04,               !- Flow Rate per Zone Floor Area [m3/s-m2]
    ,                       !- Flow Rate per Person [m3/s-person]
    ,                       !- Air Changes per Hour
    Natural,                !- Ventilation Type
    ,                       !- Fan Pressure Rise [Pa]
    ,                       !- Fan Total Efficiency
    1,                      !- Constant Term Coefficient
    0,                      !- Temperature Term Coefficient
    0,                      !- Velocity Term Coefficient
    0,                      !- Velocity Squared Term Coefficient
    0,                      !- Minimum Indoor Temperature [C]
    ,                       !- Minimum Indoor Temperature Schedule Name
    40,                     !- Maximum Indoor Temperature [C]
    ,                       !- Maximum Indoor Temperature Schedule Name
    2,                      !- Delta Temperature [deltaC]
    ,                       !- Delta Temperature Schedule Name
    -100,                   !- Minimum Outdoor Temperature [C]
    ,                       !- Minimum Outdoor Temperature Schedule Name
    40,                     !- Maximum Outdoor Temperature [C]
    ,                       !- Maximum Outdoor Temperature Schedule Name
    40;                     !- Maximum Wind Speed [m/s]


      ! 1st Floor, 1st Floor, Ground floor

   BuildingSurface:Detailed, S_208_0_0_0,         !- Surface name

      Floor, 1,                                   !- Class and Construction Name
      208,                                        !- Zone Name
      Ground, ,                                   !- Outside Face Environment
      NoSun,                                      !- Sun Exposure
      NoWind,                                     !- Wind Exposure
      1,                                          !- View Factor to Ground
      4,                                          !- Number vertices
       12.04808076,0,0,                 !- Vertex 1
       0,0,0,                   !- Vertex 2
       0,7.71077168641,0,                 !- Vertex 3
       12.04808076,7.71077168641,0;               !- Vertex 4


 ! 1st Floor, 1st Floor, Ceiling

   BuildingSurface:Detailed, C_220_1_0_0,         !- Surface name

      Ceiling, 4,                                 !- Class and Construction Name
      208,                                        !- Zone Name
      Surface, F_265_8_0_10003,                   !- Outside Face Environment
      NoSun,                                      !- Sun Exposure
      NoWind,                                     !- Wind Exposure
      0,                                          !- View Factor to Ground
      4,                                          !- Number vertices
       0,0,3,                 !- Vertex 1
       12.04808076,0,3,               !- Vertex 2
       12.04808076,7.71077168641,3,             !- Vertex 3
       0,7.71077168641,3;               !- Vertex 4


   ! 1st Floor, 1st Floor, Ceiling

   BuildingSurface:Detailed, F_265_8_0_10003,     !- Surface name - reverse definition

      Floor, 5,                                   !- Class and Construction Name
      265,                                        !- Zone Name
      Surface, C_220_1_0_0,                       !- Outside Face Environment
      NoSun,                                      !- Sun Exposure
      NoWind,                                     !- Wind Exposure
      0,                                          !- View Factor to Ground
      4,                                          !- Number vertices
       12.04808076,0,3,               !- Vertex 1
       0,0,3,                 !- Vertex 2
       0,7.71077168641,3,               !- Vertex 3
       12.04808076,7.71077168641,3;             !- Vertex 4


   ! 1st Floor, 1st Floor, East Wall

   BuildingSurface:Detailed, W_220_2_0_0,         !- Surface name

      Wall, 3,                                    !- Class and Construction Name
```

```
    208,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .5,                                         !- View Factor to Ground
    4,                                          !- Number vertices
     12.04808076,0,0,                 !- Vertex 1
     12.04808076,7.71077168641,0,               !- Vertex 2
     12.04808076,7.71077168641,3,             !- Vertex 3
     12.04808076,0,3;               !- Vertex 4


    ! East Window

    FenestrationSurface:Detailed, W_220_2_0_0_0_0_Win,  !- Window name

       Window,                                  !- Class
       101,                                     !- Construction Name
       W_220_2_0_0,                             !- Base surface
       ,                                        !- corresponding other window subsurface
       .5,                                      !- View Factor to Ground
       1111,                                    !- Window shading control
       ,                                        !- Frame divider name
       1,                                       !- Multiplier
       4,                                       !- Number vertices
        12.04808076,1.2851286144,0.375,             !- Vertex 1
        12.04808076,6.42564307201,0.375,             !- Vertex 2
        12.04808076,6.42564307201,2.625,            !- Vertex 3
        12.04808076,1.2851286144,2.625;             !- Vertex 4


 ! 1st Floor, 1st Floor, North Wall

 BuildingSurface:Detailed, W_220_3_0_0,         !- Surface name

    Wall, 3,                                    !- Class and Construction Name
    208,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .5,                                         !- View Factor to Ground
    4,                                          !- Number vertices
     12.04808076,7.71077168641,0,               !- Vertex 1
     0,7.71077168641,0,                 !- Vertex 2
     0,7.71077168641,3,               !- Vertex 3
     12.04808076,7.71077168641,3;             !- Vertex 4

    ! North Window

    FenestrationSurface:Detailed, W_220_3_0_0_0_0_Win,  !- Window name

       Window,                                  !- Class
       101,                                     !- Construction Name
       W_220_3_0_0,                             !- Base surface
       ,                                        !- corresponding other window subsurface
       .5,                                      !- View Factor to Ground
       1111,                                    !- Window shading control
       ,                                        !- Frame divider name
       1,                                       !- Multiplier
       4,                                       !- Number vertices
        6.82724576401, 7.71077168641, 0.375,          !- Vertex 1
        5.22083499601, 7.71077168641, 0.375,          !- Vertex 2
        5.22083499601, 7.71077168641, 2.625,          !- Vertex 3
        6.82724576401, 7.71077168641, 2.625;          !- Vertex 4


 ! 1st Floor, 1st Floor, West Wall

 BuildingSurface:Detailed, W_220_4_0_0,         !- Surface name

    Wall, 3,                                    !- Class and Construction Name
    208,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .5,                                         !- View Factor to Ground
    4,                                          !- Number vertices
     0,7.71077168641,0,                 !- Vertex 1
     0,0,0,                   !- Vertex 2
     0,0,3,                 !- Vertex 3
     0,7.71077168641,3;               !- Vertex 4

    ! West Window

    FenestrationSurface:Detailed, W_220_4_0_0_0_0_Win,  !- Window name

       Window,                                  !- Class
       101,                                     !- Construction Name
       W_220_4_0_0,                             !- Base surface
       ,                                        !- corresponding other window subsurface
       .5,                                      !- View Factor to Ground
       1111,                                    !- Window shading control
       ,                                        !- Frame divider name
       1,                                       !- Multiplier
       4,                                       !- Number vertices
```

```
          0,6.42564307201,0.375,              !- Vertex 1
          0,1.2851286144,0.375,              !- Vertex 2
          0,1.2851286144,2.625,              !- Vertex 3
          0,6.42564307201,2.625;              !- Vertex 4


   ! 1st Floor, 1st Floor, South Wall

   BuildingSurface:Detailed, W_220_5_0_0,        !- Surface name

      Wall, 3,                                   !- Class and Construction Name
      208,                                       !- Zone Name
      Outdoors, ,                                !- Outside Face Environment
      SunExposed,                                !- Sun Exposure
      WindExposed,                               !- Wind Exposure
      .5,                                        !- View Factor to Ground
      4,                                         !- Number vertices
       0,0,0,                  !- Vertex 1
       12.04808076,0,0,                !- Vertex 2
       12.04808076,0,3,              !- Vertex 3
       0,0,3;                !- Vertex 4

      ! South Window

      FenestrationSurface:Detailed, W_220_5_0_0_0_Win,  !- Window name

         Window,                                 !- Class
         101,                                   !- Construction Name
         W_220_5_0_0,                            !- Base surface
         ,                                       !- corresponding other window subsurface
         .5,                                     !- View Factor to Ground
         1111,                                   !- Window shading control
         ,                                       !- Frame divider name
         1,                                      !- Multiplier
         4,                                      !- Number vertices
          3.61442422801,0,0.375,              !- Vertex 1
          8.43365653202,0,0.375,              !- Vertex 2
          8.43365653202,0,2.625,              !- Vertex 3
          3.61442422801,0,2.625;              !- Vertex 4


Shading:Building:Detailed, Pitched roof overhang West,  , 4,  !- site shading

   -0.75,8.46077168641,3,                !- Vertex 1
   -0.75,-0.75,3,               !- Vertex 2
    0,0,3,                      !- Vertex 3
    0,7.71077168641,3;                    !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang North,  , 4,  !- site shading

    0,7.71077168641,3,                    !- Vertex 1
    12.04808076,7.71077168641,3,                 !- Vertex 2
    12.79808076,8.46077168641,3,               !- Vertex 3
   -0.75,8.46077168641,3;                !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang East,  , 4,  !- site shading

    12.79808076,-0.75,3,                !- Vertex 1
    12.79808076,8.46077168641,3,                !- Vertex 2
    12.04808076,7.71077168641,3,                  !- Vertex 3
    12.04808076,0,3;                    !- Vertex 4

Shading:Building:Detailed, Pitched roof overhang South,  , 4,  !- site shading

   -0.75,-0.75,3,               !- Vertex 1
    12.79808076,-0.75,3,              !- Vertex 2
    12.04808076,0,3,                   !- Vertex 3
    0,0,3;                      !- Vertex 4


! Roof 1 - Roof

Zone, 265,                                       !- Zone Name

   0,                                            !- Relative North (to building)
   0,                                            !- X Origin [m]
   0,                                            !- Y Origin [m]
   0,                                            !- Z Origin [m]
   1 ,                                           !- Zone Type
   1,                                            !- Zone multiplier
   ,                                             !- Zone ceiling height - Let EnergyPlus work it out
   autocalculate,                                !- Zone volume
   Detailed;                                     !- Zone inside convection algorithm

   PEOPLE, People 265,                           !- Name

      265,                                       !- Zone Name
      7,                                         !- Number of People SCHEDULE Name
      People,                                    !- Number of People
       0,                                        !- Number of People
      ,                                          !- People per Zone Area
      ,                                          !- Zone Area per Person
       .5,                                       !- radiant fraction
      AUTOCALCULATE,                             !- User Specified Sensible Fraction
      Activity Schedule 265,                     !- Activity level SCHEDULE Name (units W/person, real)
```

```
    No,                                         !- Enable ASHRAE 55 comfort warnings
    ZoneAveraged,                               !- MRT Calculation Type
    ,                                           !- no particular surface is weighted
    Work efficiency,                            !- Work Efficiency SCHEDULE Name (0.0-1.0,real)
    Clothing Schedule 265,                      !- Clothing Insulation SCHEDULE Name (real)
    AirVelocitySchedule;                        !- Air Velocity SCHEDULE Name (units m/s, real)

 Schedule:Compact, Activity Schedule 265,       !- activity schedule W/person

    Any Number,                                 !- Type
    Through: 12/31,                             !- Type
    For: AllDays,                               !- All days in year
    Until: 24:00,  117;                         !- Constant value

 Schedule:Compact, Clothing Schedule 265,       !- Clothing schedule clo

    Any Number,                                 !- Type
    Through: 4/1,                               !- Type
    For: AllDays,                               !- All days in year
    Until: 24:00,  1,                           !- Constant value
    Through: 9/30,                              !- Type
    For: AllDays,                               !- All days in year
    Until: 24:00,  .5,                          !- Constant value
    Through: 12/31,                             !- Type
    For: AllDays,                               !- All days in year
    Until: 24:00,  1;                           !- Constant value


 ZoneInfiltration:DesignFlowRate, 265 Infiltration,  !- Name

    265,                                        !- Zone Name
    On,                                         !- Infiltration SCHEDULE Name
    AirChanges/Hour,                            !- Design Volume Flow Rate calculation method
    ,                                           !- Design Volume Flow Rate [m3/s]
    ,                                           !- Flow per Zone Floor Area [m3/s/m2]
    ,                                           !- Flow per Exterior Surface Area [m3/s/m2]
    0.5,                                        !- Air Changes Per Hour
    1,                                          !- Constant Term Coefficient
    0,                                          !- Temperature Term Coefficient
    0,                                          !- Velocity Term Coefficient
    0;                                          !- Velocity Squared Term Coefficient

 ! Roof 1, Roof, East Wall

 BuildingSurface:Detailed, W_265_0_0_0,         !- Surface name

    Wall, 6,                                    !- Class and Construction Name
    265,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .5,                                         !- View Factor to Ground
    4,                                          !- Number vertices
     12.04808076,0,3,                   !- Vertex 1
     12.04808076,7.71077168641,3,                 !- Vertex 2
     12.04808076,7.71077168641,3.35,                !- Vertex 3
     12.04808076,0,3.35;                  !- Vertex 4


 ! Roof 1, Roof, North Wall

 BuildingSurface:Detailed, W_265_1_0_0,         !- Surface name

    Wall, 6,                                    !- Class and Construction Name
    265,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .5,                                         !- View Factor to Ground
    4,                                          !- Number vertices
     12.04808076,7.71077168641,3,                 !- Vertex 1
     0,7.71077168641,3,                   !- Vertex 2
     0,7.71077168641,3.35,                  !- Vertex 3
     12.04808076,7.71077168641,3.35;                !- Vertex 4


 ! Roof 1, Roof, West Wall

 BuildingSurface:Detailed, W_265_2_0_0,         !- Surface name

    Wall, 6,                                    !- Class and Construction Name
    265,                                        !- Zone Name
    Outdoors, ,                                 !- Outside Face Environment
    SunExposed,                                 !- Sun Exposure
    WindExposed,                                !- Wind Exposure
    .5,                                         !- View Factor to Ground
    4,                                          !- Number vertices
     0,7.71077168641,3,                   !- Vertex 1
     0,0,3,                     !- Vertex 2
     0,0,3.35,                    !- Vertex 3
     0,7.71077168641,3.35;                  !- Vertex 4


 ! Roof 1, Roof, South Wall
```

```
   BuildingSurface:Detailed, W_265_3_0_0,         !- Surface name

      Wall, 6,                                    !- Class and Construction Name
      265,                                        !- Zone Name
      Outdoors, ,                                 !- Outside Face Environment
      SunExposed,                                 !- Sun Exposure
      WindExposed,                                !- Wind Exposure
      .5,                                         !- View Factor to Ground
      4,                                          !- Number vertices
       0,0,3,                   !- Vertex 1
       12.04808076,0,3,               !- Vertex 2
       12.04808076,0,3.35,              !- Vertex 3
       0,0,3.35;                  !- Vertex 4


   ! Roof 1, Roof, North External roof

   BuildingSurface:Detailed, R_265_4_0_0,         !- Surface name

      Roof, 6,                                    !- Class and Construction Name
      265,                                        !- Zone Name
      Outdoors, ,                                 !- Outside Face Environment
      SunExposed,                                 !- Sun Exposure
      WindExposed,                                !- Wind Exposure
      .067,                                       !- View Factor to Ground
      3,                                          !- Number vertices
       12.04808076,7.71077168641,3.35,               !- Vertex 1
       0,7.71077168641,3.35,                 !- Vertex 2
       6.02404038001,3.85538584321,7.5;             !- Vertex 3

   ! Roof 1, Roof, East External roof

   BuildingSurface:Detailed, R_265_5_0_0,         !- Surface name

      Roof, 6,                                    !- Class and Construction Name
      265,                                        !- Zone Name
      Outdoors, ,                                 !- Outside Face Environment
      SunExposed,                                 !- Sun Exposure
      WindExposed,                                !- Wind Exposure
      .067,                                       !- View Factor to Ground
      3,                                          !- Number vertices
       12.04808076,0,3.35,              !- Vertex 1
       12.04808076,7.71077168641,3.35,               !- Vertex 2
       6.02404038001,3.85538584321,7.5;             !- Vertex 3

   ! Roof 1, Roof, South External roof

   BuildingSurface:Detailed, R_265_6_0_0,         !- Surface name

      Roof, 6,                                    !- Class and Construction Name
      265,                                        !- Zone Name
      Outdoors, ,                                 !- Outside Face Environment
      SunExposed,                                 !- Sun Exposure
      WindExposed,                                !- Wind Exposure
      .067,                                       !- View Factor to Ground
      3,                                          !- Number vertices
       0,0,3.35,                  !- Vertex 1
       12.04808076,0,3.35,              !- Vertex 2
       6.02404038001,3.85538584321,7.5;             !- Vertex 3

   ! Roof 1, Roof, West External roof

   BuildingSurface:Detailed, R_265_7_0_0,         !- Surface name

      Roof, 6,                                    !- Class and Construction Name
      265,                                        !- Zone Name
      Outdoors, ,                                 !- Outside Face Environment
      SunExposed,                                 !- Sun Exposure
      WindExposed,                                !- Wind Exposure
      .067,                                       !- View Factor to Ground
      3,                                          !- Number vertices
       0,7.71077168641,3.35,                 !- Vertex 1
       0,0,3.35,                  !- Vertex 2
       6.02404038001,3.85538584321,7.5;             !- Vertex 3


! - Basement Surfaces Output
Output:Variable, S_208_0_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_208_2_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_208_3_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_208_4_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_208_5_0_0, Opaque Surface Inside Face Conduction, monthly;

! - First Floor Surfaces Output
Output:Variable, C_220_1_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_220_2_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_220_2_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_220_2_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_220_2_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_220_3_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_220_3_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_220_3_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_220_3_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_220_4_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_220_4_0_0_0_Win, Window Heat Gain, monthly;
```

```
Output:Variable, W_220_4_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_220_4_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_220_5_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_220_5_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_220_5_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_220_5_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, F_208_0_0_10001, Opaque Surface Inside Face Conduction, monthly;

! - Second Floor Surfaces Output
Output:Variable, C_171_1_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_171_2_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_171_2_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_171_2_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_171_2_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_171_3_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_171_3_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_171_3_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_171_3_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_171_4_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_171_4_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_171_4_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_171_4_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_171_5_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_171_5_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_171_5_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_171_5_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, F_208_0_0_10002, Opaque Surface Inside Face Conduction, monthly;

! - Third Floor Surfaces Output
Output:Variable, C_280_1_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_280_2_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_280_2_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_280_2_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_280_2_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_280_3_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_280_3_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_280_3_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_280_3_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_280_4_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_280_4_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_280_4_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_280_4_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, W_280_5_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_280_5_0_0_0_0_Win, Window Heat Gain, monthly;
Output:Variable, W_280_5_0_0_0_0_Win, Window Heat Loss, monthly;
Output:Variable, W_280_5_0_0_0_0_Win, Window Transmitted Solar, monthly;
Output:Variable, F_265_8_0_10003, Opaque Surface Inside Face Conduction, monthly;

! - Roof Surfaces Output
Output:Variable, F_265_8_0_10003, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_265_0_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_265_1_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_265_2_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, W_265_3_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, R_265_4_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, R_265_5_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, R_265_6_0_0, Opaque Surface Inside Face Conduction, monthly;
Output:Variable, R_265_7_0_0, Opaque Surface Inside Face Conduction, monthly;

Output:Variable, *, Outdoor Dry Bulb, monthly;
Output:Variable, 208, Zone Mean Air Temperature, monthly, On;
Output:Variable, 208, Zone Mean Radiant Temperature, monthly, On;
Output:Variable, 208, Zone Air Relative Humidity, monthly, On;
Output:Variable, 208, Zone Infiltration Air Change Rate, monthly;
Output:Variable, 208, Zone Ventilation Total Heat Loss, monthly;
Output:Variable, 208, Zone Ventilation Total Heat Gain, monthy;
Output:Variable, 208, Zone/Sys Sensible Heating Rate, monthly;
Output:Variable, 208, Zone/Sys Sensible Cooling Rate, monthly;
Output:Variable, 208, Zone People Sensible Heat Gain, monthly;
Output:Variable, 208, Zone Transmitted Solar, monthly;
Output:Variable, 208, Zone Infiltration Sensible Heat Loss, monthly;
Output:Variable, 208, Zone Infiltration Sensible Heat Gain, monthly;

Output:Meter, 208GeneralLights*, monthly;
Output:Meter, 208Appliances*, monthly;
Output:Meter, 208DHW*, monthly;

Output:Surfaces:Drawing, DXF, Triangulate3DFace;
Output:Surfaces:List,Details;
Output:Constructions,Constructions;
Output:VariableDictionary, regular;
Output:Diagnostics, DisplayAdvancedReportVariables, DisplayExtraWarnings;

!
! ------------------------------------------------------------
! HVAC Definition
! ------------------------------------------------------------
!

ScheduleTypeLimits,
    HVACTemplate Any Number;        !- Name

Schedule:Compact,
    HVACTemplate-Always 4,          !- Name
    HVACTemplate Any Number,        !- Type
```

```
    Through: 12/31,                 !- Field
    For: AllDays,                   !- Field
    Until: 24:00,                   !- Field
    4;                              !- Field

Schedule:Compact,
    HVACTemplate-Always 1,          !- Name
    HVACTemplate Any Number,        !- Type
    Through: 12/31,                 !- Field
    For: AllDays,                   !- Field
    Until: 24:00,                   !- Field
    1;                              !- Field

ThermostatSetpoint:DualSetpoint,
    Zone 208 Thermostat Dual SP Control,    !- Name
    Zone 208 Heating SP Sch,                !- Heating Setpoint Temperature Schedule Name
    Zone 208 Cooling SP Sch;                !- Cooling Setpoint Temperature Schedule Name

ZoneControl:Thermostat,
    208 Thermostat,                         !- Thermostat Name
    208,                                    !- Zone Name
    HVACTemplate-Always 4,                  !- Control Type Schedule Name
    ThermostatSetpoint:DualSetpoint,        !- Control Type
    Zone 208 Thermostat Dual SP Control;    !- Control Type Name

Sizing:Zone,
    208,                            !- Zone Name
    14,                             !- Zone cooling design supply air temperature [C]
    50,                             !- Zone heating design supply air temperature [C]
    0.008,                          !- Zone cooling design supply air humidity ratio [kg-H20/kg-air]
    0.008,                          !- Zone heating design supply air humidity ratio [kg-H2O/kg-air]
    Flow/Area,                      !- Outdoor Air Method
    ,                               !- outside air flow per person [m3/s]
    3.55E-04,                       !- outside air flow per zone area [m3/s-m2]
    ,                               !- outside air flow per zone [m3/s]
    ,                               !- Zone Sizing Factor
    DesignDay,                      !- Cooling Design Air Flow Method
    ,                               !- cooling design air flow rate [m3/s]
    ,                               !- cooling min air flow per zone area [m3/s-m2]
    ,                               !- cooling min air flow [m3/s]
    ,                               !- cooling min air flow fraction []
    DesignDay,                      !- Heating Design Air Flow Method
    ,                               !- heating design air flow rate [m3/s]
    ,                               !- heating min air flow per zone area [m3/s-m2]
    ,                               !- heating min air flow [m3/s]
    ;                               !- heating min air flow fraction []

ZoneHVAC:EquipmentConnections,
    208,                            !- Zone Name
    208Equipment,                   !- Zone Conditioning Equipment List Name
    208 HVAC Delivery,              !- List Name: Zone Air Inlet Nodes
    ,                               !- List Name: Zone Air Exhaust Nodes
    208 Zone Air,                   !- Zone Air Node Name
    208 Zone Return;                !- Zone Return Air Node Name (HVAC to zone)

ZoneHVAC:EquipmentList,
    208Equipment,                   !- Name
    ZoneHVAC:IdealLoadsAirSystem,   !- Zone Equipment 1 Object Type
    208 IdealHVAC,                  !- Zone Equipment 1 Name
    1,                              !- CoolingPriority
    1;                              !- HeatingPriority

ZoneHVAC:IdealLoadsAirSystem,
    208 IdealHVAC,                  !- Air system name
    208 HVAC Delivery,              !- Zone Supply Air Node (HVAC delivery)
    50,                             !- Heating Supply Air Temp
    14,                             !- Cooling Supply Air Temp
    0.008,                          !- Heating Supply Air Humidity Ratio
    0.008,                          !- Cooling Supply Air Humidity Ratio
    NoLimit,                        !- Heating Limit
    ,                               !- Max Heating Flow
    NoLimit,                        !- Cooling Limit
    ,                               !- Max Cooling Flow
    NoOutdoorAir,                   !- Outdoor air
    ,                               !- Outdoor air flow rate
    208 Heating Availability Sch,   !- Heating Avail Sch
    208 Cooling Availability Sch;   !- Cooling Avail Sch

! Modified schedule: Heating Setback
Schedule:Compact,
    Zone 208 Heating SP Sch, !- Name
    Temperature,             !- Schedule Type Limits Name
    Through: 31 May,         !- Field 1
    For: AllDays,            !- Field 2
    Until: 05:00,20,         !- Field 3
    Until: 09:00,20,         !- Field 5
    Until: 17:00,20,         !- Field 7
    Until: 24:00,20,         !- Field 9
    Through: 30 September,   !- Field 11
    For: AllDays,            !- Field 12
    Until: 05:00,0,          !- Field 13
    Until: 09:00,0,          !- Field 15
    Until: 17:00,0,          !- Field 17
    Until: 24:00,0,          !- Field 19
    Through: 31 December,    !- Field 21
```

```
    For: AllDays,            !- Field 22
    Until: 05:00,20,         !- Field 23
    Until: 09:00,20,         !- Field 25
    Until: 17:00,20,         !- Field 27
    Until: 24:00,20;         !- Field 29

! Modified schedule: Heating Availability
Schedule:Compact,
    208 Heating Availability Sch,  !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 May,         !- Field 1
    For: AllDays,            !- Field 2
    Until: 05:00,1,          !- Field 3
    Until: 09:00,1,          !- Field 5
    Until: 17:00,1,          !- Field 7
    Until: 24:00,1,          !- Field 9
    Through: 30 September,   !- Field 11
    For: AllDays,            !- Field 12
    Until: 05:00,0,          !- Field 13
    Until: 09:00,0,          !- Field 15
    Until: 17:00,0,          !- Field 17
    Until: 24:00,0,          !- Field 19
    Through: 31 December,    !- Field 21
    For: AllDays,            !- Field 22
    Until: 05:00,1,          !- Field 23
    Until: 09:00,1,          !- Field 25
    Until: 17:00,1,          !- Field 27
    Until: 24:00,1;          !- Field 29

! Modified schedule: Cooling Setback
Schedule:Compact,
    Zone 208 Cooling SP Sch, !- Name
    Temperature,             !- Schedule Type Limits Name
    Through: 31 May,         !- Field 1
    For: AllDays,            !- Field 2
    Until: 05:00,100,        !- Field 3
    Until: 09:00,100,        !- Field 5
    Until: 17:00,100,        !- Field 7
    Until: 24:00,100,        !- Field 9
    Through: 30 September,   !- Field 11
    For: AllDays,            !- Field 12
    Until: 05:00,25,         !- Field 13
    Until: 09:00,25,         !- Field 15
    Until: 17:00,25,         !- Field 17
    Until: 24:00,25,         !- Field 19
    Through: 31 December,    !- Field 21
    For: AllDays,            !- Field 22
    Until: 05:00,100,        !- Field 23
    Until: 09:00,100,        !- Field 25
    Until: 17:00,100,        !- Field 27
    Until: 24:00,100;        !- Field 29

! Modified schedule: Cooling Availability
Schedule:Compact,
    208 Cooling Availability Sch,  !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 May,         !- Field 1
    For: AllDays,            !- Field 2
    Until: 05:00,0,          !- Field 3
    Until: 09:00,0,          !- Field 5
    Until: 17:00,0,          !- Field 7
    Until: 24:00,0,          !- Field 9
    Through: 30 September,   !- Field 11
    For: AllDays,            !- Field 12
    Until: 05:00,1,          !- Field 13
    Until: 09:00,1,          !- Field 15
    Until: 17:00,1,          !- Field 17
    Until: 24:00,1,          !- Field 19
    Through: 31 December,    !- Field 21
    For: AllDays,            !- Field 22
    Until: 05:00,0,          !- Field 23
    Until: 09:00,0,          !- Field 25
    Until: 17:00,0,          !- Field 27
    Until: 24:00,0;          !- Field 29
```