Building Energy Analysis of SGH Office in Waltham, MA

A Major Qualifying Project

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Simpson, Gumpertz, and Heger

Design Statement

In the following report, we considered the energy efficiency of SGH's headquarter office in Waltham, MA. We attempted to model the energy use of the building using an energy simulation software, DesignBuilder. The goal of the project was to analyze the building's current energy use and produce design proposals that lead to energy savings.

The United States, responsible for approximately 17-19% of the world's energy consumption, tracked one-third of its energy use back to the building sector in 2013.[1] The building sector, including commercial and residential, took up 41% of the total U.S. energy consumption. Due to such high consumption of energy by buildings, there is a high potential for energy savings in the building sector.[2] Therefore, our project focused on simulating building energy use and predicting the effectiveness of various energy saving measures that address the environmental concerns raised in building energy use. Furthermore, improving the building's performance not only addresses the sustainability, but also the monetary aspect of energy consumption.

Compared to the simulation results –which displayed ideal energy consumption assuming accurate modeling –the monthly utility data was very high. As we analyzed the monthly utility data and spot measurements in-depth to identify possible cause of discrepancy, we observed some irregularity and came to the conclusion that there could be issues with HVAC operation. Though we could not complete a full analysis of the building's HVAC system due to time

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[1] "Transition to Sustainable Buildings: Strategies and Opportunities to 2050," International Energy Agency, p. 109. Retrieved from: https://www.iea.org/media/training/presentations/etw2014/publications/Sustainable_Buildings_2013.pdf

[2] Figure 2.1: D&R International, Ltd., "2011 Buildings Energy Data Book," Building Technologies Program, Energy Efficiency and Renewable Energy, U.S Department of Energy, 2. Retrieved from: http://buildingsdatabook.eren.doe.gov/docs/DataBooks/2011_BEDB.pdf

constraints, we gained a thorough understanding of the building's energy consumption through the process and provided three energy conservation measures that could result in energy savings.

Professional Licensure Statement

Work of engineering can be defined as "public or private service or creative work, the adequate performance of which requires engineering education, training, and experience in applying special knowledge or judgment of the mathematical, physical, or engineering sciences to that service or creative work."[3] Professional Licensure for engineers is a way to prove their credentials. Licensed engineers take on more responsibility and have authority to prepare, seal, and submit engineering plans.

The process and requirements to become a professional engineer vary by state. To be eligible for PE in Massachusetts, one must have an ABET accredited Bachelor of Science degree in engineering with three years of acceptable experience or other equivalent requirements that satisfy the eligibility.[4]

There are various views regarding professional licenses: "Practitioners of licensed occupations usually support licensing on the ground that it is in the public interests; many economists, on the other hand, feel that such licensing is designed to give monopoly power to the members of the occupation."[5] While it is interesting that professional licensure affects economy, it is difficult to view professional licensure as an unnecessary piece of paper that makes the profession elitist and exclusive. In general, professional license ensures a quality work for the consumers by "establishing minimum requirements for individuals who plan and design certain facilities and products used by the public."[6] Furthermore, professional license opens up opportunities for the engineers. As the license shows one's competence of engineering skills and

[3] "Is a Texas Licensed Engineer Required?" Texas Board of Professional Engineers. Web. 18 Apr. 2015
[4] "Massachusetts PE Eligibility Requirements," Professional Credential Services. Accessed March 17, 2016. https://www.pcshq.com/?page=engineeringandrelatedfields,umassachusettspebycomityeligibilityrequi.
[5] Thomas G. Moore, "The purpose of licensing," Journal of Law and Economics (1961): 93-117.
[6] Walesh, Stuart G. Engineering your future: The professional practice of engineering. John Wiley & Sons, 2012.

commitment to the career, the engineer will be "able to do higher level work, be responsible for more engineering projects, have access to more favorable employment opportunities, and be in a position to someday own and operate his or her consulting engineering or other engineering-based business."[7] Studies have also shown that licensed engineers earn higher pay throughout their careers.[8]

Professional licensure is integral to the safety and quality assurance of engineering. Professional Engineers assume responsibility for the work they approve and are expected to review and deliver engineering while maintaining a standard of integrity.

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[7] Walesh, Engineering your future.
[8] "Why Get Licensed?" National Society of Professional Engineers. Web. 18 Apr. 2015.

Abstract

The U.S. building sector is responsible for over one-third of the country's entire energy consumption. Because of this, efforts to reduce energy consumption in buildings can have a significant effect on the overall energy demand. This paper considers a case study of an office, provides an in-depth review of the building's characteristics and attempts to simulate the building in DesignBuilder. Using BES, energy consumption of the office is analyzed and ECMs are suggested to reduce energy usage.

Acknowledgments

We would like to thank our advisor, Steven van Dessel for guiding this project. His excitement and encouragement for the success of the project was integral in its completion.

We would also like to express our gratitude to our project sponsors: Jason Der Ananian, Brent Gabby, and Mike Roche from Simpson, Gumpertz, and Heger. Without their assistance, this project would not have been possible.

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Executive Summary

Introduction

Buildings comprise a significant portion of the energy consumption in the United States. As such, engineers, architects, and building operators should take the building's influence on energy savings and reduction into serious consideration. This paper provides an in-depth energy analysis of an office building in Waltham, MA. The techniques of building energy simulation and heating-degree-day analysis are used to develop an understanding of the energy consumption of the office building and provide recommendations for energy reduction.

Background

The United States, responsible for approximately 17-19% of the world's energy consumption, tracked one-third of its energy use back to the building sector in 2013.[9] Within the building itself, the highest site energy consumption for buildings in 2010 was space heating, followed by water heating, space cooling, and lighting.[10] The energy use in those sectors added up to 68% of the total building site energy consumption.

Building Energy Simulation (BES) is a method by which engineers can study the energy consumption in buildings. With a model, engineers can run simulations on a variety of different scenarios and test the benefits and disadvantages of retrofitting existing buildings or design changes in new construction. BES is not a simple undertaking, and requires a significant amount of time and effort. The potential for error increases with each parameter, and inputting poor data

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[9] "Transition to Sustainable Buildings: Strategies and Opportunities to 2050," International Energy Agency, p. 109. Retrieved from: https://www.iea.org/media/training/presentations/etw2014/publications/Sustainable_Buildings_2013.pdf
Note: IEA writes "roughly 17% of global final energy consumption" and the DOE considers 19%. IEA is a more recent publication.
[10] Book, Buildings Energy Data. "Energy Efficiency and Renewable Energy." *US Department of Energy* (2011).

will compromise the validity of the model. ASHRAE Guideline 14 outlines methods for measuring the energy and demand savings in buildings, and provides a methodology for whole building calibrated simulation.

Case Study

The case study for this project is the SGH office headquarters in Waltham, MA. The building, a former Raytheon complex, was originally renovated in 2002 into an office space. SGH, as tenants, expanded their square footage twice (2005 and 2012), such that the building is now as it exists today, at approximately 90,000 square feet. In the pursuit of calibrating an energy model of the building, we followed the methodology outlined in ASHRAE Guideline 14.

To begin with, we developed a simulation plan involving three parts: the baseline scenario, the retrofit scenario, and spot and short-term measurements. For the baseline scenario, we collected the floor plans and utility data and conducted on-site surveys of the lighting systems, plug load, HVAC systems, and building envelope. We also surveyed the building occupants to assess the perceived comfort level, actual occupancy schedules, and the use of the space, and interviewed the building manager to determine the operation of the building. Using this information, we developed a model of the building in DesignBuilder software.

For the retrofit scenario, we conducted a small parametric study on the baseline model. Though we were unable to calibrate the model, we still could analyze the effects of different parameters on the energy consumption of our simulated building. By testing different retrofit scenarios, we were able to determine a set of energy conservation measures (ECMs) that we suggested for implementation.

The other aspect of our plan included spot and short-term measurements of the building to increase the accuracy of our data. These measurements included confirming the geometry of the building –floor plans as compared to as-built measurements– as well as temperature and humidity sensors for capturing data in varying locations across the office.

Energy Conservation Measures

The design case study for this project involved implementing the energy conservation measures (ECMs) into our baseline model and testing their effects. There were three ECMs that we decided to pursue, two of which we modeled, and one that we suggested (though could not model). The latter of these is weather forecasting. Throughout the course of this study, we were able to collect temperature data on the building during a period in which the HVAC system was offline. The building performed well, and as such, we believe that the office should take better advantage of optimal weather. Weather forecasting could involve the installation of a smart building automation system which receives forecasted weather data that allows the HVAC to be proactive rather than reactive.

The two other ECMs we considered were radiant floor heating and increased air tightness. Radiant floor heating was studied due to the geometry of the building and comfort of the occupants. The building has high ceilings and a large, mostly flat floor plan. Radiant floor heating would keep the heat closer to the occupants and reduce the risk of heating unused space. The third ECM was to increase the air tightness of the building. Though an air-blower door test conducted on the office showed that it was relatively tight, the simulated model output revealed that one of the largest contributors to heat loss was air infiltration. Using the model, we were able to implement a different air changes per hour value, and test the outcome. The energy reduction was significant, especially because heating is the largest contributor to energy consumption for the building.

Conclusion and Recommendations

In this paper, we have initially reviewed various methods of energy analysis for the project site, SGH office headquarters, located in Waltham. DesignBuilder, a plug-in for EnergyPlus, was concluded to be suitable for the case study. ASHRAE Guideline 14, Measurement of Energy and Demand savings, was used to properly conduct an energy analysis on DesignBuilder. We have collected building data for building geometry, building envelope, lighting, plug loads, HVAC, utility data and spot measurements. Furthermore, a user survey was conducted to ensure better understanding of the occupant behaviors. While inputting the collected data in the software, and calibrating the model to monthly utility data, we observed some irregularity in the office's monthly utility data. Heating Degree Days analysis was conducted on the utility data and it was observed that the building's energy use, especially HVAC operation, did not display any noticeable trend that is expected from buildings located in similar environment.

Though the DesignBuilder model could not be calibrated to the utility data, the closest model produced using measured inputs was used to identify possible energy conservation measures. Out of three considered methods–weather forecasting, radiant floor heating with natural ventilation, and increased air tightness–weather forecasting and increased air tightness seemed to be most effective, with weather forecasting being more applicable.

Due to a lack of data and time constraints, we could not further our study in identifying the cause of the oddity in the HVAC system and evaluating energy conservation measures. Therefore, this report recommends further work to:

- collect more information on every HVAC unit with the spot measurement devices
- collect more detailed utility data through sub-metering units
- gain better understanding on the system such as location of thermostats, etc
- research further the claim that increasing air tightness and weather forecasting are effective energy conservation measures.

Establishing the validity of this claim could impact the energy use of SGH's office headquarters in Waltham.

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1. Introduction

Engineers, architects, and energy assessors use Building Energy Simulation (BES) in order to reproduce unobserved situations in a computerized model.[11] Energy models have the ability to both calculate and visually represent energy consumption in buildings, and provide valuable data in many phases of a building's life, from design to operation. For existing buildings, engineers can use BES to determine Energy Conservation Measures (ECMs).[12] ECMs are methods that can lead to a reduction in energy consumption, and thus energy cost savings. Engineers use BES during the design phase of new building construction to study the potential energy consumption of a building. Determining energy usage of a building before it is constructed can alert engineers of ECMs while it is easier to adjust the design. Considering the energy consumption of existing buildings is also important, as implementing an energy reduction strategy can not only reduce costs but also benefit the environment.[13] In addition, BES is utilized as a tool for determining how well a building fits into the energy requirements of programs like LEED (Leaders in Energy and Environmental Design).[14] More and more programs like LEED are pushing for reduction in energy usage, giving a lot of weight (points) to energy aspects of building design and operation.

BES, however, is not used to its fullest capacity because of two main complications: modeling and calibration.[15] Garbage in, garbage out, otherwise referred to as GIGO, is the

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[11] Daniel Coakley, Paul Raftery, and Marcus Keane. "A review of methods to match building energy simulation models to measured data." *Renewable and Sustainable Energy Reviews* 37 (2014): 123-141.
[12] Paul Raftery, Marcus Keane, and James O'Donnell. "Calibrating whole building energy models: An evidence-based methodology." *Energy and Buildings* 43, no. 9 (2011): 2356-2364.
[13] Daniel Daly, Paul Cooper, and Zhenjun Ma. "Understanding the risks and uncertainties introduced by common assumptions in energy simulations for Australian commercial buildings." *Energy and Buildings* 75 (2014): 382-393.
[14] Energy and Atmosphere credit, LEED v4
[15] Coakley, Raftery, and Keane.

concept that if the user inputs incorrect data, the output will be incorrect too. While it seems simple enough to fix, the trouble with energy simulation software is that sometimes not all of the data is available. This is often the case with existing buildings seeking an energy analysis. If the owner wishes to model and simulate the current system and a proposed retrofitted system to determine potential cost savings, the modeller may run into some trouble. For example, simulating older mechanical equipment is often difficult, and some of the existing conditions might be unknown (especially if opening up a wall is not an option) or the plans are no longer available for the building. Other issues arise with the location of the building, such as limited availability of weather data files.[16] When data is available, the weather stations are often located at more remote airports that might not be the best representation of the building's site.

Beyond simulation complications, calibration brings a whole new set of uncertainties that makes accurate prediction of a building's energy consumption difficult even though physical characteristics and operation data may be available.[17] Calibration is the measure of model accuracy.[18] Engineers can calibrate BES models by following the methods outlined in ASHRAE Guideline 14.[19] This paper considers the Whole Building Calibrated Simulation approach as described in ASHRAE Guideline 14.

[16] Yun Kyu Yi and Ning Feng, "Dynamic integration between building energy simulation (BES) and computation fluid dynamics (CFD) simulation for building exterior surface," (School of Design, University of Pennsylvania) 20 January 2013.
[17] Daniel Daly, Paul Cooper, and Zhenjun Ma. "Understanding the risks and uncertainties introduced by common assumptions in energy simulations for Australian commercial buildings." *Energy and Buildings* 75 (2014): 382-393.
[18] Mohammad Royapoor and Tony Roskilly. "Building model calibration using energy and environmental data." *Energy and Buildings* 94 (2015): 109-120.
[19] Coakley, Raftery, and Keane.

1.1 SGH Case Study

Figure 1.1: SGH Office, Waltham, MA

The Simpson, Gumpertz, and Heger (SGH) Office Headquarters is located in Waltham, MA. Previously used as a Raytheon Complex, the owner converted the building into an office space in 2002. The exterior brick envelope was updated with EIFS (exterior insulation and finish system). The existing office footprint (~90,000 sq. ft.) is the culmination of three projects: the initial office (2002) 48,000 sq. ft., a 15,000 sq. ft. expansion (2005) and a 27,000 sq. ft expansion (2012). The majority of the floor plan is single level, open office; however there are three mezzanine level spaces, as well as enclosed offices and conference rooms of varying sizes.

The official hours of operation are 8:00am to 5:00pm; however, employees arrive before and leave after these official times. The office is also conditioned and open to employees from 6:00am to 12:00pm on Saturdays. There are approximately 150 employees.

The building footprint is NE/SW. There is no glazing on the NE wall of the office as it abuts another office space. At the time of this study, the space on the other side of the wall was being renovated. We are unsure of the effect of the adjacent space and when it has (and has not) been conditioned. The SW wall is the entrance to the office space and features a fully-glazed entry-way. The remaining portion of the SW façade is brick with 3'x8' double glazed windows. Figure 1.2 shows an aerial view of the office and its orientation.

Figure 1.2: SGH Office Orientation, photo courtesy of Google Maps

There are 14 Air Handling Units (AHUs). Two of the AHUs service the seminar space in the third expansion zone. One is dedicated for the laboratory, and another for the main cafeteria area. The server rooms have separate mechanical equipment from the rest of the building.

1.2 Scope of Study

The main focus of this paper is a case study of the Simpson, Gumpertz, and Heger office headquarters in Waltham, MA. In addition to developing a simulated energy model of the building, we also reviewed relevant codes and standards, and recommended energy conservation measures to the tenant.

2. Background

In this chapter we discuss several topics related to building energy use, energy modeling, and relevant standards. A significant portion is dedicated to ASHRAE Guideline 14: Measurement of Energy and Demand Savings.

2.1 Building Energy Use

The United States, responsible for approximately 17-19% of the world's energy consumption, can track one-third of its energy use back to the building sector.[20] In Figure 2.1, the charts breaks down energy consumption by country, by United States zone, and by energy type used in the commercial and residential building zones. [21] The building sector, which included commercial and residential, takes up 41% of the total U.S. energy consumption. Due to such high consumption of energy by buildings, there is a high potential for energy savings in the building sector.

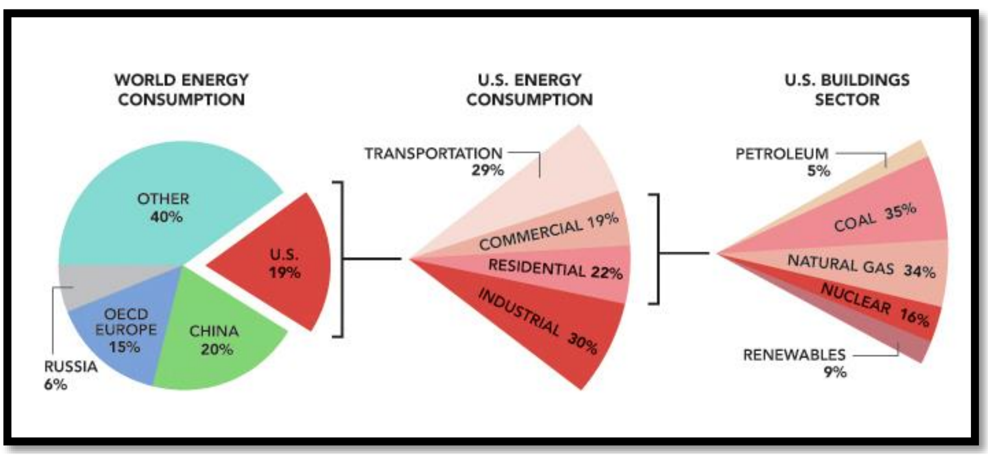

Figure 2.1: Energy Consumption Breakdown of 2010, DOE 2011 Buildings Energy Data Book

[20] "Transition to Sustainable Buildings: Strategies and Opportunities to 2050," International Energy Agency, p. 109. Retrieved from: https://www.iea.org/media/training/presentations/etw2014/publications/Sustainable_Buildings_2013.pdf
Note: IEA writes "roughly 17% of global final energy consumption" and the DOE considers 19%. IEA is a more recent publication.
[21] Figure 2.1: D&R International, Ltd., "2011 Buildings Energy Data Book," Building Technologies Program, Energy Efficiency and Renewable Energy, U.S Department of Energy, 2. Retrieved from: http://buildingsdatabook.eren.doe.gov/docs/DataBooks/2011_BEDB.pdf

According to data provided by the Department of Energy, the highest site energy consumption for buildings in 2010 was space heating, followed by water heating, space cooling, and lighting.[22] The energy use in those sectors adds up to 68% of the total building site energy consumption as can be seen in the pie chart distribution in Figure 2.2. Because of this distribution, energy consumption reduction strategies focused on those sectors could have the largest influence.

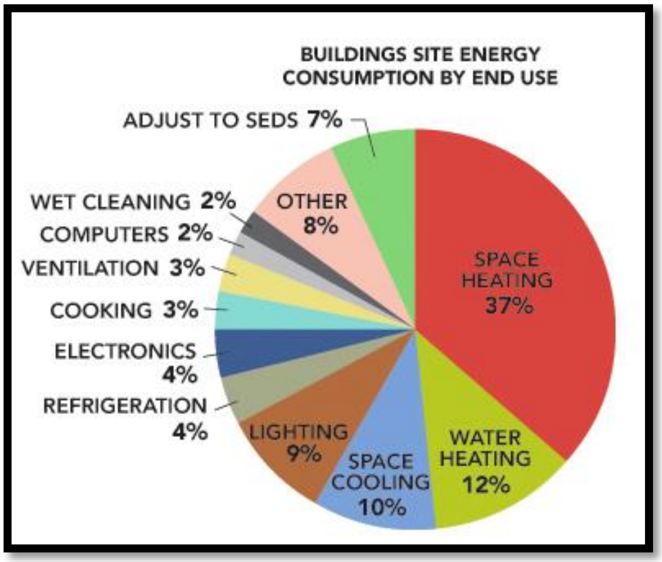

Figure 2.2: Building Site Energy Consumption by End Use in 2010, DOE 2011 Buildings Energy Data Book

The International Energy Agency (IEA) reiterates the importance of energy savings in the heating, cooling, and lighting sectors.[23] In its publication "Transition to Sustainable Buildings: Strategies and Opportunities to 2050," the IEA writes that "Improvements in electrical end-use efficiencies, space heating equipment and building envelopes are expected to contribute a major portion of energy savings…."[24] Figure 2.3, taken from the "Transition to Sustainable Buildings" report, shows the energy savings potential in the residential and services building sector from

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[22] Book, Buildings Energy Data. "Energy Efficiency and Renewable Energy." *US Department of Energy* (2011).
[23] "Transition to Sustainable Buildings: Strategies and Opportunities to 2050," International Energy Agency, p. 111. Retrieved from:
https://www.iea.org/media/training/presentations/etw2014/publications/Sustainable_Buildings_2013.pdf
[24] "Transition to Sustainable Buildings: Strategies and Opportunities to 2050," IEA, p. 111

2010 to 2050. The residential graph displays that space heating, water heating, as well as building envelope, which is directly related to space heating, are predominant factors in energy savings. For services, appliance and other equipment, which include electrical end-uses, account for the greatest energy savings; however, space heating, building envelope, lighting, as well as water heating, play considerable role in energy savings.

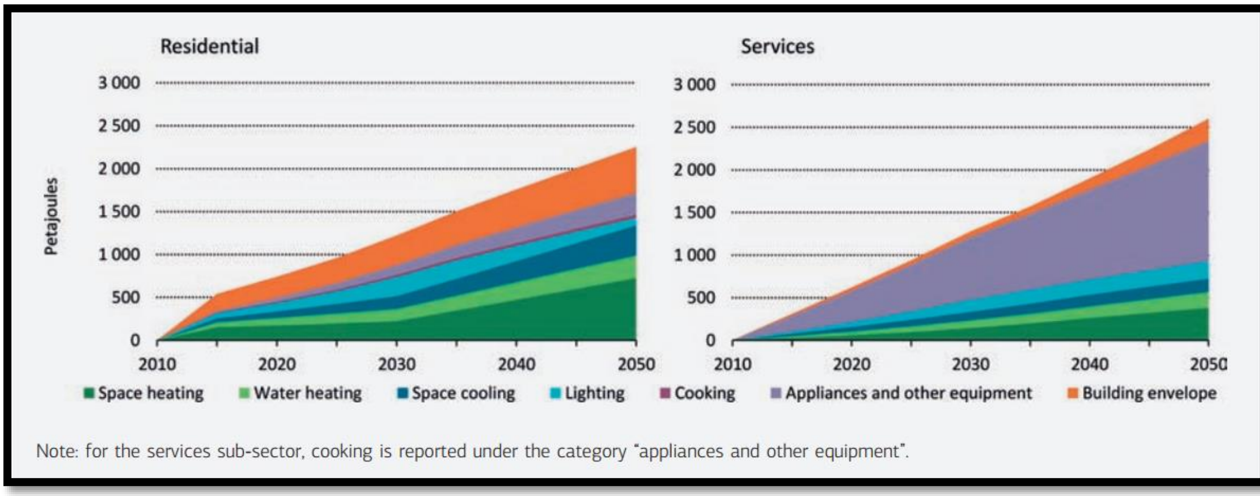

Figure 2.3: Energy Savings Potential in the Residential and Services Building Sector, International Energy Agency

2.2 Energy Modeling- pros/cons/uses

Building Energy Simulation (BES), while not a new tool for the building engineering industry, has seen many improvements in the past forty-plus years.[25] These changes can be attributed to developments in computer technology as well as the algorithms used in simulation.[26] This paper does not attempt to provide a history of, nor a thorough analysis of the types of simulation programs now available, but does acknowledge that the use of BES is

[25] Tamami Kusuda, "Early History and Future Prospects of Building System Simulation," IBPSA Conference Proceeding, 1999.

[26] Sukjoon Oh, "Origins of Analysis Methods in Energy Simulation Programs Used for Higher Performance Commericial Buildings," Thesis, Texas A&M University, August 2013.

becoming more common in the industry.[27] As such, we consider the benefits and disadvantages to the use of whole building energy simulation for determining the energy consumption of buildings. Particular focus is given to existing buildings, as this is most relevant to our case study of the Simpson, Gumpertz, and Heger (SGH) office headquarters in Waltham, MA.

Whole Building Energy Calibrated Simulation is one of three approaches outlined by ASHRAE Guideline 14 Measurement of Energy and Demand Savings.[28] The other two options include the Whole Building Approach and the Retrofit Isolation Approach. Each of these three methods have strengths and weaknesses, and should be selected on a case-by-case basis. It is up to the user to determine which one is most appropriate. The three approaches are summarized in Table 2.1 below:[29]

Table 2.1: Summary of ASHRAE Guideline 14 Approaches

Approach	Summary
Whole Building	One main meter measures the energy flow (electric, gas, thermal, or oil). Compare energy flow from pre- and post-retrofit situations, often through study of monthly utility bills or more accurate records.
Retrofit Isolation	Meters to isolate different subsystems affected by ECMs. Data recorded at minimum, once before and once after retrofit, although continuous/frequent monitoring is also a possibility. Measured energy savings can be assumed to be similar for other unmetered systems within the same facility as long as they share the same characteristics.
Whole Building Calibrated Simulation	A computer model of the building is simulated in software under pre-retrofit conditions and outputs are calibrated against actual measured data. Inputs are modified to simulate post-retrofit conditions and the two scenarios are compared.

[27] For commercial building example, see, Paul Raftery, Marcus Keane, and Andrea Costa, "Calibrating whole building energy models: detailed case study using hourly measured data," Energy and Buildings 43 (2011), 3666-3679.
For Industrial Hall example, see Bruno Lee, Marija Trcka, and Jan L. M. Hensen. 2014. Building energy simulation and optimization: A case study of industrial halls with varying process loads and occupancy patterns. Building Simulation 7 (3): 229-36.
For Residential example, see Mathieu Barbason, and Sigrid Reiter, "Coupling building energy simulation and computational fluid dynamics: Application to a two-storey house in a temperate climate." Building and Environment Volume 75, May 2014, P 30-39.

[28] ASHRAE Guideline 14-2002, page 10.

[29] ASHRAE Guideline 14-2002, page 10.

The benefits of the Whole Building Calibrated Simulation approach, and building energy simulation in general, stem primarily from the ability to test many parameters. With a calibrated energy model, the user can experiment with a variety of different retrofit scenarios, and determine potential cost savings before actual work has started. When a model is calibrated off of existing data, and thus simulated results match actual data, the model becomes much more valuable. Parametric studies can then be conducted: the effects of increasing insulation R-values, shading, air infiltration, and, for new construction additional parameters like building orientation.

While energy modeling provides a convenient means of energy use estimation, there are limitations that cause difficulty in simulation. There are three major types of limitations: dynamic, stocastic, and probabilistic.[30] Dynamic limitations relate to fabric properties and HVAC systems. Hygrothermal software, such as WUFI, provide more accurate data than programs like DesignBuilder which assume properties of building material as constants in their models. Stocastic limitations refer to occupant uses. Because many input parameters in DesignBuilder are based on occupancy, correct measurement of occupant use of the building is necessary. Lastly, probabilistic limitations such as accuracy of weather data cause difficulty in energy modeling. Unless a weather station is located on the project site, it is highly likely that the weather data from nearby weather station--usually located at the airport--would differ from weather on site.

With given limitations, there are chances that the initial modeling results created by energy simulation software will contain errors. There are two major types of errors: measurement error embedded in the actual data and modeling error due to the simulation process.[31] Measurement error, such as equipment performance, can be addressed by referring to equipment

[30] Mohammad Royapoor and Tony Roskilly, "Building model calibration using energy and environmental data."
[31] Royapoor, et. al. "Building model calibration."

manufacturer literature or conducting equipment calibration. Modeling error caused usually by inaccurate specification of building fabric and systems, over-simplification of reality, and imprecise parameterization can be addressed by more detailed modeling and calibration of the model.

2.2.1 Bin Calculation

The Bin Calculation method for energy consumption uses historical weather data. The method starts by selecting an exterior weather parameter and dividing it into discrete ranges, or bins, to sort the number of hours in a year that falls under the designated ranges. The parameter used for bin calculation is dry bulb temperature. After selection of a parameter, an average value of the parameter in each bin is calculated for energy calculations. To calculate loads of each bin, first, the energy use load for the bin should be specified. Then, the load should be multiplied by hours of occurrence of the bin to calculate total energy used for the bin. Lastly, the calculated loads should be summed to evaluate the total load.[32] Bin method allows prediction of energy use without the use of any software. However, since it only calculates HVAC consumption, it is not possible to evaluate whole building energy analysis with bin calculation.

2.2.2 COMcheck

COMcheck facilitates the compliance check of buildings with codes such as IECC or ASHRAE Standard 90.1. COMcheck currently provides code compliance in three sectors of the building: envelope, lighting, and mechanical. Only basic information such as basic building geometry, orientation, thermal properties of walls and windows, fixture information, are

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[32] Celeste Cizik, "Tips and Tricks for Estimating Energy Savings." Building Commissioning Association. Accessed February 29, 2016. http://www.bcxa.org/ncbc/2009/docs/Cizik_NCBC09.pdf.

necessary to conduct COMcheck.[33] Compared to complex building simulation, there are relatively less parameters to input, making the process much simpler and easier. Furthermore, COMcheck is freeware, making it available for many professionals in the building industry. However, due to over simplification, it is difficult to accurately predict complicated computational data such as detailed energy use or hourly temperature variance with COMcheck.

2.3 EnergyPlus and DesignBuilder

EnergyPlus is a building energy simulation software developed by the U.S. Department of Energy (DOE) in 2001.[34] The program provides the opportunity to simulate an entire building and all of its MEP (Mechanical, Electrical, and Plumbing) systems. This allows the user to determine the characteristics of a fully integrated building in all phases of construction. Through this software, realistic data can be extracted to perform accurate energy analysis and calculate realistic MEP loads.

EnergyPlus itself does not have a user-friendly interface. As such, there are a variety of different third-party software packages that use EnergyPlus as a platform and provide a graphical interface. For example, DesignBuilder, Simergy, AECOsim Energy Simulator, and many others.[35] These programs allow the user to follow a series of steps to model and input data about his building. The more data that the user can provide, the more accurate the results.

DesignBuilder is a user-friendly 3-dimensional, energy modeling software that runs on EnergyPlus.[36] Currently in its fourth version, DesignBuilder is useful for architects, engineers,

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[33] Rose Bartlett and Pam Cole. "COMcheck Basics," Energy Efficiency and Renewable Energy. Accessed March 2, 2016. http://www.neo.ne.gov/home_const/iecc/pdf/comcheckbasics.pdf.
[34] "EnergyPlus Energy Simulation Software," DOE, December 11, 2015. http://apps1.eere.energy.gov/buildings/energyplus/pdfs/energyplus_fs.pdf
[35] For a full list, please refer to: https://energyplus.net/interfaces
[36] "DesignBuilder – Simulation Made Easy," DesignBuilder. http://www.designbuilder.co.uk/content/view/43/64/

and energy assessors. Using EnergyPlus as its backbone, DesignBuilder makes visualization of energy an easier and more intuitive process.

The software has various capabilities, and is available in multiple forms depending on the end-user. DesignBuilder is useful at all phases of design, and as we plan to use it, for existing buildings. In addition to the 3-d modeling capacity, DesignBuilder has nine other modules: visualization, certification, simulation, daylighting, HVAC (Heating, Ventilation, Air Conditioning), cost, LEED, optimization, and CFD (Computational Fluid Dynamics).[37] Figure 2.4, as found on the DesignBuilder website, depicts the three user class types, and the modules available to each software package.

	Energy Assessor		Architectural		Engineering		
	Essentials	Plus	Essentials	Plus	Essentials	Plus	Pro
Modules:							
3-D Modeller	✓	✓	✓	✓	✓	✓	✓
Visualisation	✓	✓	✓	✓	✓	✓	✓
Certification	✓	✓					
Simulation		✓	✓	✓	✓	✓	✓
Daylighting		✓	✓	✓	✓	✓	✓
HVAC					✓	✓	✓
Cost				✓	✓	✓	✓
LEED					✓	✓	✓
Optimisation				✓		✓	✓
CFD							✓

Figure 2.4: DesignBuilder Capabilities by Version, DesignBuilder Website

[37] "DesignBuilder Software Product Overview," DesignBuilder. http://www.designbuilder.co.uk/content/view/144/223/

2.4 Standards

This paper considers several different standards, including ASHRAE 90.1, ASHRAE Standard 140, and ASHRAE Guideline 14.

2.4.1 Energy Efficiency

ASHRAE 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings, provides minimum requirements for energy-efficient design of buildings.[38] It describes the minimum energy requirements that need to be met by newly constructed buildings and the systems it is consisted of, as well as the newly installed systems in existing buildings. The standard also describes the criteria for compliance with the requirements in detail.

The standard provides both a prescriptive path and performance path for meeting the requirements, providing flexibility for its users. For the prescriptive path, the standard encompasses building envelope, HVAC, DHW, power, lighting, and other equipment with significant energy demand.[39] For performance path, a baseline Energy Cost Budget (ECB) is provided based on the building size and program. The ECB is determined from a baseline building, which meets prescriptive code requirements, with a similar scope as the project building. Then, the ECB is compared with the cost budget of the project building, modelled with building energy simulation.

2.4.2 Software Validation

The purpose of ASHRAE Standard 140: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs is to specify "test procedures for evaluating the

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[38] K. Gowri, M. A. Halverson, and E. E. Richman. "Analysis of Energy Saving Impacts of ASHRAE 90.1-2004 for the State of New York." *Richland, WA: Pacific Northwest National Laboratory* (2007).
[39] ASHRAE 90.1.

technical capabilities and ranges of applicability of computer programs that calculate the thermal performance of buildings and their HVAC systems."[40] The procedures are not all encompassing; however, they are useful for determining major flaws or limitations in the capabilities of the program. Standard 140 separates test cases into two Classes: I and II. Class I cases are more detailed programs with simulation time step capabilities of hourly or sub-hourly. Class II test cases can be used for all software packages and have no minimum time-step requirement.[41]

For this study, we will be using DesignBuilder, a software program that is validated by Standard 140 (2004 version).[42] It used the Class I test procedures. Standard 140 allows for programs in question to be compared against approved programs (whether it is a previous version or different program). DesignBuilder compares its newer versions against the version that went through the 140 procedure.[43]

2.4.3 Calibrated Models

ASHRAE developed Guideline 14, Measurement of Energy and Demand Savings to set a standard for "reliably measuring the energy and demand savings due to building energy management projects."[44] When determining energy savings because of an Energy Conservation Measure (ECM), the calculation is not as simple as baseline minus post-retrofit energy usage. Several other factors have an influence on energy usage, like occupancy and weather conditions.

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[40] ASHRAE Standard 140-2014: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs, page 7.
[41] ASHRAE Standard 140-2014, page 4.
[42] "ANSI/ASHRAE Standard 140-2004 Building Thermal Envelope and Fabric Load Tests," DesignBuilder, 2006. http://www.designbuilder.co.uk/documents/ANSI_ASHRAE.pdf
[43] "ANSI/ASHRAE Standard 140-2004 Building Thermal Envelope and Fabric Load Tests," DesignBuilder, 2006. http://www.designbuilder.co.uk/documents/ANSI_ASHRAE.pdf
[44] ASHRAE Guideline 14-2002, page 4

In order to account for this, Guideline 14 considers how to project the baseline case into the conditions of the post-retrofit scenario. With this in mind, ASHRAE gives the formula:

$$\frac{(Baseline\ energy\ use\ or\ demand\ projected\ to\ Post\ retrofit\ conditions) - (Post\ retrofit\ energy\ use\ or\ demand)}{Savings}$$ [45]

One of the difficulties with determining energy savings stems from variable factors like weather and occupancy. The relationship between variable factors and energy savings can never be definitively defined.[46] But users can reduce the amount of uncertainty. However, it is key to note that with greater certainty comes greater potential cost (time and effort), which might outweigh the returns. ASHRAE provides a method for calculating quantifiable uncertainties in Section 5.2.11 of Guideline 14-2002.

As previously discussed, there are three approaches outlined in ASHRAE Guideline 14: Whole Building, Retrofit Isolation, and Whole Building Calibrated Simulation. While all three of the approaches share some of the same requirements, there are also four unique compliance paths.[47] Of these, there are three "performance paths" that vary in the method of measuring actual energy use and demand and one "prescriptive path." The prescriptive path is intended for use with the whole building approach for situations under which the conditions require no uncertainty analysis.[48] Table 2.2, from ASHRAE Guideline 14-2002, gives the considerations for each of the compliance paths.[49]

[45] ASHRAE Guideline 14-2002, page 4.
[46] ASHRAE Guideline 14-2002, page 5.
[47] ASHRAE Guideline 14-2002, page 6.
[48] ASHRAE Guideline 14-2002, page 6.
[49] ASHRAE Guideline 14-2002, page 20.

Table 2.2: Considerations in Selecting a Compliance Path, ASHRAE Guideline 14-2002

TABLE 5-4
Considerations in Selecting a Compliance Path

	Considerations	Best Applications for Each Path			
		Whole Building		Retrofit Isolation	Whole Building Calibrated Simulation
		Prescriptive	Performance		
1	Ability to determine savings of individual ECMs	No	No	Yes*	Yes
2	Nature of possible future baseline adjustments	Minor but can be estimated adequately	Minor but can be estimated adequately	Complex, or effect on ECM performance is simple to estimate adequately	Many or complex
3	Impact of ECMs	Any component of the facility	Any component of the facility	No reduction of building envelope losses	Any component of the facility
4	Understanding by nontechnical personnel	Can be simple	Can be simple	Can be very simple	Difficult
5	Special skills of personnel			Metering systems	See Table 5-2
6	ECMs' interaction with the energy use of the rest of the facility	Can be complex	Can be complex	To be ignored or measured	Can be complex
7	Best length of post-retrofit period	Multiyear	At least one year	Representative periods	Maybe none

*. The cost of using the retrofit isolation path for multiple ECMs in the same facility should be compared to the cost of using the whole building or calibrated simulation paths.

The general approach of Guideline 14 for all three options is summarized in Section 3.5.3 Minimum Requirements for Compliance with this Guideline. Figure 2.5, as found in ASHRAE Guideline 14, describes the general approach and is shown below for the convenience of the reader.[50] In addition, it is important to note that Guideline 14 specifies that for each of three performance paths, "the level of uncertainty shall not be greater than 50% of the annual reported savings (at the 68% confidence level)."[51]

[50] ASHRAE Guideline 14-2002, page 7.
[51] ASHRAE Guideline 14-2002, page 7.

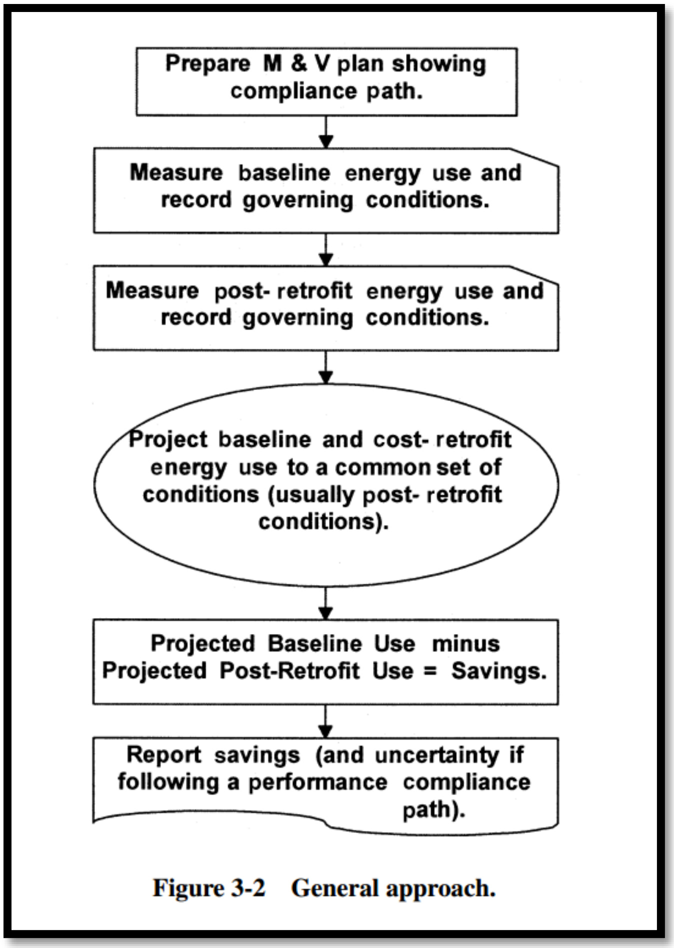

Figure 2.5: General Approach, ASHRAE Guideline 14

For the purpose of this research, we will be following the guidelines set forth for the Whole Building Calibrated Simulation approach. The following information however, summarized from Section 5: Requirements and Common Elements, can be applied to any three of the approaches. ASHRAE Guideline 14 defines weather as one of the most important independent variables to assessing energy use and demand.[52] Variables like temperature, humidity, and wind can all affect energy usage. Occupancy, infiltration, and schedules are other key factors. It is important to determine the variables that have the greatest influence on the

[52] ASHRAE Guideline 14-2002, page 10.

energy use and demand for the building being studied. Section 5.2.1 writes, "All reasonable variables should be tested, using such parameters as the "t-test" to determine which variables are substantive."[53]

Guideline 14 specifies that there are several factors that should go into determining the baseline period. The closer the baseline is to the retrofit, the less human error or bias from operating staff trying to remember the conditions.[54] In addition, the baseline period should be established as a designated interval of time, whether it is yearly, seasonal, monthly, etc. In most cases, more data is better. If the user has data for 13 months, they should only use 12 in order to avoid over representing a specific time period. Documenting the conditions of the baseline period is essential to determining energy savings. ASHRAE lists several items that should be documented, including but not limited to: occupancy pattern, density, schedule; spot measurements under known operating conditions; non-routine functions of the facility, dates, and impacts on operations; and equipment nameplate data.

The equipment being used to measure the energy use should also be considered as a source of error. That is, there is error inherent in the equipment, which may factor into the energy savings calculations.[55] Weather data, as previously mentioned, is another source of error. For this particular case-study, an onsite weather station is available. However, in instances where an on-site weather station is not an option, choosing data from the nearest site is next best, followed by a site with similar conditions although not nearby. It is recommended in Guideline 14 that on-site weather data be checked periodically against other data collected from a nearby station. In

[53] ASHRAE Guideline 14-2002, page 11.
[54] ASHRAE Guideline 14-2002, page 11.
[55] ASHRAE Guideline 14-2002, page 11.

addition, the weather station's location should not be altered during pre- and post-retrofit periods.[56]

When calculating energy savings, there should be a single set of conditions that both the baseline and retrofit cases are subject to. The Guideline lists three different sets of conditions:

1.) use the actual post-retrofit conditions,

2.) use a standard set of general or average conditions,

3.) use the baseline period conditions.[57]

Depending on which set of conditions is chosen, the calculation of energy savings will vary slightly. Guideline 14's method of analysis is mostly curtailed to follow with condition #1.[58] When adjustments to baseline conditions need to be made, they should be documented in order to keep track of uncertainty. Adjustments may be necessary in situations where changes other than ECMs result in different conditions between the baseline and post-retrofit scenarios.

When determining whether or not to use the Whole Building Calibrated Simulation approach, ASHRAE recommends considering a variety of criteria. Table 2.3, Criteria for Calibrated Simulations, summarizes when to use and when not to use the calibrated simulation technique.

[56] ASHRAE Guideline 14-2002, page 11.
[57] ASHRAE Guideline 14-2002, page 12.
[58] ASHRAE Guideline 14-2002, page 13.

Table 2.3: Criteria for Calibrated Simulation

When to use Calibrated Simulation	When to NOT use Calibrated Simulation
Either pre-retrofit or post-retrofit whole-building metered electrical data are not available.	Measures that can be analyzed without building simulation.
Savings cannot be easily determined using before-after measurements.	Buildings that cannot be readily simulated.
Measures interact with other building systems, and it is desired to account for those interactions, and retrofit isolation methods are not readily feasible.	HVAC systems that cannot be simulated.
Only whole-building energy use data are available but savings from individual retrofits are desired.	Retrofits that cannot be simulated.
Baseline adjustments needs.	Project resources are not sufficient to support calibrated simulation.
Future improvements	

ASHRAE Guideline 14-2002 requires that for Whole Building Calibrated Simulation, the user must "explicitly model at least the following:"[59]

Taken directly from ASHRAE:

- 8,760 hours per year
- Thermal mass effects
- Occupancy and operating schedules that can be separately defined for each day of the week and holidays
- Individual setpoints for thermal zones or HVAC components
- Actual weather data
- User-definable part-load performance curves for mechanical equipment
- User-definable capacity and efficiency correction curves for mechanical equipment operating at non-rated conditions.

The methodology for the Calibrated Simulation approach will be outlined in the next section of this report.

[59] ASHRAE Guideline 14-2002, page 18.

3. Problem Statement & Objective

This paper considered an energy analysis of an approximately 90,000 square foot office in Waltham, MA. The building is single-story, with office occupancy as its primary use; however, there is an active laboratory. Renovated from a Raytheon complex into an office space in 2002, SGH, the building tenant, contracted two additional renovations in 2005 and 2012 (15,000 and 28,000 square feet, respectively) to bring the office to its current size. The purpose of the project was to simulate and analyze the energy consumption of the office, and then propose possible energy conservation measures.

4. Scope of Study

In order to follow the steps outlined in ASHRAE Guideline 14, the first step for Whole Building Calibrated Simulation was to develop a plan. The following was the intended plan for this case study.

1. The Baseline Scenario

In order to determine the baseline scenario for the SGH office in Waltham, MA, we collected floor plans and utility data and conducted on-site surveys of the lighting systems, plug loads, HVAC systems, and building envelope. We surveyed the building occupants to assess perceived comfort level, actual occupancy schedules, and use of the space. To understand operation of the building, we interviewed the facilities operator. With all of this information, we developed an energy model and attempted to calibrate it to monthly measured data in DesignBuilder, Version 4.2.0.054.

2. The Retrofit Scenario

The proposed retrofit scenario was determined after conducting a parametric study on the baseline model. We investigated which parameters had the greatest influence on energy consumption in the building, and researched possible modifications in order to reduce energy use. Considering all of the data, we suggested energy conservation measures (ECMs) that will, in theory, reduce the energy consumption of the building. These ECMs involved modifications to the building itself and changes to the operation and management of the building.

3. Spot and Short-Term Measurements

We conducted spot and short-term measurements of the building to increase the accuracy of our data. These measurements included confirming the geometry of the building– floor plans as compared to as-built measurements– as well as temperature and humidity sensors for capturing data in varying locations across the office. We used HOBOware technology, specifically the UX100-011 series of data loggers and the UA-002 series. UX100 technology records temperature and relative humidity data and is stationary, while UA-002 is wearable technology that records temperature and light levels.[60]

[60] For UX100, see http://www.onsetcomp.com/products/data-loggers/ux100-011
For UA-002, see http://www.onsetcomp.com/products/data-loggers/ua-002-08

5. Data Collection and Relevant Analysis

We followed ASHRAE Guideline 14 Section 6.3.3.2 to collect necessary data for energy simulation. The section specifies to collect building plans, utility data, on-site surveys, occupant interviews, spot and short-term measurements, and weather data. On-site surveys include surveys of lighting systems, plug loads, HVAC systems, building envelope, and building occupants.

To conduct the case study, we first collected information about building geometry using building plans. Then we collected monthly utility data of the building. We compared the utility data with the weather data. We surveyed lighting, plug loads, HVAC, and envelope. Through occupant interviews, we surveyed building occupants. Finally, with data loggers, we collected spot and short-term measurements.

- Building geometry
- Monthly utility data and weather data
- On-site surveys
    - Lighting
    - Plug loads
    - HVAC
    - Envelope
- Occupant Interview
- Spot and short-term measurements

Though this section mainly focuses on the data collection to be used as simulation inputs, some analysis apart from simulation had to be conducted to validate the collected or measured data. To study the validity of the utility data, HDD analysis as well as utility vs. weather data analysis was conducted. To further this study, the spot and short-term measurement results were analyzed. These analyses not only facilitated the understanding of the building for simulation input purposes, but also expanded the understanding of building management and performances.

5.1 Building Geometry

We obtained the building plans of 41 Seyon St. Waltham, MA from the tenant (SGH). The documents consisted of three separate, incomplete plans of the building. A full set (Architectural, Structural, and MEP) were available, though not-to-scale, for the original office space (48,000 square feet), another set for the 15,000 square foot addition, and a final set for the second addition (27,000 square feet). CAD files were only available for the MEP drawings of the 27,000 square foot renovation. A complete drawing file of the entire office space as it existed in September 2015 was not available. It was our understanding that the drawings were lost in one of the three transfers of ownership of the building.

In order to confirm the accuracy of the drawings, we confirmed the geometry of the building using spot measurements (tape measurer and laser range finder). We considered using Bluebeam software to calibrate the CAD file to scale, however we determined that using actual measurements would be more accurate. The spot measurements included the dimensions and spacing of the fenestration, lengths and heights of interior massing, and ceiling heights throughout the space. We also photographed the exterior elements of the building to determine any significant shading or massing elements.

We found that the building is approximately 180 feet in width, and the office comprises roughly 484 feet in length. Looking northwest towards building's front entrance (southeast façade) in Figure 5.1, one can see that there are two distinct heights, excluding the minor slope of the roof. The central portion of the building with the clerestory window peaks at approximately 28 feet and the two sections on either side reach just over 19 feet, when measured from the interior foundation to the ceiling.

Figure 5.1: Southeast Façade of SGH Office Building

A cross section (Figure 5.2) of the building shows the height difference. There is an 88" height difference between the top of the side portion of the building and the bottom slope of the center portion's roof. This is where the clerestory windows span the length of the building. The clerestory windows are 55" high by 58" wide, with a 2" frame.

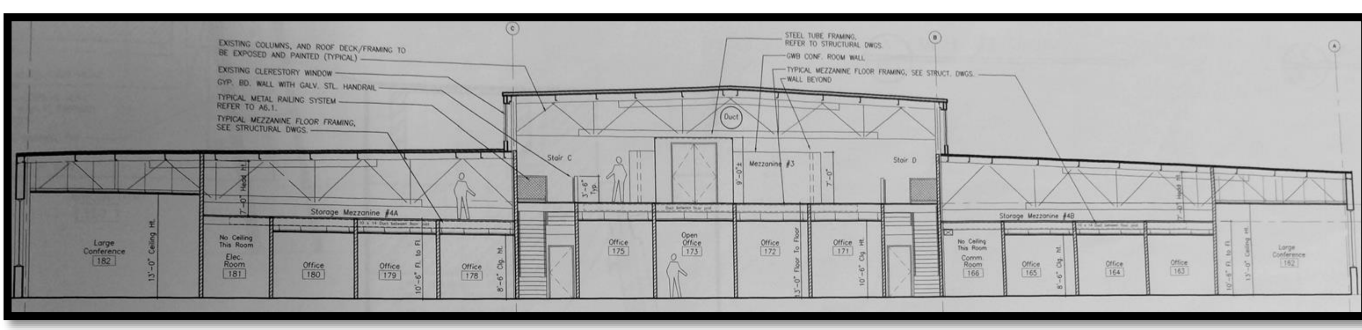

Figure 5.2: Cross Section of SGH Office

5.2 Monthly Utility Data/ Weather Data

In following section, collected monthly utility data (available in Appendix B) was compared to the weather data of Waltham. First, the HDD analysis was conducted to gain a general understanding of the validity of the utility data. Then, more in-depth analysis was conducted, comparing the utility data to weather per each month, to have a better understanding of the building's energy use.

We divided the office into several zones as shown in Figure 5.3. We reference these zones throughout the rest of the report.

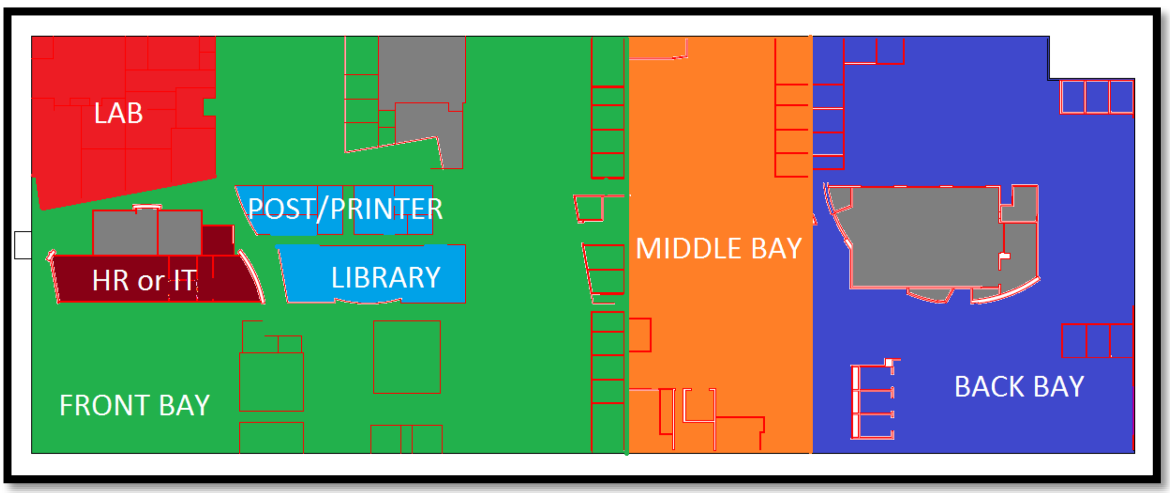

Figure 5.3: SGH Office Zones

5.2.1 HDD Analysis of Monthly Utility Data

Monthly utility data, provided by the SGH's facilities manager, was analyzed by heating degree days (HDD) method. The complete documentation of the monthly utility data starting from fall of 2002 is available in Appendix B.

First, energy use over time graph on a monthly basis was plotted (Figure 5.4). The graph revealed that the energy use does not have any relation to the weather. If the energy use correlated to the weather, it would show a sinusoidal pattern. However, the graphs plotted had no pattern to them. Generally, buildings in cold weather would have more energy consumption over the winter season that requires more heating. In SGH's building, energy consumption in Front Bay HVAC and other loads, as well as Back Bay revealed a more or less flat trend. While Middle Bay graph showed some variance, the cooling season's energy load is more prominent than the other seasons.

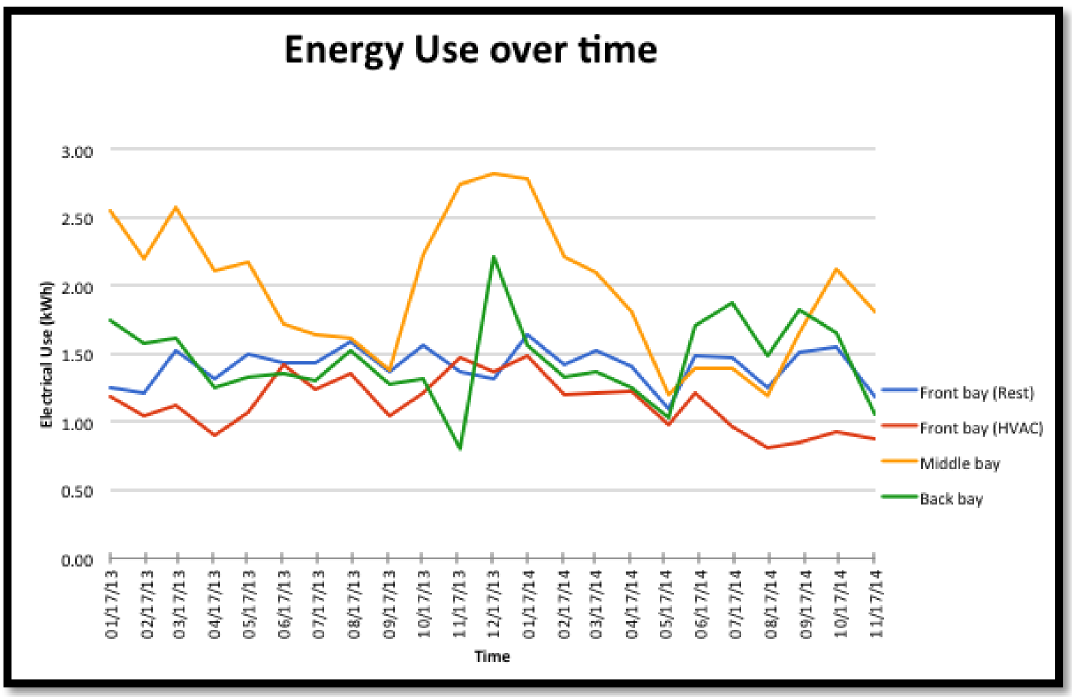

Figure 5.4: Energy Use Over 2013-2014 of Different Zones of the Building

As the result of the weather trend analysis was concerning, heating degree day analysis was conducted to gather more detailed information regarding the correlation of utility bill and weather. The weather data of the city of Waltham was gathered from the Weather Underground website.[61] After heating degree days for each monthly period were determined, energy use versus

[61] Weather Forecast & Reports - Long Range & Local | Wunderground | Weather Underground. Accessed March 02, 2016. https://www.wunderground.com/.

heating degree days graphs of various regions of SGH building were charted. In each of these graphs, the linear trend line was plotted and the linear equations in the form of y = ax+b were recorded. In these equations, "y" corresponds to the energy use, "x" corresponds to the heating degree days, the constant "a" is the gradient of the trend line, and the constant "b" represents the intersection point that represents the base load of the energy use.[62] Finally, R^2 value was determined for the graph, which measures how good the correlation is. In general, R^2 value ranging from 0.75-1 is considered acceptable.

With the above information, the Front Bay's HVAC electric use over heating degree days graph should have an intercept of 0kWh, as the sub-meter should have only recorded HVAC use and therefore have no base load (Figure 5.5). However, the Front Bay's HVAC graph has an intercept of 36,804 kWh, which shows that on the days that do not require heating, the electric use is unnecessarily high. Also, on all the graphs it can be observed that R^2 values are extremely low–with highest being below 0.4. This trend shows that the energy use does not correlate with the weather.

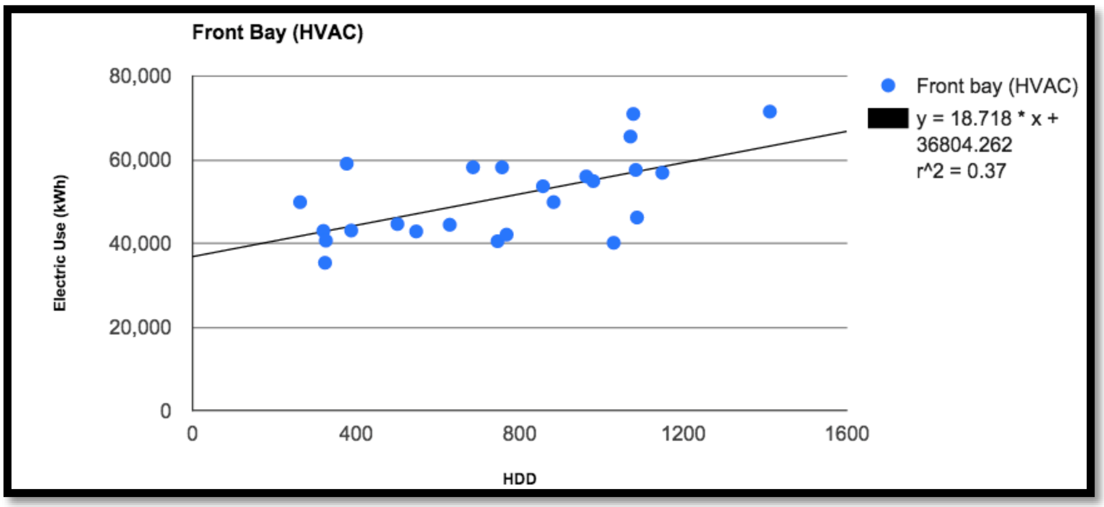

Figure 5.5: HDD Graph of the Front Bay (HVAC)

[62] "Linear Regression Analysis of Energy Consumption Data." BizEE. Accessed March 02, 2016. http://www.degreedays.net/regression-analysis.

For further understanding of the energy use, more HDD graphs of electric use per square foot were evaluated. For Middle and Back Bay, the intercepts would represent the base loads. Though Middle Bay graph showed some upward slope correlating to the weather, Back Bay graph showed a horizontal graph which showed that either the space is not heated properly during the winter, or the office used more energy for some other reason during warmer days. Overall, none of the graphs showed upward sloping trend lines that has reliable R^2 values. Furthermore, compared to Front Bay total –which would include sum of HVAC and HVAC exclusive– and Middle Bay energy use –which would be around 2.5 kWh –Back Bay's energy use was abnormally lower (refer to Figure 5.6).

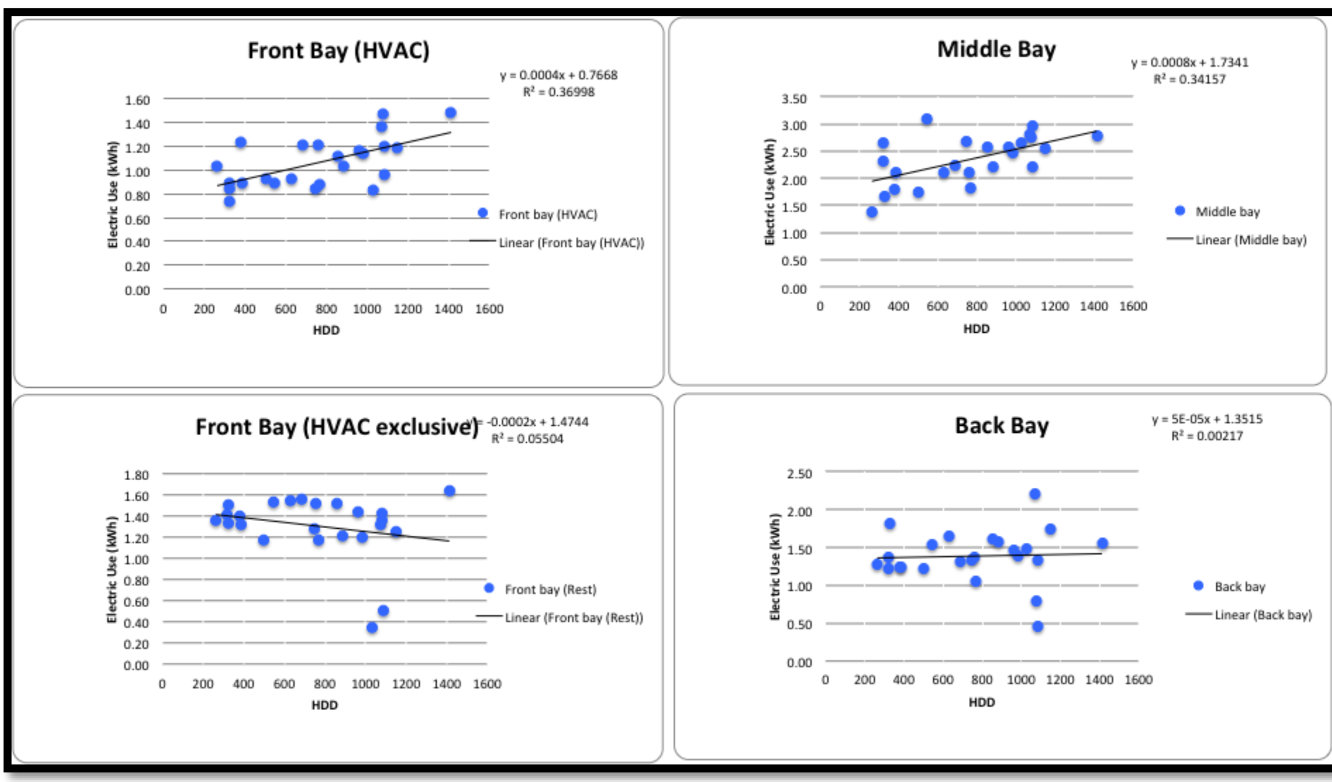

Figure 5.6: HDD of Electric Use per Square Foot of Various Zones

After talking to SGH representatives, it was noted that Front Bay has lab equipment that use significant amount of power. Though that might explain the lack of trend (upward slope) and correlation of R^2 value of Front Bay graphs, as HVAC of the Front Bay energy use is measured and analyzed separately, the lab equipment use does not explain the HVAC data's skewed results. As the Middle Bay and Back Bay are not metered separately, HDD analysis of HVAC data for those sections could not be obtained.

5.2.2 Utility Data vs. Weather Data Analysis

In order to develop a stronger understanding of SGH's energy use, we considered three years of recent utility data (2012, 2013, 2014). The office was operating at its full capacity, and its current square footage during these years. Table 5.1 details the energy use in kWh per month for each year. When this data was graphed (Figure 5.7), it was easy to see the variation in energy usage, not only by month, but by year as well. While some months experienced relatively correlated data (e.g. March, April, May and June for 2012/2013) other months showed drastic differences (e.g. January, November). To consider this data more closely, we recorded the average temperature weather data from a nearby station for each month in 2012, 2013, and 2014. Table 5.2 lists these values, and Figure 5.8 shows them visually. The largest temperature range for any particular month was March, with a range of 11.1°F, averaging 36.4°F (2014), 41.6°F (2013), and 47.5°F (2012). February had the next largest range at 6.8°F, then January and December, both with 5.6°F.

Table 5.1: 2012, 2013, 2014 SGH Monthly Utility Data (kWh)

Month	2012	2013	2014	Range
January	127,470	187,188	230,755	103,285
February	136,853	202,298	234,258	97,405
March	178,256	183,523	194,969	16,713
April	204,395	208,568	199,739	8,829
May	172,333	171,481	187,051	15,570
June	192,615	191,716	145,343	47,272
July	188,345	199,364	196,189	11,019
August	213,433	187,808	188,808	25,625
September	209,439	206,325	156,451	52,988
October	183,150	170,440	186,815	16,375
November	160,356	202,142	195,011	41,786
December	203,673	199,515	154,522	49,151

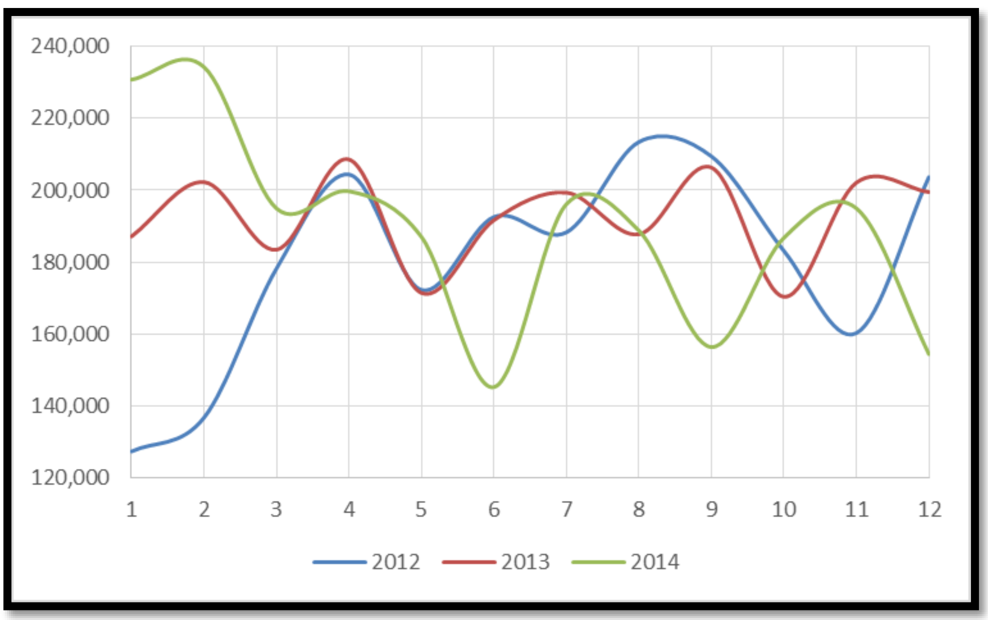

Figure 5.7: 2012, 2013, 2014 Monthly Utility Data (kWh)

Table 5.2: Average Monthly Weather Data near SGH Office (°F), WeatherUnderground (KMAWALTH6)

Weather Data	2012	2013	2014	Range
January	36.5	35.7	30.9	5.6
February	39	35.8	32.2	6.8
March	47.5	41.6	36.4	11.1
April	55	53.2	52.2	2.8
May	65	63.7	63	2
June	71.6	74.5	73.2	2.9
July	79.9	81	78.9	2.1
August	78.8	74.3	74.4	4.5
September	68.3	68.4	68.6	0.3
October	60.1	58.7	59.7	1.4
November	44.9	44.4	45.8	1.4
December	41.6	36	41.1	5.6

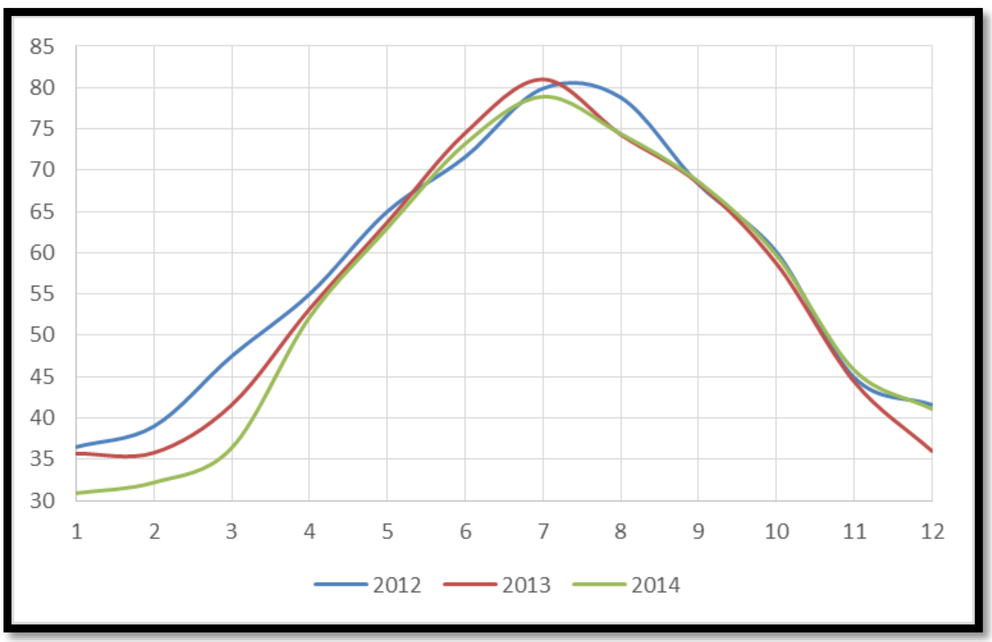

Figure 5.8: Average Monthly Weather Data near SGH Office (°F), WeatherUnderground

Taking a closer look at the month of January, consider the years 2013 and 2014, when the building was certainly operating at full capacity. The average temperature in 2013 was 35.7°F and in 2014, 30.9°. So, as 2014 was on average colder, its energy consumption should be higher- which it was: 230,755 (2014) versus 187,188 (2013) for a difference of roughly 43,500 kWh. But consider June, in 2013 the office used 191,716 kWh of energy, and in 2014, 145,343 kWh, for a difference of approximately 46,400 kWh. The difference in average temperature: 1.3°F. As heating is the largest part of the energy bill each year, there should not be such a discrepancy in June. June 2012 and 2013 energy consumption was within a 1,000 kWh of each other. But 2014 was well below both of these. September was another month in which the variation in energy consumption wass noteworthy. Weather should not be considered a factor, as the average temperatures were 68.3°F, 68.4°F, and 68.6°F for 2012, 2013, and 2014 respectively. The range in energy consumption: ~53,000 kWh.

With these discrepancies in mind, we found that calibrating our energy model to the utility data was an impossible task.

5.3 On-Site Surveys

On-site surveys of the building's lighting system, plug loads, HVAC system, and envelope were conducted to collect necessary data for building simulation according to ASHRAE Guideline 14.

5.3.1 Lighting

In order to survey the lighting system, we conducted a review of the electrical drawings. As previously mentioned, there was not a complete set of as-built drawings available for the office. Because of this, the main item that we took from the drawings was the fixture types and nameplate data. Fixture counts were performed on site and cross checked with the drawings for accuracy. We used the data that we collected through the RH/light sensors to determine the typical lighting schedule for the building. This was achieved because the individuals in possession of the sensors would leave them at their desk and the amount of light intake would decline significantly after office hours. In addition to surveying of the system, we interviewed building manager, who gave us the operation schedule.

There are two sets of schedules for the lights: the fluorescent 4' fixtures turn on at 8AM and off at 7PM; the aisle and track lights turn on at 10AM and off at 7PM. The lights are off on weekends and holidays although employees can control at the switch or via office phone. Also, there are several fluorescent 4' fixtures that are on 24/7 as night-lights per code.

5.3.2 Plug Loads

Because the building is operated as an office, it has a considerable amount of plug loads from typical office equipment such as computers, copying machine, and plotters. As the energy consumption of plug loads can be significant, accurate estimation of energy consumption by this equipment was essential. Furthermore, they also contribute heat to the space, which needs to be accounted for modeling of heating and cooling loads.

In order to account for the plug loads, we received a list of the quantity and load of large office equipment. We then took an estimation of the “load” of each employee, taken as having a desktop computer and modem. The large plug loads are listed in Table 5.3: SGH Plug Loads.

Table 5.3: SGH Plug Loads

Equipment	Consumption	# of Machines
Canon 4245	Max-1,500W	2
	Sleep- 0.9W	
Canon 5045	Max-1,800W	3
	Sleep-1W	
Canon 5051	Max-1,800W	3
	Sleep-1W	
Plotwave 500	Max-1.5kW	1
	Sleep-1W	
Xerox C70	Max-1,052W	1
	Sleep-3W	
VarioPrint 110	Max-2,000W	1
	Sleep-3W	
Canon 3035	Max-1.35kW	1
	Sleep-1W	
Canon 3045	Max-1.35kW	1
	Sleep-1W	
Canon 3380	Max-1,800W	3
	Sleep-1W	
HP 4345	Max-790W	2
	Sleep-15W	
OCE Plotter 700	Max-775W	2
	Sleep-25W	
Canon 3245	Max-1.41kW	2
	Sleep-1W	
Canon 5240	Max-1.5kW	1
	Sleep-0.8W	

5.3.3 HVAC

We observed the HVAC system over the course of multiple visits. In order to obtain the nameplate data for the rooftop packaged units, we went on top of the roof and systematically recorded the relative location and corresponding nameplate data for each of air handling units. There are a total of 14 rooftop air handling unit packages that condition the office building. All the units are a part of variable air volume HVAC system. Facilities staff informed us that four of the fourteen larger units were designated for certain areas of the building: the lab, the cafeteria, and one for each of the two seminar rooms in the final expansion. Figure 5.9 shows the relative location of the rooftop units as compared with the office floor plan. The units written in blue are smaller units. SGH RTU-14 is dedicated for the lab space, SGH RTU-1 is for the cafeteria, and SGH RTU-7 and 9 are dedicated to the seminar spaces. We have included the nameplate data in APPENDIX D.

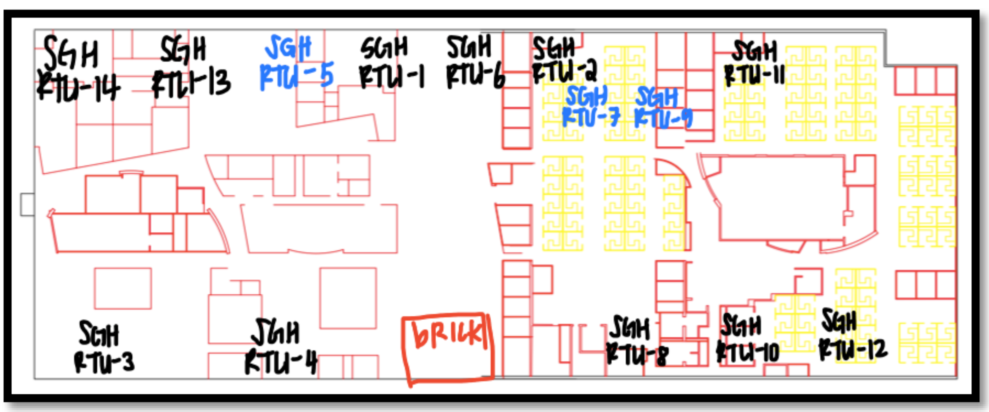

Figure 5.9: Relative Location of Rooftop Packaged Units

We used a combination of data from the HOBOware sensor and facilities staff knowledge to determine the schedule for the mechanical equipment. By placing the data sensor beneath an air supply outlet, we determined when the HVAC system was in use, what the setback air temperature was, and what the normal ambient temperature was for the building. Table 5.4 summarizes the HVAC schedule for the SGH office.

Table 5.4: HVAC Schedule

Schedule	Time	Cooling Setpoint	Heating Setpoint
Monday to Friday	6:30-19:00	74°F	70°F
Saturday	7:00-12:00	74°F	70°F
Sunday/Unoccupied	-	82°F	63°F

5.3.3.1 Construction Specification and Name Plate Data of Air Handling Units

As well as collecting nameplate data from rooftop and consulting with facilities manager, we found construction documents for the mechanical system. As the mechanical system was designed over three phases due to building expansion, the mechanical drawings were difficult to piece together. Figure 5.10 is an excerpt from the mechanical drawings for the office. Furthermore, only ten units out of fourteen main units were identified in the drawings. Due to the discrepancies between nameplate data and the construction drawings, the analysis and simulation were based on the nameplate data and not the construction drawings.

PACKAGED ROOFTOP DX AIR HANDLING UNIT

UNIT NO.	SERVICE	LOCATION	EVAPORATOR FAN										HEATING (GAS)			ELECTRICAL DATA					OPER. WT. (LBS.)	MANUFACTURER & MODEL #
			TOTAL CFM	MIN. O.A.	AMB °F	ENT °Fdb	ENT °Fwb	TOTAL CLG. (MBH)	TOTAL SENS. (MBH)	DRIVE TYPE	RPM	MOTOR H.P.	TOTAL CFH (INPUT)	TOTAL MBH (OUTPUT)	NO.OF CONTROL STEPS	VOLTS	PHASE	HZ	MCA	MOCP		
HVAC-1	OFFICE	ROOF	16,000	3200	95	80	67	462.0	342.0	BELT	1200	20	400.0	328.0	2	480	3	60	115.2	125	6500	CARRIER 48EKD044
HVAC-2	OFFICE	ROOF	16,000	3200	95	80	67	462.0	342.0	BELT	1200	20	400.0	328.0	2	480	3	60	115.2	125	6500	CARRIER 48EKD044
HVAC-3	OFFICE	ROOF	16,000	3200	95	80	67	462.0	342.0	BELT	1200	20	400.0	328.0	2	480	3	60	115.2	125	6500	CARRIER 48EKD044
HVAC-4	OFFICE	ROOF	16,000	3200	95	80	67	462.0	342.0	BELT	1200	20	400.0	328.0	2	480	3	60	115.2	125	6500	CARRIER 48EKD044
HVAC-5	LAB	ROOF	10,000	2000	95	80	67	291.0	222.0	BELT	1283	10	275.0	223.0	2	480	3	60	68.0	80	2500	CARRIER 48TJD028
HVAC-6	CAFE/ TRAINING	ROOF	3960	800	95	80	67	118.9	89.8	BELT	1085	3	180.0	144.0	2	480	3	60	22.6	25	1300	CARRIER 48TJD012

Figure 5.10: A Section of Construction Specification of the HVAC Units, SGH Mechanical Plans

5.3.3.2 Packaged Air Handling Units

An Air Handling Unit (AHU) serves as the center point of the air-conditioning system that distributes the conditioned air to various parts of the building through the ventilation ductwork.\ While air-handling units come in various types and sizes, the ones being used in SGH office building are packaged air handling units. Packaged air handling units serve as all-in-one solution to conditioning of the building; it serves for both heating and cooling. The air-handling unit is housed within a framing casing and insulated panels. Within the casing, it has filtration section, heat transfer component and fan.[63] These units are assembled by the manufacturer off-site and installed as a single unit.[64] The AHU units at the SGH are variable air volume units. Figure 5.11 is a picture of one of the units on SGH's roof. Variable air volume (VAV) is a type of HVAC system that supplies airflow at a variable temperature. VAV conditions air by both controlling ventilation and temperature. Compared to constant air volume units (CAV) that supplies airflow at constant temperature, VAV is known to be more energy efficient. By allowing the supply of airflow to have varying temperature, it enables zone-specific supply of air, and thereby increasing energy savings as well as user comfort. This flexibility also enables to respond quickly to changing load conditions.

Figure 5.11: Packaged Rooftop Air Handling Unit on SGH Roof

[63] "Air Handling Unit - Definition and Configuration Types - AHUmagazine." AHUmagazine. February 12, 2015. Accessed March 02, 2016. http://www.ahumagazine.com/air-handling-unit-definition-and-configuration-types/.
[64] Air Conditioning Principles and Systems: An Energy Approach. 4th Edition. Edward G. Pita, p. 7

5.3.3.3 SEER/EER and COP values from IECC

To measure the energy efficiency of the HVAC units, we found the energy efficiency ratio (EER) and seasonal energy efficiency ratio (SEER). With the found values, we calculated Coefficient of Performance (CoP) values to be used in energy simulation.

While heating CoP values were readily available from the nameplates of the units, the efficiency for cooling was not. EER value is defined as net capacity divided by power input.[65] While the net capacity of the units were listed on the nameplates, as the power input for the units were not individually sub-metered, EER values could not be calculated. As the manufacturer, Carrier, did not provide detailed data on the outdated models,[66] SEER values from IECC code were used in the DesignBuilder model. Based on the size, category and year of purchase, SEER values were retrieved from IECC codes from 2000, 2003 and 2009.[67] From the SEER values, CoP values were calculated by dividing SEER by 3.41, conversion factor from BTUH to kW, as summarized in Table 5.5. For energy simulation, COP per zone was calculated by taking weighted average of the corresponding units (Table 5.6).

[65] "HVAC Efficiency Definitions." US Air Conditioning. Accessed March 2, 2016. http://www.usair-eng.com/pdfs/efficiency-definitions.pdf.
[66] "Product Data." HVACpartners.com. Accessed March 2, 2016. http://dms.hvacpartners.com/docs/1005/Public/02/48_50A-5PD.pdf.
[67] "International Energy Conservation Code." International Code Council. Accessed March 02, 2016. http://publicecodes.cyberregs.com/icod/iecc/.

Table 5.5: Energy Efficiency Data of the SGH HVAC Units

SGH#	Model#	Year	Nominal Capacity (Tons)	Total net (MBH)	Thermal efficiency	Weighted Thermal efficiency	SEER values from IECC	CoP from SEER
1	48AKD040	2001	40	480000	0.81	32.4	8.5	2.49
2	48A3S020A1	2010	20	240000	0.81	16.2	9.5	2.78
3	48AKD040	2001	40	480000	0.81	32.4	8.5	2.49
4	48AKD040	2001	40	480000	0.81	32.4	8.5	2.49
5	48TFD012	2001	12	144000	0.8	9.6	8.5	2.49
6	48AKD025-P	2005	25	300000	0.81	20.25	9.5	2.78
7	48HCRB07A2A6A0F5CO	2011	6.25	75000	0.82	5.125	10.3	3.02
8	48AKD025-P	2005	25	300000	0.81	20.25	9.5	2.78
9	48HCRB07A2A6A0F5C0	2011	6.25	75000	0.82	5.125	10.3	3.02
10	48A3S020A1	2010	20	240000	0.81	16.2	9.5	2.78
11	48A3S020A1	2010	20	240000	0.81	16.2	9.5	2.78
12	48A3S020A1	2010	20	240000	0.81	16.2	9.5	2.78
13	48AKD040	2001	40	480000	0.81	32.4	8.5	2.49
14	48TMD028	2001	28	336000	0.81	22.68	8.5	2.49

Table 5.6: COP Values by Zone

	CoP
Zone 1: Front Bay	2.491
Zone 2: Kitchen	2.491
Zone 3: Middle Bay	2.784
Zone 4: Back Bay	2.784
Seminar Room	3.019

5.3.4 Envelope

SGH does not own the building nor has access to the plans that describe the building envelope. As such, we investigated the envelope through observation and made predictions based on the minimum code requirements at the time of renovation. The following pages describe five different parts of the building envelope. The five elements are EIFS walls, roof, floor, foundation, and window. Figure 5.12 depicts the location of these elements on a cross section of the building.

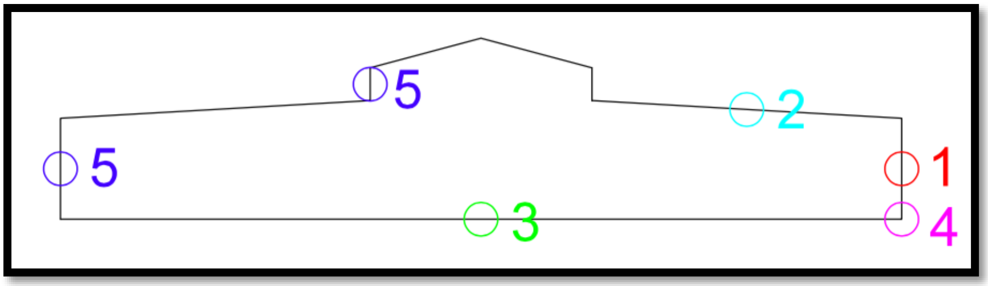

Figure 5.12: Different Elements of SGH Office Building Envelope

1.) EIFS Walls, 2.) Roof, 3.) Floor, 4.) Foundation, 5.) Windows/Clerestory

1. <u>EIFS Walls</u>

To determine the thickness of the walls with exterior insulation finish system (EIFS), we measured the width of the wall in a doorway. We found this thickness to be 18-1/8”. A hole in the interior portion of the wall (Figure 5.13) allowed us to determine that from the inside out, the wall was composed of 5/8” gypsum wall board, a plastic layer, 3” fiberbatt wool insulation, and then an air cavity of 1”. From the outside, we measured 4.5” of EIFS. In addition, we considered photographs taken during the original renovation of the building into an office space (Figure 5.14).

Figure 5.13: Hole in Interior Wall of SGH Office

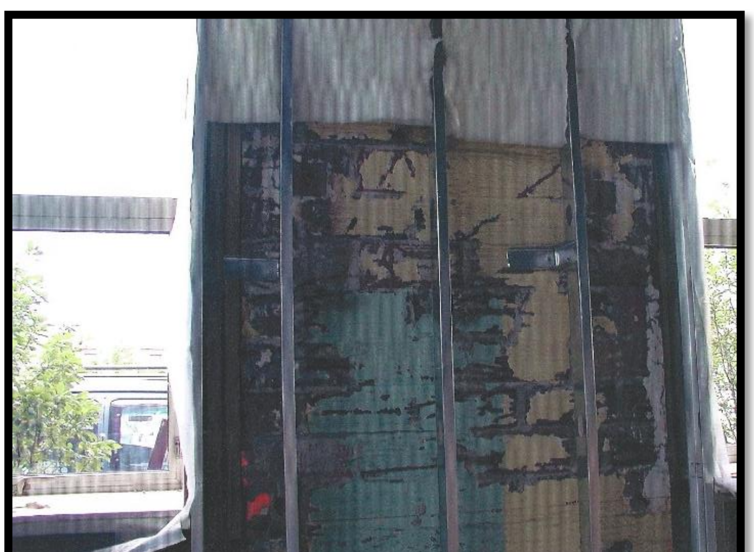

Figure 5.14: Photo from during original building renovation, SGH

Figure 5.15 shows a cross section of the wall. Using typical insulation values, we developed Table 5.7.[68,69,70]

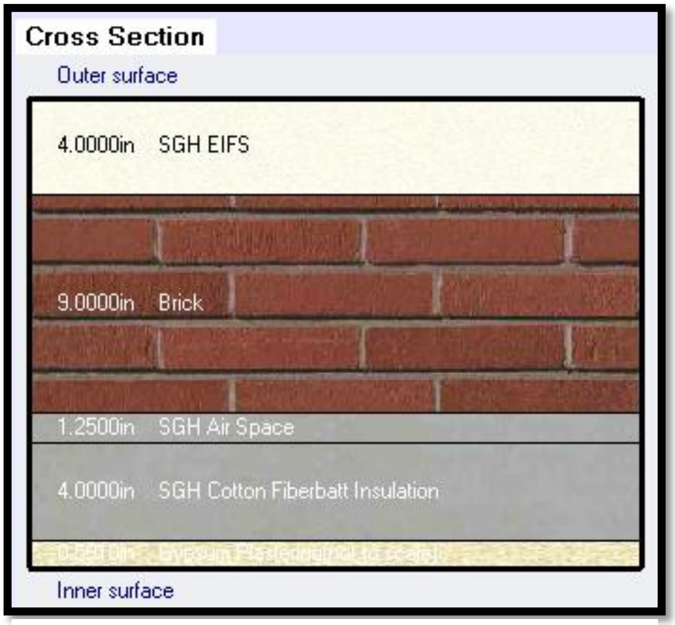

Figure 5.15: Wall Cross Section

Table 5.7: EIFS Wall Composition

Assembly	Thickness (in)	R-value range (per inch)	R-value
Exterior air film	N/A	N/A	0.17
EIFS	4.5"	3.8-4.4	18
Brick	9"	0.2	1.8
Air	1"	1	1
Insulation/studs	3"	6.6	19.8
Gypsum	5/8"	N/A	0.5625
Interior air film	N/A	N/A	0.68

68 "R-Value of EIFS." PAREXUSA. Accessed March 2, 2016. http://www.parex.com/tech-bulletins/common/TB004-R-VALUEOFEIFS.pdf.
69 "Exterior Insulation." Saturn Resource Management. 2011. Accessed March 02, 2016. http://blog.srmi.biz/energy-saving-tips/insulation-air-sealing/exterior-insulation/.
70 "R-values of Insulation and Other Building Materials - Archtoolbox.com." Archtoolbox.com. Accessed March 02, 2016. http://www.archtoolbox.com/materials-systems/thermal-moisture-protection/rvalues.html.

2. Roof

With the assistance of SGH, we confirmed the roof assembly to be as follows from inside to outside: Metal roof deck, 3" polyisocyanurate insulation[71], ½" wood fiberboard[72,73], and 60 mil EPDM membrane (Figure 5.16). Figure 5.17 shows a cross section of the roof build-up. Table 5.8 depicts the breakdown with typical insulation values.[74,75]

Figure 5.16: SGH Roof EPDM

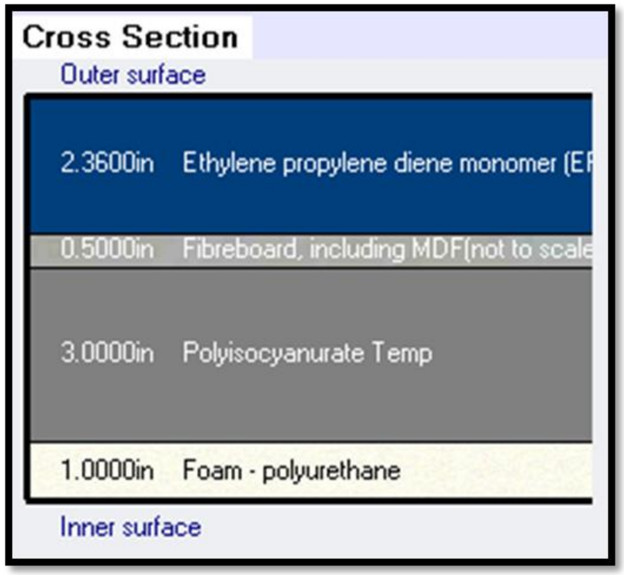

Figure 5.17: Roof Cross Section

Table 5.8: Roof Composition

Assembly	Thickness (in)	R-Wood value range (per inch)	R-value
Roof membrane- Carlisle	2.36"	N/A	N/A
Wood fiberboard	0.5"	0.62 per ½"	0.62
Insulation board	3"	6	18
Steel decking	N/A	N/A	N/A
Acoustical Insulation	1"	3-3.85	3.5

71 "Info-502: Temperature Dependence of R-values in Polyisocyanurate Roof Insulation." Building Science Corporation. April 12, 2013. Accessed March 02, 2016. http://buildingscience.com/documents/information-sheets/info-502-temperature-dependent-r-value.
72 Except on the clerestory roof for the office expansion beyond the Newmark room.
73 "R-values of Insulation and Other Building Materials - Archtoolbox.com." Archtoolbox.com. Accessed March 02, 2016. http://www.archtoolbox.com/materials-systems/thermal-moisture-protection/rvalues.html.
74 "Carlisle's Roofing Systems." Nvelop. Accessed March 2, 2016. http://www.carlislenvelop.com/pdfs/CarlisleRoofingsystem.pdf.
75 "Table of Insulation R-Values and Properties for Various Insulation Materials & Building Materials." InspectApedia. Accessed March 02, 2016. http://inspectapedia.com/insulation/Insulation_Values_Table.php.

3. <u>Floor</u>

When SGH first occupied the building, the original flooring was 6" concrete slab. SGH added an additional 4" of concrete slab, above the system of perforated piping used for dehumidification of the concrete slab. Parts of the office have carpeted floors and the rest have exposed concrete as the floor. As the exact mixture of the concrete is unknown, the insulating value of the floor is difficult to estimate.[76] The R-value was selected assuming both concrete slabs are normal-weight, non-insulating concrete. This information is summarized in Table 5.9.

Table 5.9: Floor Composition

Assembly	Thickness (in)	R-value range (per inch)	R-value
Concrete flooring	4"	0.065-0.11	0.26
Concrete slab	6"	0.065-0.11	0.39

4. <u>Foundation</u>

The foundation of the building is concrete footing foundation. Figure 5.18 shows the construction detail of the foundation system. As the insulation is discontinuous from the wall to the floor, the foundation is susceptible to thermal bridging.

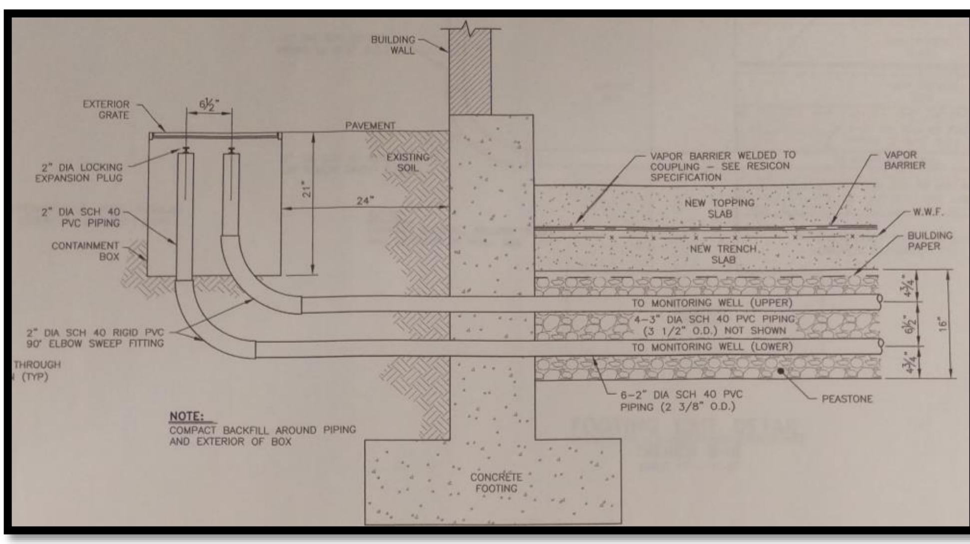

Figure 5.18: SGH Foundation from Plans

[76] "Structural Concrete." Norlite Lightweight Aggregate. Accessed March 02, 2016. http://www.norliteagg.com/structuralconcrete/insulation.asp.

5. Window

SGH’s office building’s walls are composed of approximately 47% glazing. The windows on the main level are taken to be 8225TL fixed windows by KAWNEER. The majority of these windows are about 3’ wide by 8’ tall, with the exception of a few. SGH modeled the window in THERM software. Table 5.10 summarizes the key information from the THERM simulation output. The clerestory windows have similar properties.

Table 5.10: SGH Window Information

Window	U-Factor	Solar Heat Gain Coefficient	Shading Coefficient
KAWNEER 8225TL	0.291	0.392	0.450

5.3.4.1 Minimum Code Requirements

To evaluate the building envelope's code compliancy, two different codes were used: Massachusetts Building Code and IECC. SGH's building was renovated circa 2002. This is before the state adopted other energy codes as part of its legislation. Therefore, we adopted the 6th Basic Code Edition of Massachusetts to investigate the thermal performances of unknown assemblies in this project.

Within the code, Chapter 34 applies to Repair, Alteration, Addition and Change of Use of Existing Structures. As the building was remodeled for office use, SGH's office would have had to comply with this chapter. 780 CMR3407.2, which is the compliance clause of energy provisions of existing buildings, redirect the readers to Chapter 13, which addresses Energy Conservation. Chapter 13 covers the thermal performance requirement in great detail. This information is charted in tabular format in Tables 1304 2.1 through 2.12 based on the climate zone and glazing area of the façade walls. Based on Table 1303.1, Waltham (Middlesex County) is considered as climate zone 13a. Therefore, based on the glazing area of the building itself, Table 1304.2.6, 7, or 8 will be used to estimate the thermal performance of the unknown assemblies.

The original masonry walls are finished on the inside with sheetrock supported by a metal frame. Assuming standard brick was used, approximately 17.7 bricks that weigh 4.5 lbs compose one square foot section of the wall.[77] Therefore, according to Table 1304.2.8, we need R-11 insulation on top of R-3 of continuous insulation. For windows, the structure has projection factor (PF) value of 0, calculated by dividing the distance measured horizontally from the extremity of any overhang to vertical surface of the glazing by the distance measured vertically

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[77] "Brick Dimension Guide." The Belden Brick Company. 2013. Accessed March 02, 2016. http://www.beldenbrick.com/brick-dimensions-guide.asp.

from the bottom of the glazing to the underside of the overhang, as there is no overhang or eave on the windows (Section 1304.2.3). Therefore, the windows require to have a solar heat gain coefficient (SHGC) value of 0.4 and U-value of 0.4. For the roof assembly, it is highly likely that it consists of metal purlins without thermal break, meaning that it needs R-30 insulation between framing and R-24 continuous insulation. Finally the floor is made out of concrete slabs and therefore requires R-17 continuous insulation. We included Table 1304.2.8: Building Envelope Requirements as Table 5.11 for the convenience of the reader.

Table 5.11: Building Envelope Requirements, Chapter 13, 6th Basic Code Edition of Massachusetts

TABLE 1304.2.8
BUILDING ENVELOPE REQUIREMENTS
Climate Zone 13a
Glazing Area Over 40% but not greater than 50% of Above Grade Wall Area

Above-Grade Walls:	Continuous Insulation (or average insulation value)*	Metal Framing (c.i. = continuous insulation)	Wood Framing
Framed or Masonry < 35 psf.	R-7	R-13 + R-3 c.i.	R-11
Masonry ≥ 35 psf.	R-5	R-11 + R-3 c.i.	R-11

Window Assemblies:	SHGC (maximum)	U-Value (maximum)
PF < 0.25	0.4	0.4
0.25 ≤ PF < 0.50	0.5	0.4
PF ≥ 0.50	0.7	0.4
Skylights - U-Value (maximum)	X	0.8

Roof Assemblies: (either/or)	Insulation Between Framing	Continuous Insulation
All-Wood Joist/Truss	R-30	R-23
Non-wood Joist/Truss	R-30	R-24
Concrete Slab or Deck	NA	R-23
Metal Purlin with Thermal Break	R-30	R-24
Metal Purlin w/o Thermal Break	R-38	R-24

Floor Assemblies: (either/or)	Insulation Between Framing	Continuous Insulation
All-Wood Joist/Truss	R-19	R-16
Non-wood Joist/Truss	R-25	R-17
Concrete Slab or Deck	NA	R-17
Slab, Perimeter, Below-Grade Wall	R-5	

The building's exterior wall composition has R-value of 19.8 in between the studs and continuous insulation of R-18, which surpass the code requirements. The window assemblies' SHGC value does not meet the code's requirement, by 0.006, which is an insignificant value. It has a much lower U value (0.291) than the code requirement of 0.4. The roof assembly only has R-18 of continuous insulation as to required R-24. Though the acoustical insulation adds to the total insulation value, it is not enough to make up for the difference. Finally, the floor assembly lacks the continuous insulation of R-17 and therefore also fails to meet the code requirement.

Regarding IECC 2006 and 2009 as the minimum code requirement for building envelope, Table 502.2(1) (in text, Table 5.12) was used to evaluate building envelope performance. Massachusetts falls under climate zone 5 according to IECC's classification. As the roof's continuous insulation is entirely above deck, R-20 would be required for both versions of IECC. The roof assembly has continuous board insulation of roughly 3" which provides R-18, which does not suffice the requirement or R-20 of continuous insulation. However, the discontinuous acoustical insulation attached at the interior side adds to the roof's insulation value. For walls, the office has a brick wall, which requires R-7.6 of continuous insulation for 2006 version and 9.5 for 2009 requirement. The EIFS installed on the façade has R-18, which meets the requirement. For slab-on-grade floor, there is no requirement for insulation.

Table 5.12: Building Envelope Requirements, IECC

TABLE 502.2(1) BUILDING ENVELOPE REQUIREMENTS – OPAQUE ASSEMBLIES

CLIMATE ZONE	1	2	3	4 except Marine	5 and Marine 4	6	7	8
Roofs								
Insulation entirely above deck	R-15 ci	R-15 ci	R-15 ci	R-15 ci	R-20 ci	R-20 ci	R-25 ci	R-25 ci
Metal buildings (with R-5 thermal blocks[a])[b]	R-19 + R-10	R-19	R-19	R-19	R-19	R-19	R-19 + R-10	R-19 + R-10
Attic and other	R-30	R-30	R-30	R-30	R-30	R-30	R-38	R-38
Walls, Above Grade								
Mass	NR	NR	R-5.7ci[c, e]	R-5.7ci[c]	R-7.6 ci	R-9.5 ci	R-11.4 ci	R-13.3 ci
Metal building[b]	R-13	R-13	R-13	R-13	R-13 + R-13	R-13 + R-13	R-13 + R-13	R-13 + R-13
Metal framed	R-13	R-13	R-13	R-13	R-13 + R-3.8 ci	R-13 + R-3.8 ci	R-13 + R-7.5 ci	R-13 + R-7.5 ci
Wood framed and other	R-13	R-13	R-13	R-13	R-13	R-13	R-13	R-13 + R-7.5 ci
Walls, Below Grade								
Below grade wall[d]	NR	NR	NR	NR	NR	NR	R-7.5 ci	R-7.5 ci
Floors								
Mass	NR	R-5 ci	R-5 ci	R-10 ci	R-10 ci	R-10 ci	R-15 ci	R-15 ci
Joist/Framing	NR	R-19	R-19	R-19	R-19	R-30	R-30	R-30
Slab-on-Grade Floors								
Unheated slabs	NR	NR	NR	NR	NR	NR	NR	R-10 for 24 in. below
Heated slabs	R-7.5 for 12 in. below	R-7.5 for 12 in. below	R-7.5 for 12 in. below	R-7.5 for 12 in. below	R-7.5 for 24 in. below	R-10 for 36 in. below	R-10 for 36 in. below	R-10 for 48 in. below
Opaque Doors								
Swinging	U – 0.70	U – 0.70	U – 0.70	U – 0.70	U – 0.70	U – 0.70	U – 0.70	U – 0.50
Roll-up or sliding	U – 1.45	U – 1.45	U – 1.45	U – 1.45	U – 1.45	U – 0.50	U – 0.50	U – 0.50

IECC provides a separate table for fenestration, Table 502.2 (in text, Table 5.13). For window assemblies, the U-factor of 0.35 is required for general windows without metal frames, 0.45 for curtain wall, 0.80 for entrance door and 0.55 for any other kind of assemblies. For the SHGC, with PF=0 due to no overhang or eaves, the building requires the SHGC of 0.4. These values apply for both IECC 2006 and 2009 versions. As with the MA building code requirement, SGH's window passes the U-value requirement but not the SHGC requirement.

Table 5.13: Building Envelope Requirements: Fenestration, IECC

TABLE 502.3 BUILDING ENVELOPE REQUIREMENTS: FENESTRATION

Climate Zone	1	2	3	4 except Marine	5 and Marine 4	6	7	8
Vertical Fenestration (40% maximum of above-grade wall)								
***U*-Factor**								
Framing materials other than metal with or without metal reinforcement or cladding								
U-Factor	1.20	0.75	0.65	0.40	0.35	0.35	0.35	0.35
Metal framing with or without thermal break								
Curtain Wall/Storefront *U*-Factor	1.20	0.70	0.60	0.50	0.45	0.45	0.45	0.45
Entrance Door *U*-Factor	1.20	1.10	0.90	0.85	0.80	0.80	0.80	0.80
All Other *U*-Factor[a]	1.20	0.75	0.65	0.55	0.55	0.55	0.50	0.50
SHGC-All Frame Types								
SHGC: PF < 0.25	0.25	0.25	0.25	0.40	0.40	0.40	NR	NR
SHGC: 0.25 ≤ PF < 0.5	0.33	0.33	0.33	NR	NR	NR	NR	NR
SHGC: PF ≥ 0.5	0.40	0.40	0.40	NR	NR	NR	NR	NR
Skylights (3% maximum)								
Glass								
U-Factor	1.60	1.05	0.90	0.60	0.60	0.60	0.60	0.60
SHGC	0.40	0.40	0.40	0.40	0.40	0.40	NR	NR
Plastic								
U-Factor	1.90	1.90	1.30	1.30	1.30	0.90	0.90	0.60
SHGC	0.35	0.35	0.35	0.62	0.62	0.62	NR	NR

5.4 Occupant Interview

To gain a better understanding of occupant use of the building, a user survey was conducted. The survey was divided into three major sections: user profile, HVAC comfort and lighting comfort evaluation. For the user profile, we collected user related information such as their location throughout work day, the type of office (open or closed ceiling), time they come in and out of the office, and activity level, etc. This information was used to better understand user behaviors and to create a schedule for typical office hours for the weekdays and weekends. Furthermore, with the participants' provided locations within the building, the comfort level of the occupants could be assessed at zone level. The HVAC comfort section of the survey collected user's comfort level in hot and cold weather, the time of day they feel the discomfort in, and the cause of the discomfort. With this information, the overall trend of the discomfort caused by HVAC was assessed. Finally, the lighting comfort section evaluated the user satisfaction of lighting level, visual comfort level as well as the cause of the discomfort.

5.4.1 User Profile

The survey received responses from about 80 people, which is about 45 percent of the occupants. Therefore, we received responses from a broad range of the occupants, which made it possible to assess the user comforts at each zone. Figure 5.19 shows the percentage of the occupants from varying zones of the building. As Front Bay has largest floor area, most of the participants were located in the Front Bay. We had considerable amount of participants from Middle Bay and Back Bay as those zones also have considerable amount of floor area. Finally we had some participants from IT, lab, HR office, and etc. As participants were from varying zones of the building, the HVAC discomfort at zone level could be analyzed precisely.

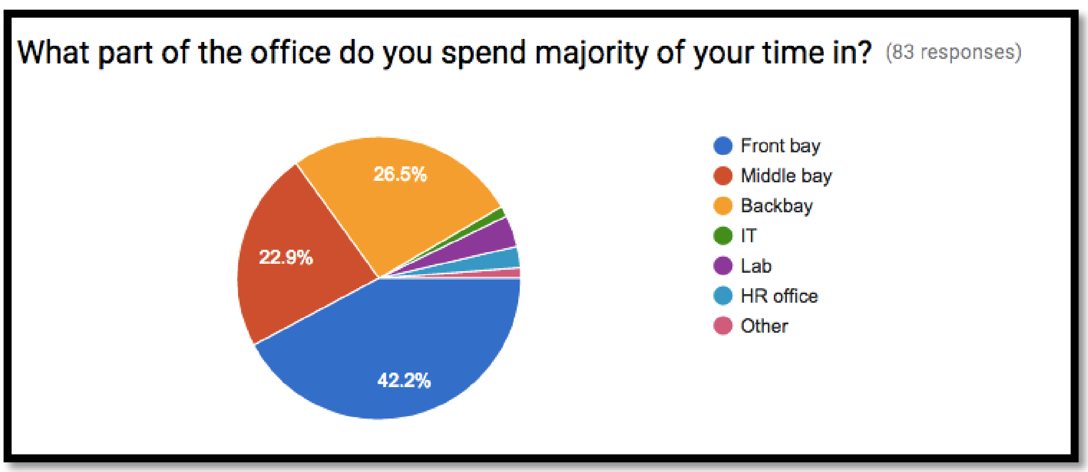

Figure 5.19: Percentage of Survey Participants by Zone

By analyzing SGH employees' arrival times and departure times, an occupant schedule was formulated (Figure 5.20) Most of the occupants would arrive by 8:30 AM and at the latest by 9:00 AM. Most of the occupants would start to leave around 5:00 PM and few occupants would stay until after 6:30 PM. The occupant schedule shown below was inputted into the DesignBuilder software by first setting overall occupancy with occupant per sq. ft. and then creating a schedule with percentage of occupants present per time span of 30 minutes.

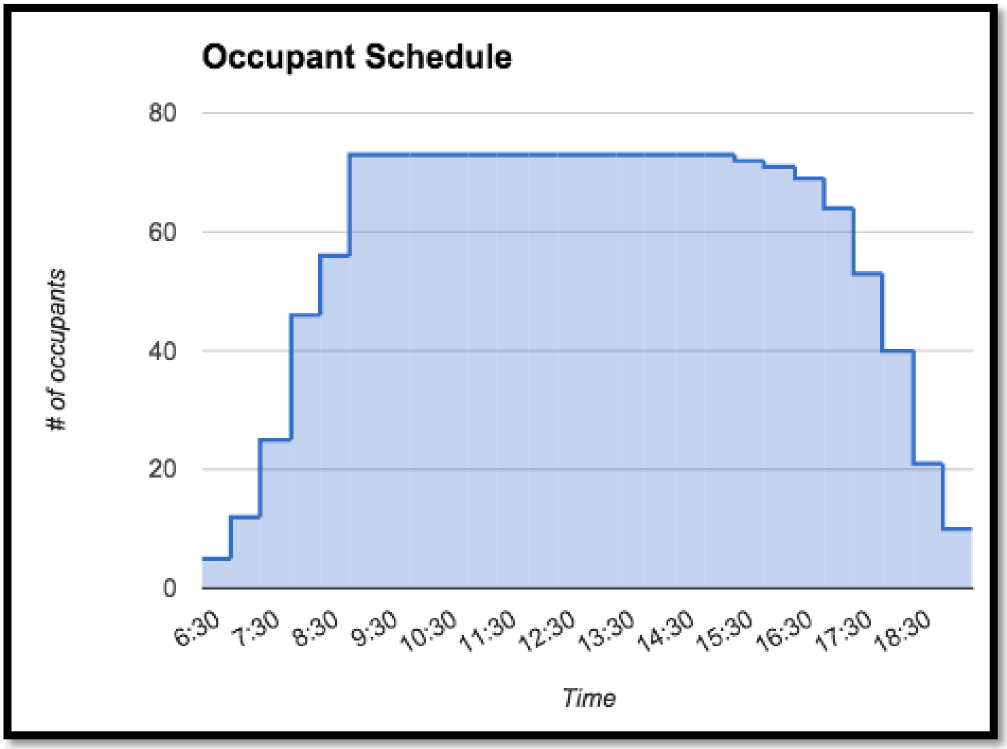

Figure 5.20: Occupant schedule of the users broken down into 15 minute interval

Finally, the activity levels of the occupants were evaluated with the survey. With 0 being very sedentary and 6 being very active, Figure 5.21 shows that a majority of the occupants are sedentary. As the sedentary occupants would have lower metabolism than active occupants, the building would have to be suitable for the majority occupants that does not generate heat by being active.[78]

[78]Weisenberger, Jill. "Understanding Calories." InnerBody. Accessed March 02, 2016. https://www.innerbody.com/nutrition/understanding-calories.

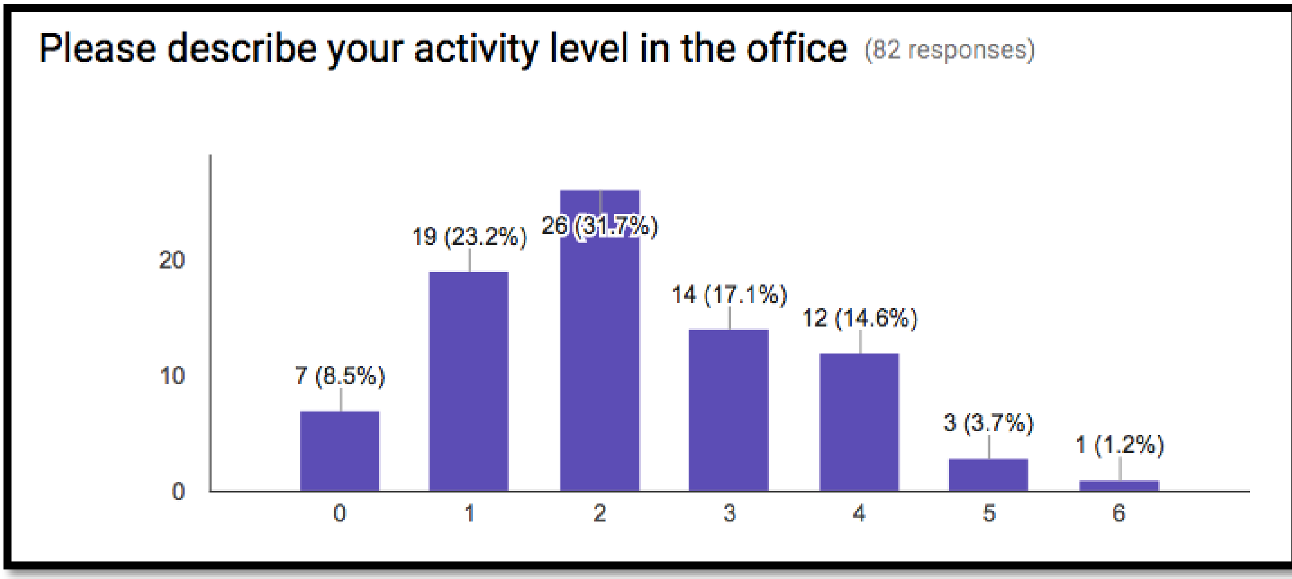

Figure 5.21: Activity Level of the Survey Participants

5.4.2 HVAC comfort

The HVAC comfort survey results showed that the occupants of the building were generally cold throughout the year. The results, broken down by zones, are shown in the graphs below. Though very few occupants expressed that they were hot in the building in hot weather, the majority of the occupants expressed that they were cold even in hot weather. While being cold in cold weather could be explained by not enough heating, the building too cold during hot weather raises concerns for HVAC management (Figure 5.23 and Figure 5.22). Furthermore, about 40 percent of the occupants expressed that they were always uncomfortable within the building and 30 percent expressed that they were uncomfortable in the morning, and the other 30% in the afternoon. The majority of the occupants that were expressing discomfort with the HVAC system said that either the vented air was too cold (56.2%), or the workspace is colder than the rest of the office (32.8%) (APPENDIX E). The occupants expressed their discomfort even though the set point was at 70F in winter and 74F in summer, within the comfort range set by ASHRAE 55[79]. However, an ASHRAE journal written by Steve Tom suggests that people tend to be more productive between 72°F and 77°F.[80]

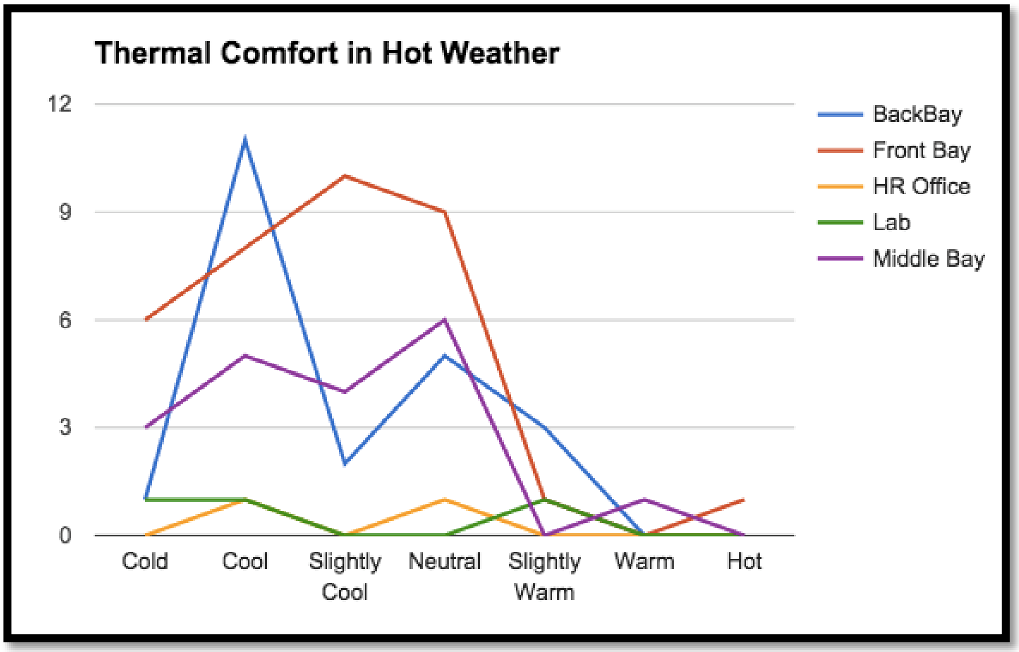

Figure 5.23: Thermal Comfort of the Occupants in Hot Weather by Zone

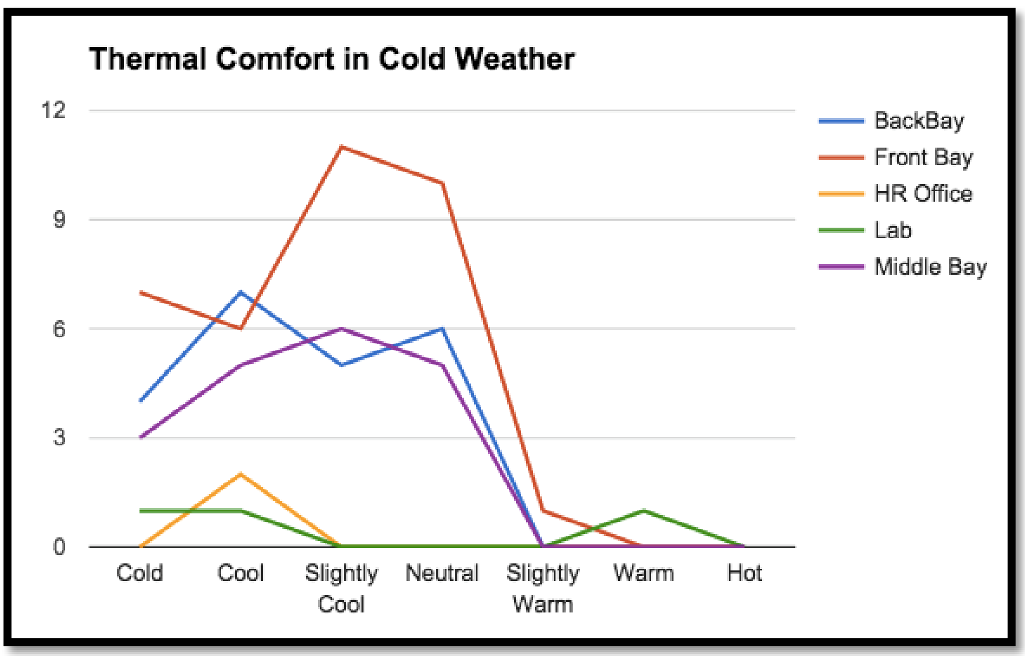

Figure 5.22: Thermal Comfort of the Occupants in Cold Weather by Zone

[79] Richard J de Dear, and Gail S. Brager, "Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55," *Energy and buildings* 34.6 (2002): 549-561.
[80] Steve Tom, "Managing energy and comfort," *ASHRAE Journal* 50.6 (2008): 18-27.

5.4.3 Lighting Comfort

The lighting survey consisted of two major questions: satisfaction regarding amount of light and visual comfort. Below charts show the occupants' answers ranging from the scale of 0-6 with 0 being very dissatisfied and 6 being very satisfied (Figure 5.24). The results showed that, overall, the occupants are either neutral about the lighting, if not more satisfied. The concerns regarding lighting comfort included the glare from clerestory for some users and lack of natural lighting in some zones of the building (APPENDIX E).

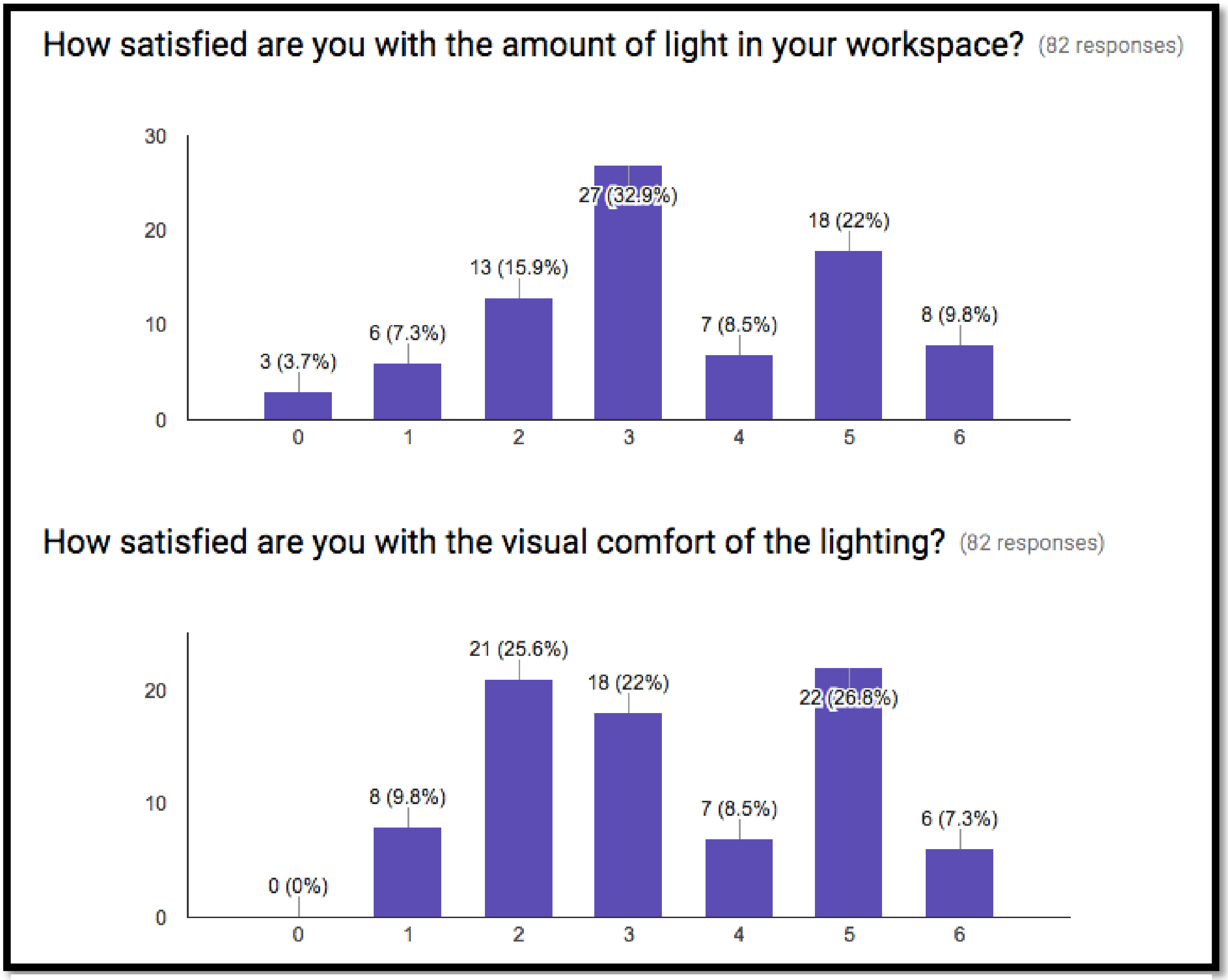

Figure 5.24: Occupant satisfaction regarding amount of light and visual comfort in the workplace

5.5 Spot and Short-Term Measurements

In order to gain a better understanding of the interior building environment, we ran several iterations of spot measurements. There were five different phases of spot measurement data, which were taken using three types of instruments. Phase 1 used HOBOware UA-002 pendant loggers that measured temperature and light. These loggers were worn by five members of the staff. Phase 2, 3, 4 used HOBOware UX100-011 stationary loggers that recorded temperature and relative humidity (RH). Phase 5 used Veriteq Spectrum 2000 loggers, which also recorded temperature and relative humidity. Figure 5.25 depicts the location of the loggers and Table 5.14 lists their location, as well as their start and end date.

Figure 5.25: Data Logger Locations

Table 5.14: Data Logger Locations and Time Durations

PHASE	LOGGER	LOCATION	START DATE	END DATE
PHASE 2	1	Front Desk	09-24-2015	10-28-2015
	2	Large Cafeteria	09-24-2015	10-28-2015
	3	Office Space	09-24-2015	10-28-2015
	4	*HVAC Damper	09-24-2015	10-28-2015
PHASE 3	A	Conference Room	11-04-2015[81]	12-06-2015
	B	Truss in Front Bay	11-11-2015	12-06-2015
	C	Window Sill	11-04-2015[82]	12-06-2015
	D	Seminar Room B	11-04-2015	12-06-2015
PHASE 4	a	Slab by Lab	11-25-2015	11-30-2015
	c	Slab in Office Space	11-25-2015	11-28-2015
PHASE 5	i	HR Office	12-21-2015	02-10-2016
	ii	Office Space	12-21-2015	02-10-2016
	iii	Truss in Back Bay	12-21-2015	02-10-2016
	iv	*HVAC Damper	12-21-2015	02-10-2016
	v	SGH RTU-4	12-21-2015	02-10-2016

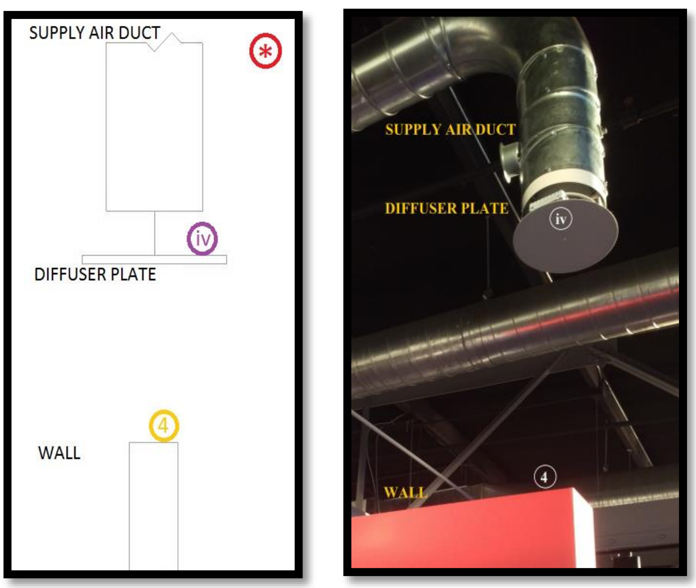

Figure 5.26: Clarification of Logger "4" and "iv" Locations

For clarification, Figure 5.26 details the location of loggers "4" and "iv". In Phase 2, Logger 4 was placed on top of a partition wall beneath the HVAC supply air duct and its diffuser plate. In Phase 5, Logger iv was placed on top of the diffuser plate and directly exposed to the HVAC supply air temperature.

[81] The logger was moved from Location "A" to "a" from 11-25-2015 to 11-30-2015
[82] The logger was moved from Location "C" to "c" from 11-25-2015 to 11-28-2015

5.5.1 Phase 1

Five participants wore the wearable loggers around the office for two weeks [9/24/2015-10/08/2015]. The participants were chosen from diverse locations around the building. We had a participant from front lobby [Peggy], IT mezzanine [Ben], the Middle Bay [Jason], the Back Bay [Emily], and finally the Front Bay [Steve, who also continuously moved around within the office]. Table 5.15 summarizes the collected data.

Table 5.15: Phase 1 Spot Measurement Results

		Emily	Ben	Jason	Steve	Peggy
Temp (°F)	Highest	96.17	97.14	88.47	87.92	90.68
	Lowest	69.45	72.03	69.28	68.59	63.28
	Average	72.75	76.59	73.16	74	73.98
	Median	71.86	74.96	72.54	73.41	73.41
Intensity	Highest	128	3968	18432	20480	3968
	Lowest	0	0	0	0	0
	Average	7.7	25.2	5.38	13.47	8.76
	Median	2	0	0	2	0

5.5.2 Phase 2

The second phase of spot measurements occurred from 9/24/2015 until 10/28/2015. Logger 1 was placed in the front lobby. This area of the building is exposed to a significant amount of light due to the full glazing of the entry. It is also subject to the opening and closing of doors, which although there is a vestibule, still brings in some outdoor air. The occupancy of the space is generally just that of the secretary, although there is some foot traffic throughout the day as people come and go.

Logger 2 was placed in the largest cafeteria, located in the original office space. This particular space experiences varying levels of occupancy throughout the day. There is a glazed garage door as well as an exit door that open directly to the outside. The exit door is used by employees throughout the day to come and go from the building.

Logger 3 was set up in the Front Bay of the building on an office desk. Most of the occupants in the space are sedentary. The desk was located in the central part of the office, and therefore exposed to some light from the clerestory windows. The intention of Logger 3 was to provide better understanding of user comfort of most of the office workers.

Logger 4 was installed on the mezzanine between the Front Bay and the Middle Bay. Its location, as depicted above in Figure 5.26, is on top of a wall partition near the HVAC supply. We intended to use this to verify the HVAC schedule for the building. Logger 3 and Logger 4 were placed relatively close to each other, though at varying heights. The intention was to understand the varying temperature in vertical manner. Table 5.16 summarizes the collected data.

Table 5.16: Phase 2 Spot Measurement Results

		Logger 1	Logger 2	Logger 3	Logger 4
Temp (F)	Highest	86.22	78.09	77.96	82.45
	Lowest	67.93	68.06	68.15	67.55
	Average	72.92	70.88	71.99	72.31
	Median	72.49	70.77	72.06	72.1
RH (%)	Highest	79.32	81.76	67.4	66.55
	Lowest	16.35	17.47	18.08	16.53
	Average	39.07	41.42	41.27	39.55
	Median	38.87	40.97	41.43	39.7

5.5.3 Phase 3

Phase 3 occurred from 11/04/2015 until 12/06/2015, although it is important to note that Phase 4 displaced Phase 3 for a short period. Phase 3 used the stationary HOBOware UX100-011 loggers. Logger A was placed in the front conference room. This room has multiple sets of large doors that are left open when the space is not in use. This conference room is one of the larger meeting spaces in the office. Logger B was initially located on the IT Mezzanine; however, the majority of its logging period was spent on top of a truss in the Front Bay to record temperature data close to the roof. Logger C was set on a window sill in the Middle Bay. The intention was to collect data close to an outside wall/windows. Logger D was installed in Seminar Room B. Seminar Room B is located in the Back Bay area, and experiences varying occupancy levels depending on events. Table 5.17: Phase 3 Spot Measurement ResultsTable 5.17 summarizes the results of Phase 3.

Table 5.17: Phase 3 Spot Measurement Results

		Logger A	Logger B	Logger C	Logger D
Temp (F)	Highest	79.62	78.17	76.65	73.09
	Lowest	70.08	69.13	53.04	63.14
	Average	74.03	73.54	65.68	69.56
	Median	73.87	73.44	65.79	69.44
RH (%)	Highest	55.61	46.24	64.84	56.80
	Lowest	13.03	13.62	16.83	18.15
	Average	28.56	26.02	38.28	32.35
	Median	26.69	24.62	38.48	31.07

5.5.4 Phase 4

The fourth phase occurred within Phase 3, from 11/25/2015 to 11/28,30/2015. Phase 4 is best described as the period during which the HVAC system was shut down for the office. We coordinated this shutdown with the facilities manager for the Thanksgiving holiday. The purpose of the shutdown was to collect data from the building over a period of time in which there was no HVAC use. This would theoretically allow us to model the building without HVAC equipment and calibrate the simulated scenario.

Loggers B and D remained in their Phase 3 location while Loggers A and C were moved to locations "a" and "c". Logger a was moved to the slab outside of the lab, close to the conference room. Logger c was removed from the window sill and placed on the floor in a more interior location. Table 5.18 summarizes the data collected during Phase 4.

Table 5.18: Phase 4 Spot Measurement Results

		Logger a	Logger B	Logger c	Logger D
Temp (F)	Highest	72.96	77.08	69.78	69.74
	Lowest	69.22	69.13	65.49	68.36
	Average	70.86	71.95	67.78	69.09
	Median	70.85	71.63	67.85	69.05
RH (%)	Highest	40.00	37.48	47.81	37.29
	Lowest	19.86	19.41	24.13	23.49
	Average	30.15	29.67	37.73	30.12
	Median	30.25	31.14	41.17	31.63

5.5.5 Phase 5

The final period of data logging occurred between 12/21/2015 and 2/10/2016. Unlike Phases 2-4, Phase 5 used Veriteq 2000 data loggers. Five loggers were used. Logger i was installed in the HR office space. This location was chosen as a result of the user survey (5.4). Occupants in the HR office space felt this area was colder than other spaces. Logger ii was placed on a desk in the Front Bay office space, similar in location to Logger 3, in order to give us ambient office space data. Logger iii was located on top of a beam in the Back Bay, near the rear wall (which separates the SGH office from other portions of the building). Logger iv was set on the HVAC diffuser plate in the Front Bay, and Logger v was placed on the corresponding HVAC unit outside. Logger iv gave us data regarding the air leaving the HVAC supply air duct, while Logger v supplied information from about the conditions entering the mechanical system. The data collected during Phase 5 is summarized in Table 5.19.

Table 5.19: Phase 5 Spot Measurement Results

		Logger i	Logger ii	Logger iii	Logger iv	Logger v
Temp (F)	Highest	75.66	76.01	74.73	90.17	105.43
	Lowest	67.66	67.67	66.25	57.64	19.92
	Average	71.31	70.71	70.75	70.23	45.16
	Median	71.11	70.75	71.23	70.52	43.46
RH (%)	Highest	59.00	58.70	51.80	75.90	94.50
	Lowest	8.10	6.90	8.90	3.90	2.20
	Average	20.74	21.02	21.18	19.93	46.84
	Median	18.90	19.10	19.10	17.10	46.70

5.5.6 Data Logger Analysis

The average temperature of the data loggers (excluding Logger v which was placed outside) are shown in Figure 5.27. The range of temperatures is 65.68 to 74.03°F, or 8.35°F, with the lowest average being Logger C which was located on the window sill, and the highest average Logger A which was located inside the front conference room. This data should be considered carefully however. As is detailed in Table 5.14, the loggers were not all installed during the same time frame. Though most of the logging periods occurred during the heating season, Loggers 1, 2, 3, and 4, were installed during the month of October which did experience some cooling days. Referring back to Table 5.4, the HVAC schedule depicts that the cooling setpoint is 74°F and the heating setpoint is 70°F during occupied times (which is the majority of time logged, 82°F and 63°F are the cooling and heating setpoint, respectively, for unoccupied time). With this in mind, all of the loggers fall within this range except C, D, and c. We can reason that Logger C is low due to its proximity to the window and its placement on the sill. Upon inspection of this location, we found the sill to be significantly colder than other portions of the exterior wall due to the low thermal resistance of the window, as well as potential thermal bridging. Logger D's lower average temperature can also be explained by its location in Seminar Room B. This room is kept at a lower temperature because when there are greater numbers of people in the room, it requires more cooling. It is important to note that the survey showed that many employees found the seminar rooms to be overcooled. Logger c can be explained because of both time and location. That is, Logger c only recorded data from 11/25/2015 to 11/28/2015. This was the period that the HVAC system was shutdown, the office was unoccupied, and therefore the building's indoor environment was not mechanically regulated. Logger c is still within the temperature range indicated by the setpoints for unoccupied periods. Table 5.20

summarizes the average, median, high, and low data values for all of the loggers, and includes the time and day of highs and lows.

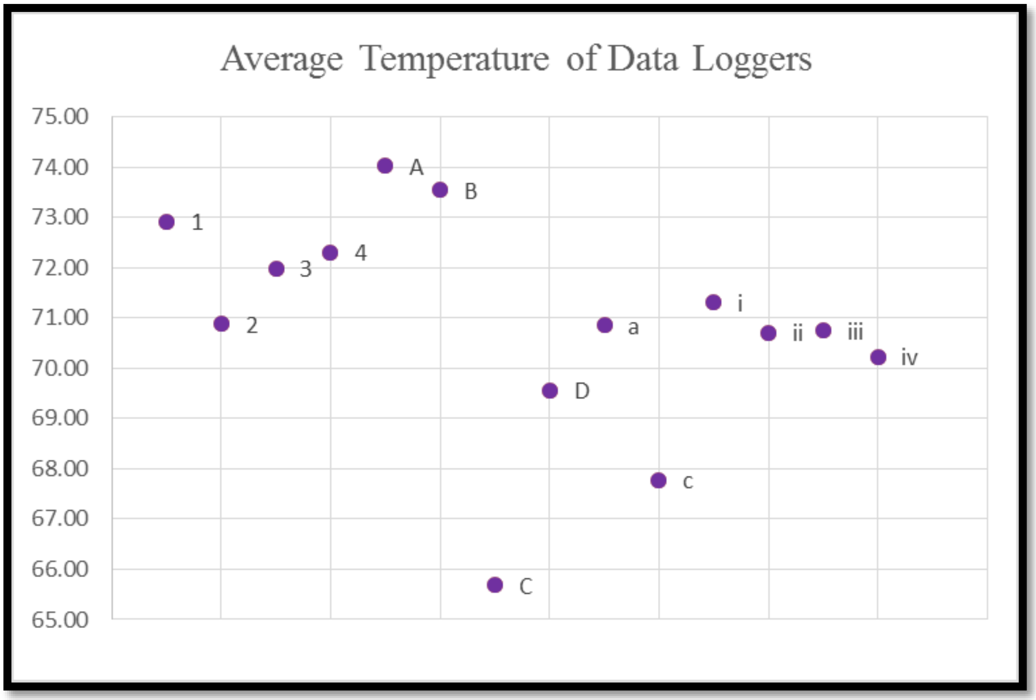

Figure 5.27: Average Temperature of Data Loggers (Phase 2-5)

Table 5.20: Overall Summary of Logger Data, Averages, Medians, Highs, and Lows

Logger	Average Temp (°F)	Median Temp (°F)	High Temp (°F)	Time	Day	Low Temp (°F)	Time	Day
1	72.92	72.49	86.22	14:30	9/27/15	67.93	5:50	10/19/15
2	70.88	70.77	78.09	14:10	9/24/15	68.06	6:30	10/19/15
3	71.99	72.06	77.96	17:30	9/27/15	68.15	5:40	10/19/15
4	72.31	72.10	82.45	18:00	9/27/15	67.55	5:30	10/27/15
A	74.03	73.87	79.62	15:00	11/6/15	70.08	5:20	11/25/15
B	73.54	73.44	78.17	14:40	11/20/15	69.13	7:20	11/26/15
C	65.68	65.79	76.65	9:50	11/5/15	53.04	4:10	12/1/15
D	69.56	69.44	73.09	16:40	11/5/15	63.14	8:50	11/17/15
a	70.86	70.85	72.96	17:00	11/25/15	69.22	8:00	11/26/15
c	67.78	67.85	69.78	17:00	11/25/15	69.78	17:00	11/25/15
i	71.31	71.11	75.66	10:50	12/21/15	67.66	5:10	1/5/16
ii	70.71	70.75	76.01	11:09	12/21/15	67.67	3:29	1/12/16
iii	70.75	71.23	74.73	11:18	12/21/15	66.25	4:38	1/28/16
iv	70.23	70.52	90.17	6:58	12/28/15	57.64	12:38	1/20/16
v	45.16	43.46	105.43	8:35	1/24/16	19.92	4:15	1/5/16

To gain a better understanding of the HVAC performance, spot temperature/RH loggers were installed on top of the diffuser plate, the corresponding HVAC unit, and nearby occupant area. By comparing data from these three locations, general observations regarding the HVAC performance were made.

Unfortunately, the logger located on the HVAC unit for outside air intake temperature was located directly below two relief dampers, causing the outside air to spike to high temperatures when the damper was on. Figure 5.28 depicts the location of the logger, the relief dampers, and the outside air intake. Other than occasional outliers when the relief damper is on, the data was reliable.

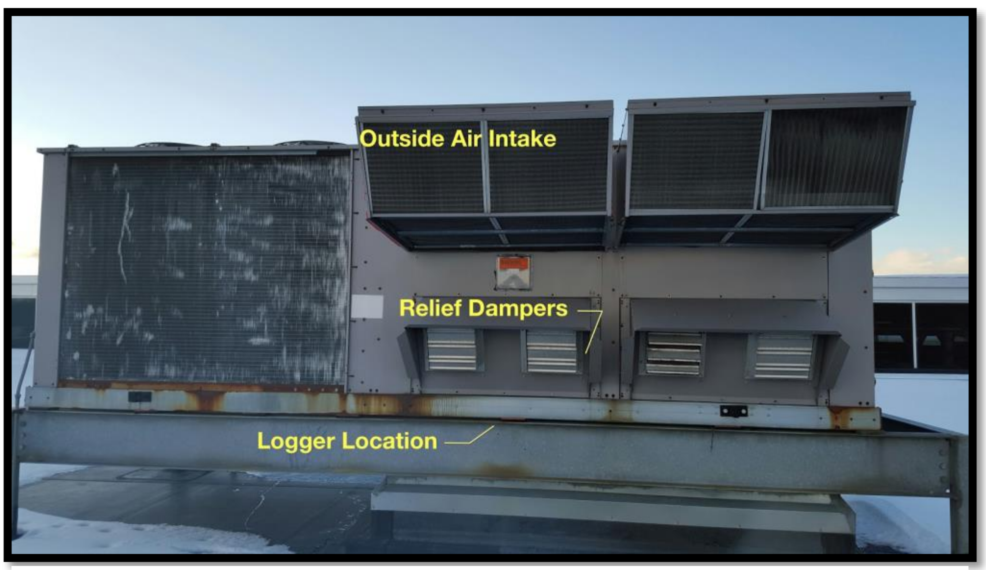

Figure 5.28: Location of Logger v on HVAC Unit

Figure 5.29 shows the data from Monday through Friday from one week in January. On Monday through Thursday, the unit is blowing cooler air into the occupant area; the temperature at diffuser is lower than the temperature at occupant space. For the set point temperature of 73°F to be met, the fan blows cool air into the building during the day time. Throughout the night, the fan runs continuously and the ambient temperature stays consistent with the supply air temperature near the setback temperature of 70°F. During the day, as the building gains heat from the sun and internal load, the ambient office temperature rises to 73°F and HVAC introduces cool air into the system to maintain the temperature. On Wednesday and Thursday, when the outside temperature was warmer than other days, the fan blows air as low as 62°F in the building. Though the outside temperature is relatively warm, occupants could feel uncomfortable with the supply temperature of 62°F in winter.

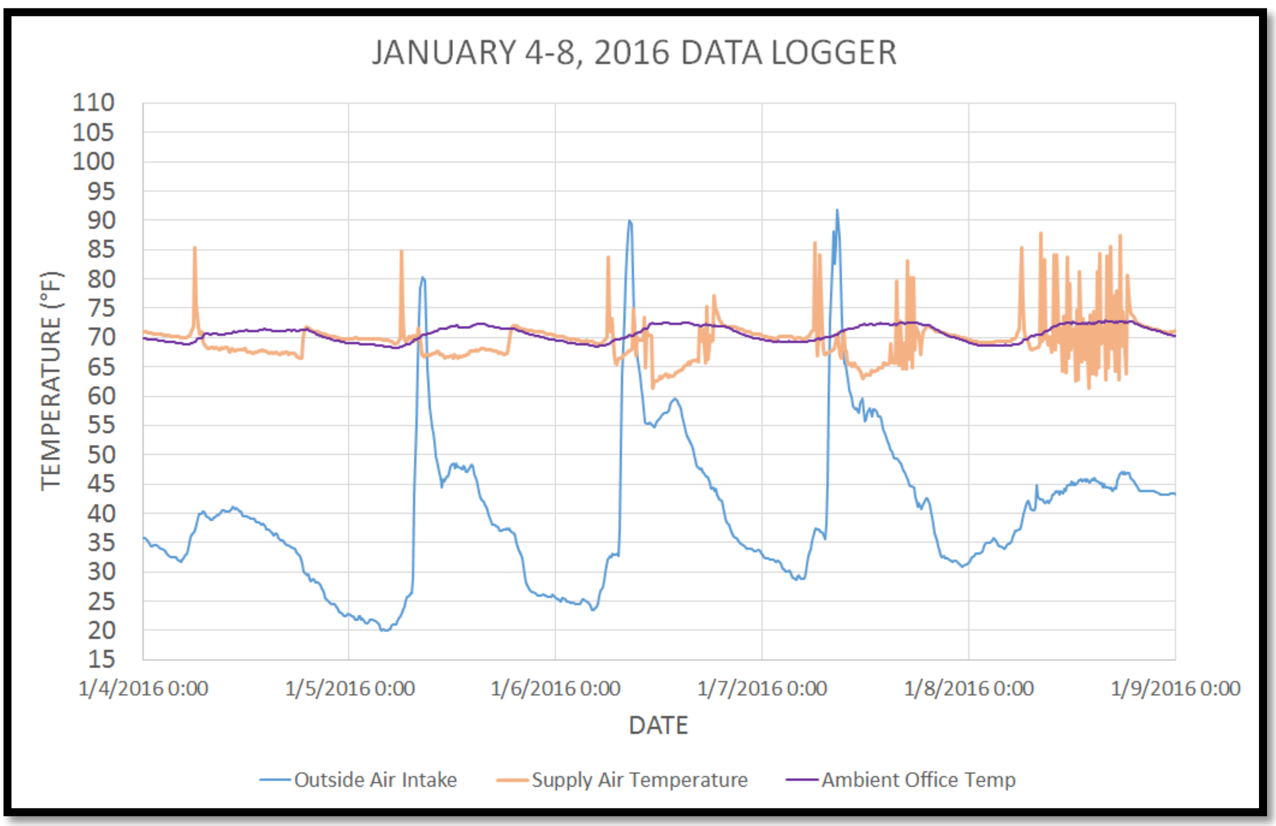

Figure 5.29: Phase 5 Logger Data for January 4-8, 2016

Furthermore, the HVAC system experiences short cycling issues. On Friday, the supply air temperature graph is very noisy. The heater continuously turns on and off, alternating between warm air and cool air. The short cycling could be due to the thermostat location or sensitivity of the control system. It could also be due to an oversized unit. If the issue is due to an oversized unit, changing the orifice on the gas supply could reduce the capacity of furnace to avoid short cycling. To better understand the system, we tried to identify the location of the thermostat to see if the thermostat setting was related to the short cycling. However, the thermostats could not be found.

Figure 5.30, which considers the office temperature, shows spot temperature measure data from the same dates as the HVAC temperature data. The graph shows that overall, the temperature during the daytime stays between 72°F and above. According to the user survey, the occupants of the HR section have reported to experience more discomfort from the cold. Based on the graph, the temperature in HR is often higher than the other sections of the office (Logger ii is in office space in Front Bay, Logger iii is in Back Bay). However, this could mean that the HVAC unit that correlates to the HR office would put out cooler air than the rest of the office space to lower the temperature to the set point of 73°F. More spot measures would have to be installed and studied to gain a better understanding of the HVAC system as a whole.

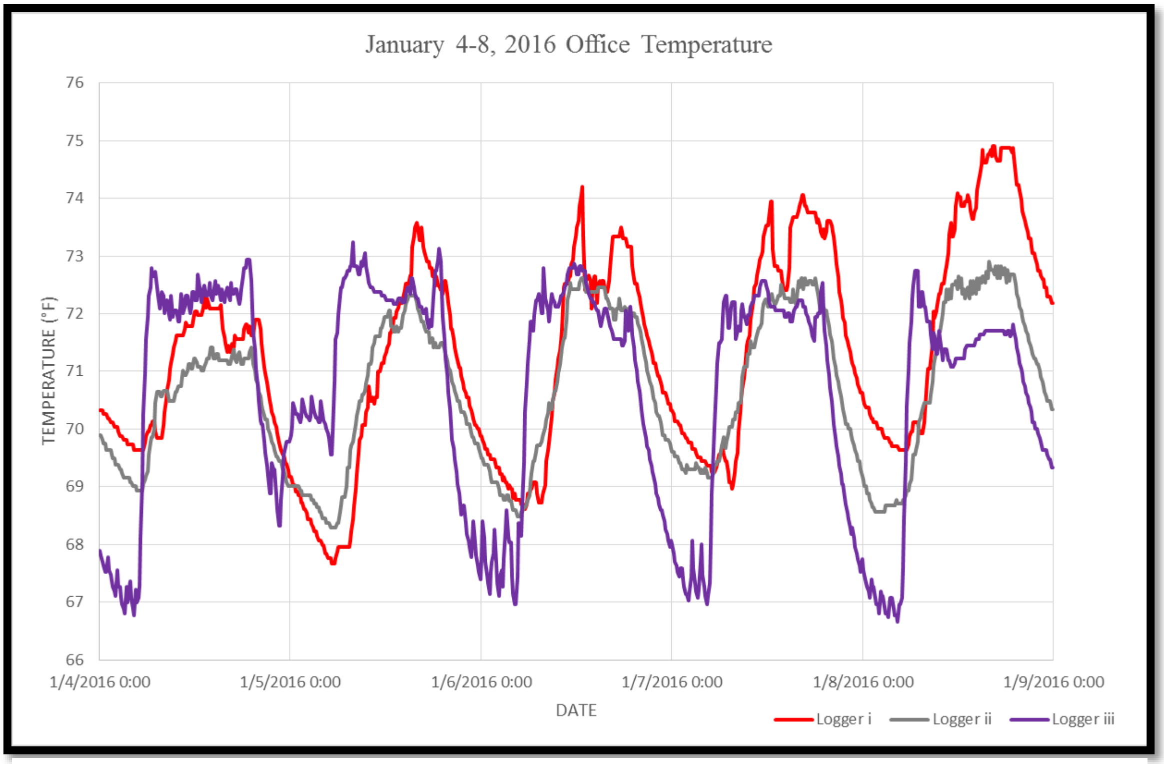

Figure 5.30: Phase 5 Data for Loggers i, ii, and iii (January 4-8, 2016)

6. Simulation

Steps listed in the following section describe how the simulation was modeled. Though calibration of the model was not possible based on the analysis made in Section 5, we used the collected data to make the model as accurate as possible. We compared the simulation data to the utility data to identify the discrepancies. Finally, we compared SGH's simulated energy consumption with that of a typical office building.

6.1 Input

While creating a baseline model, we ran into some issues such as lack of data on electrical use (not broken down into detailed use) and skeptical performance of HVAC system. Due to such issues, we could not follow through our initial calibration plan involving a parametric study of the baseline model. However, with available data that was collected, we followed through the simulation guideline to have the baseline model as similar to the actual building as possible.

The first step to modeling was to create a project in DesignBuilder. We specified Laurence G Hanscom Airport in Bedford, MA (42.41°, -71.29°) as the location, as that was the closest available location template from Waltham office (42.37°,-71.21°) (Figure 6.1). Though we understand that Bedford's weather would have numerous discrepancies due to the nature of its location (i.e Bedford's weather station is located at an elevation of 134.5 feet versus the 12 feet above sea level at the SGH office), the weather file is the most readily available. We decided to run our initial model with Bedford weather data.

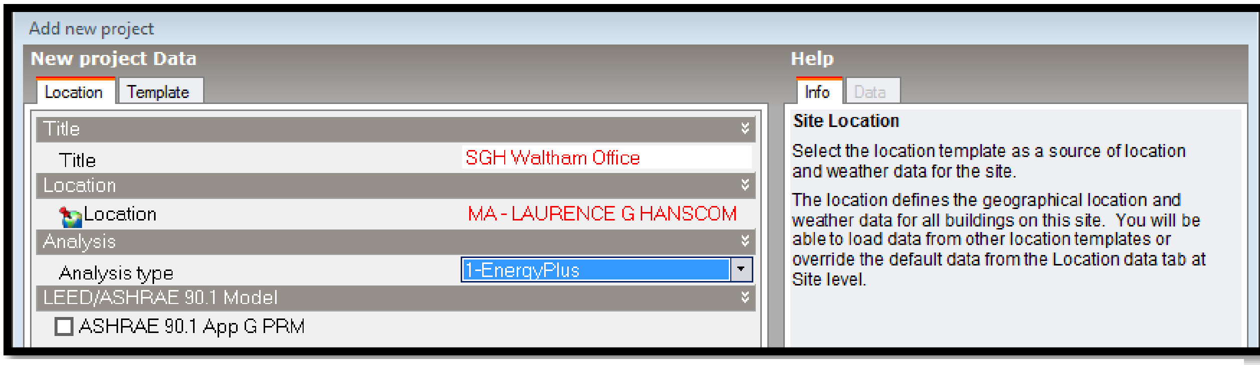

Figure 6.1: Creating a New Project in DesignBuilder

After the project was set up, we modelled the geometry of the model based on the CAD floor plan. The .dxf file was imported into DesignBuilder, with inches as base unit (Figure 6.2). With imported .dxf as a reference, building site location and site details such as site orientation (310°) were adjusted. Google maps and AutoCAD were used to make necessary measurements.

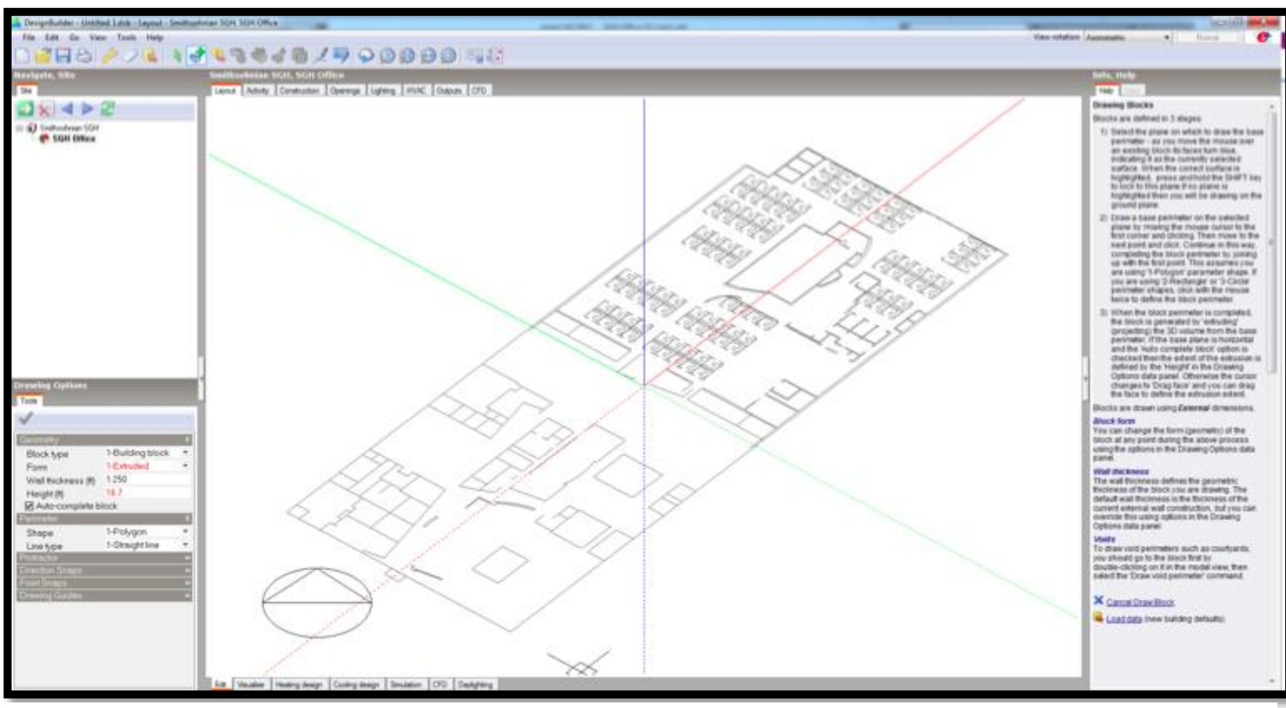

Figure 6.2: Importing the CAD Floor Plan into DesignBuilder

The next step was to create a building. For building templates, office-building template was chosen. Various inputs regarding this template such as HVAC load and electronic load were calibrated later based on further observation/documentation of the office use and thorough surveys.

Similarly, for the default data, we put in rough estimate of building type that provided template values of wall types and glazing type. These values were corrected with actual values as more data of the SGH office building were collected.

After the template was created, the building was modeled using three main blocks (Figure 6.3). The blocks were named Center Main, NW Main, and SE Main for convenience based on their actual orientation. The NW and SE Main blocks were modeled at 16.7 feet in height, and 60 feet in width. The longest length of the building was approximately 484 feet. The Center Main was modeled at 26.55 feet. In the original iterations of the model, the sloped roof was included in the model geometry; however, due to difficulties with the program considering the sloped roof block as floor space, we removed them for convenience purposes. Holes were drawn in the building blocks to connect the three to create a single indoor space, which we later divided into zones using partitions.

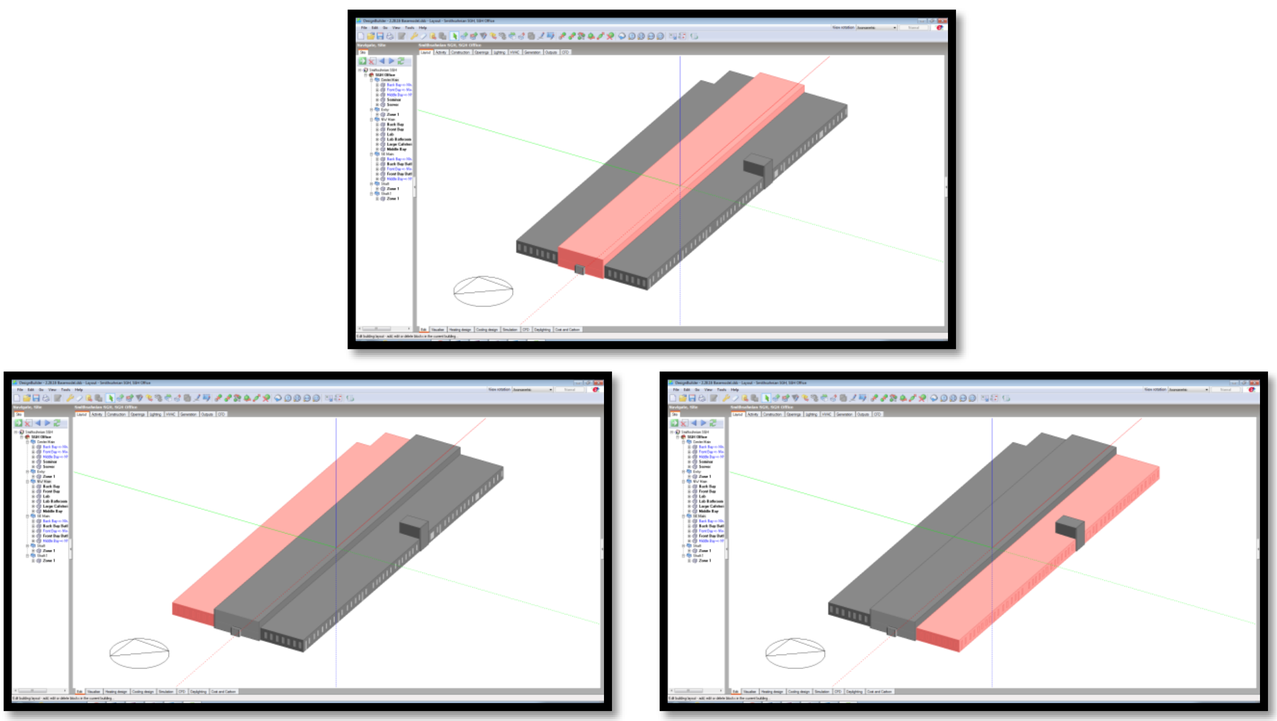

Figure 6.3: Three Main Building Blocks of SGH Office

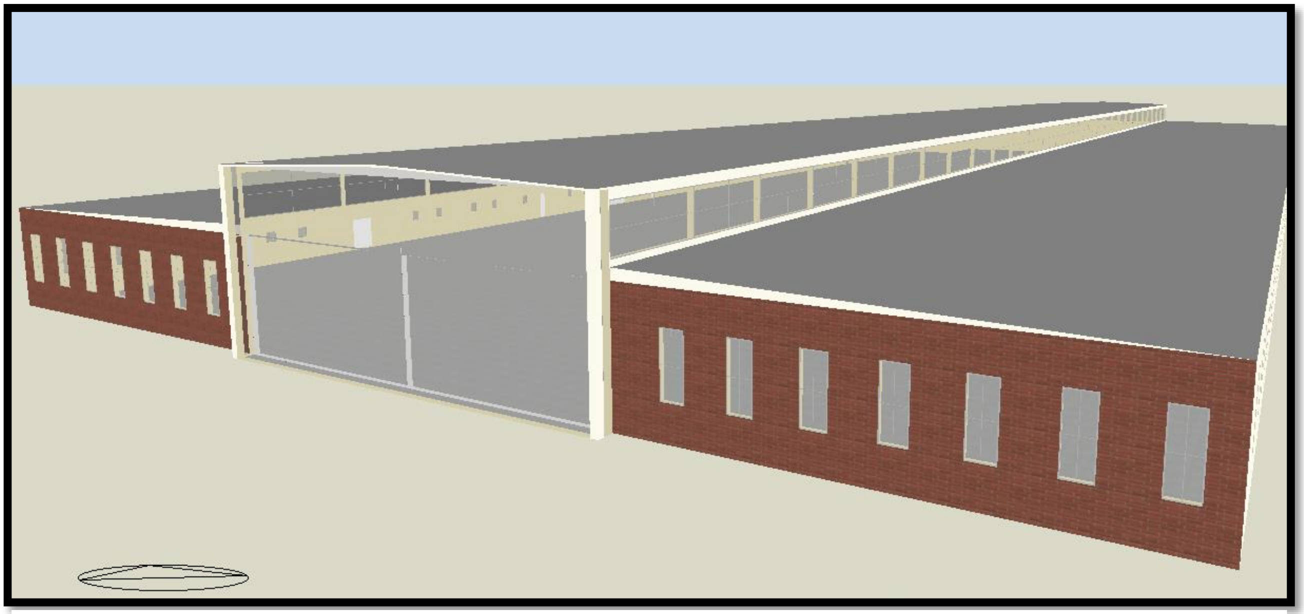

Figure 6.4: DesignBuilder Rendered Model of SGH Office

Figure 6.4 is a rendered view of the DesignBuilder model. We decided to simplify the building into 10 zones (Figure 6.5). The simplification was based on the layout of the HVAC system. Five major zones were Front Bay, Middle Bay, Back Bay, Cafeteria, and the Seminar Room. The rest of the zones were taken up by zones that have different HVAC requirements such as server rooms and restrooms.

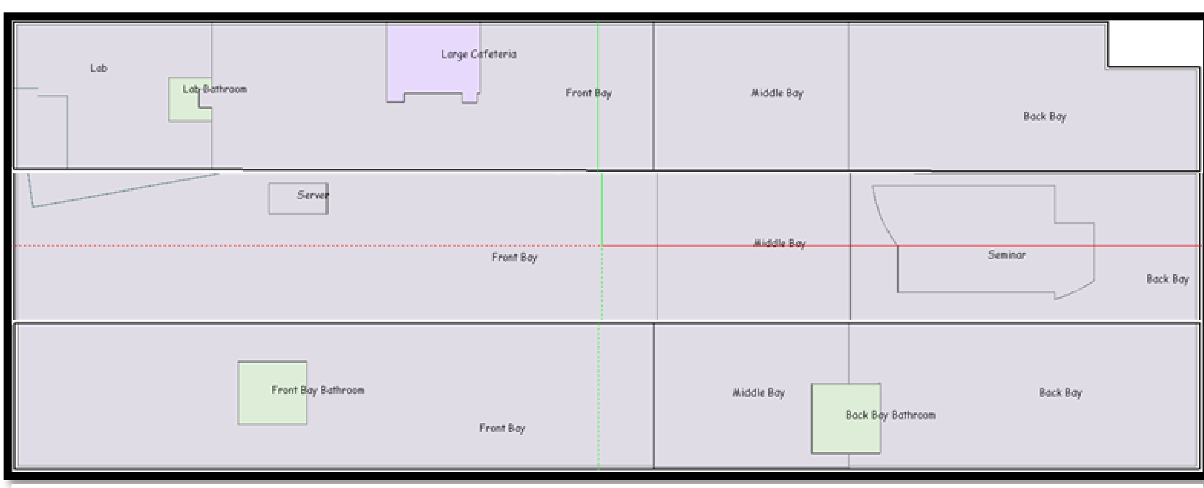

Figure 6.5: DesignBuilder Zones

Next, we inputted the openings (Figure 6.6).Kawneer Fixed Window (Figure 6.7). Refer to Section 5.3.4 of this report for the building and glazing information.

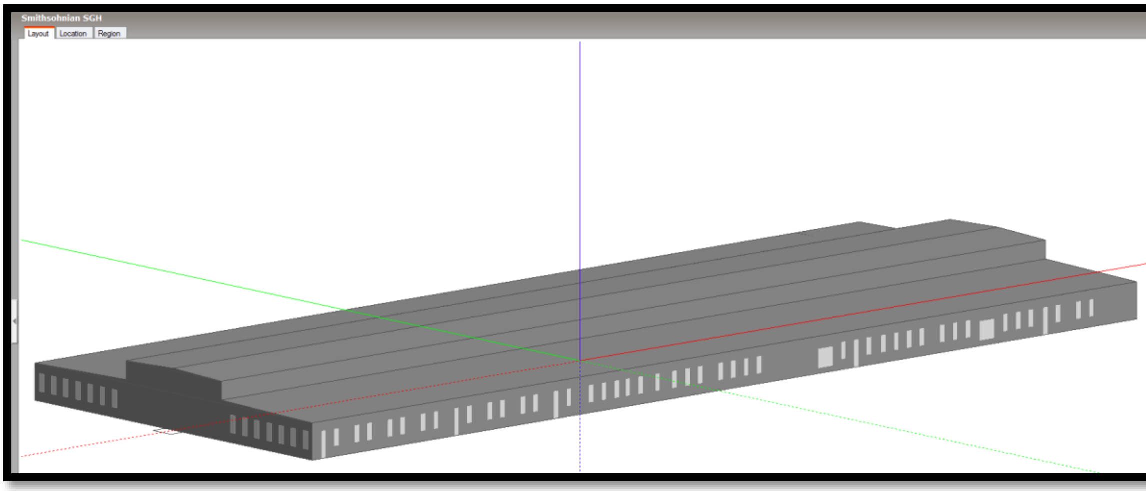

Figure 6.6: Major Building Block with Fenestration

After the window information was saved, project construction information was inputted (Figure 6.8). The major three components the building has are wall, roof and floor, which were manually inputted. Based on the results from building investigation (Section 5), the build-up and thermal properties of each component were modeled. Figure 6.9 shows the roof build-up, Figure 6.10 depicts the wall build-up, and Figure 6.11 details the floor build-up. The model infiltration value was calculated with air exchange rate of 0.278 cfm/sf that was measured and confirmed with blower door test.

Figure 6.7: Window Template in DesignBuilder

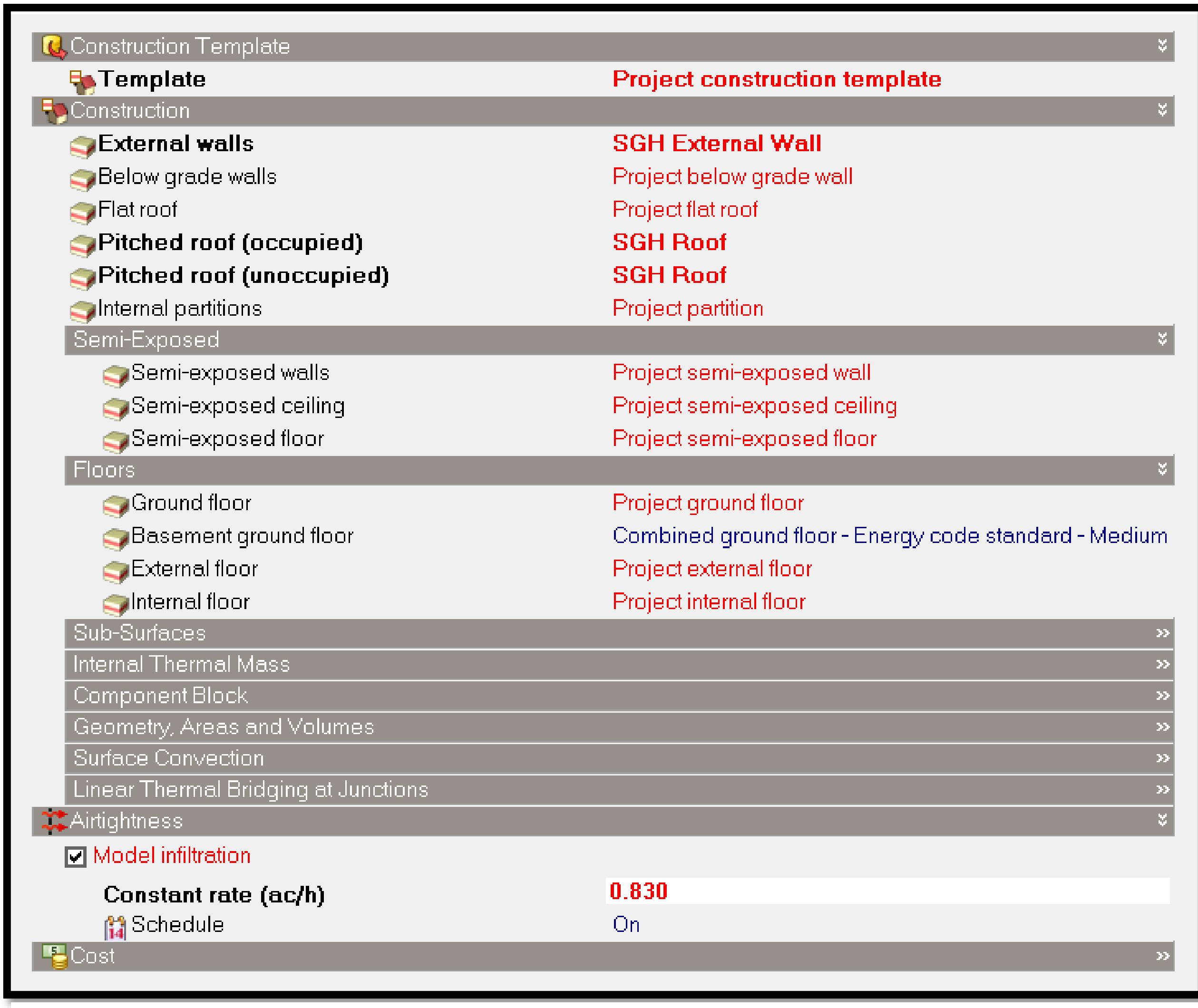

Figure 6.8: Construction Tab of DesignBuilder Project

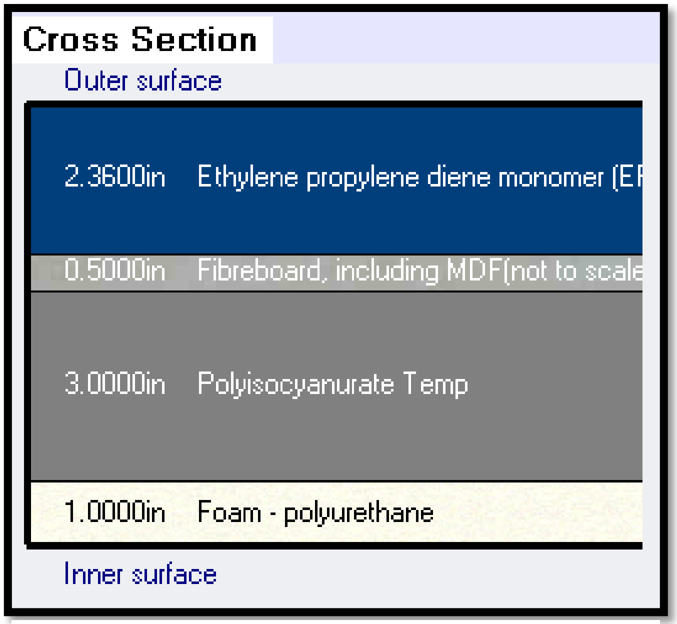

Figure 6.9: SGH Roof Build-up in DesignBuilder

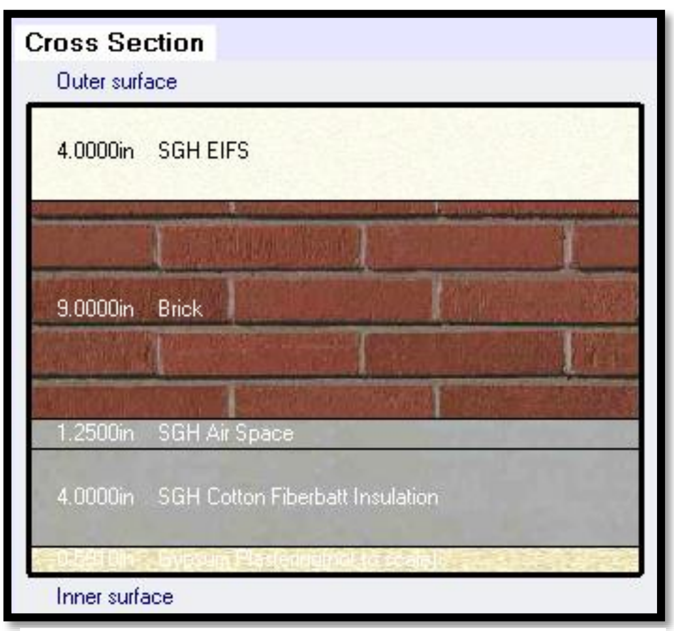

Figure 6.10: SGH Wall Build-up in DesignBuilder

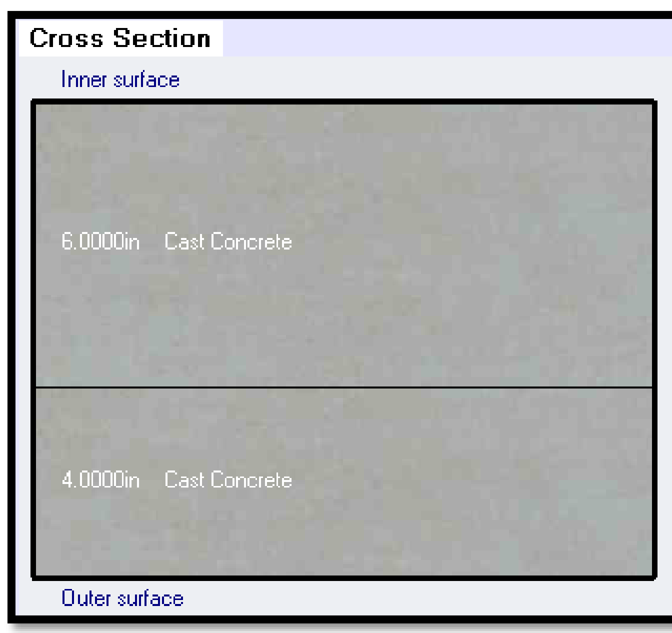

Figure 6.11: SGH Floor Build-up in DesignBuilder

With the data and analysis from Section 5.3.1, the lighting schedule was created and the lighting energy measured in watts per square foot was calculated and inputted. As the minimum requirement for office lighting level in ASHRAE 90.1 is 0.9 W/sqft, 1.0 W/sqft appeared to be a reasonable assumption for an office building Figure 6.12).[83] The lighting schedule of the SGH building shows how emergency light is left on for the entire night, and some lights come on during 8-10 AM period while the rest are turned on later (Figure 6.13). More detailed descriptions about the system are available in Section 5.3.1.

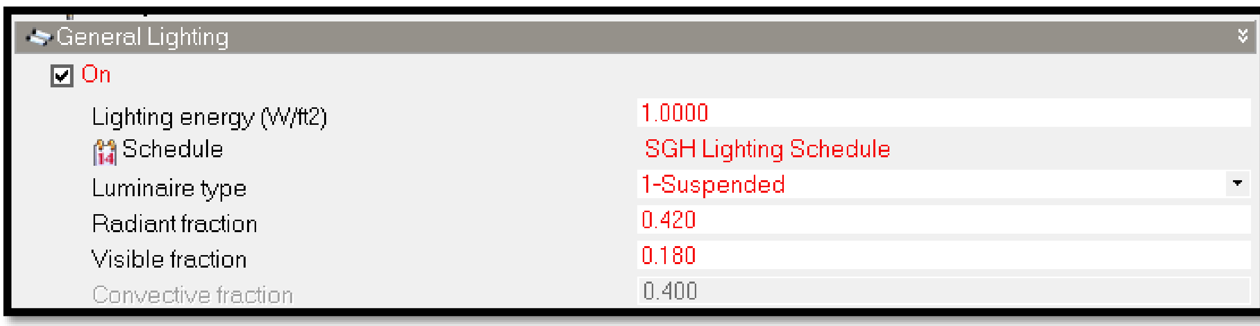

Figure 6.12: Lighting Input Tab from DesignBuilder

[83] Standard, A. S. H. R. A. E. "90.1 2007.—Energy Standard for Buildings Except Low-Rise Residential Buildings." *American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc* (2010).

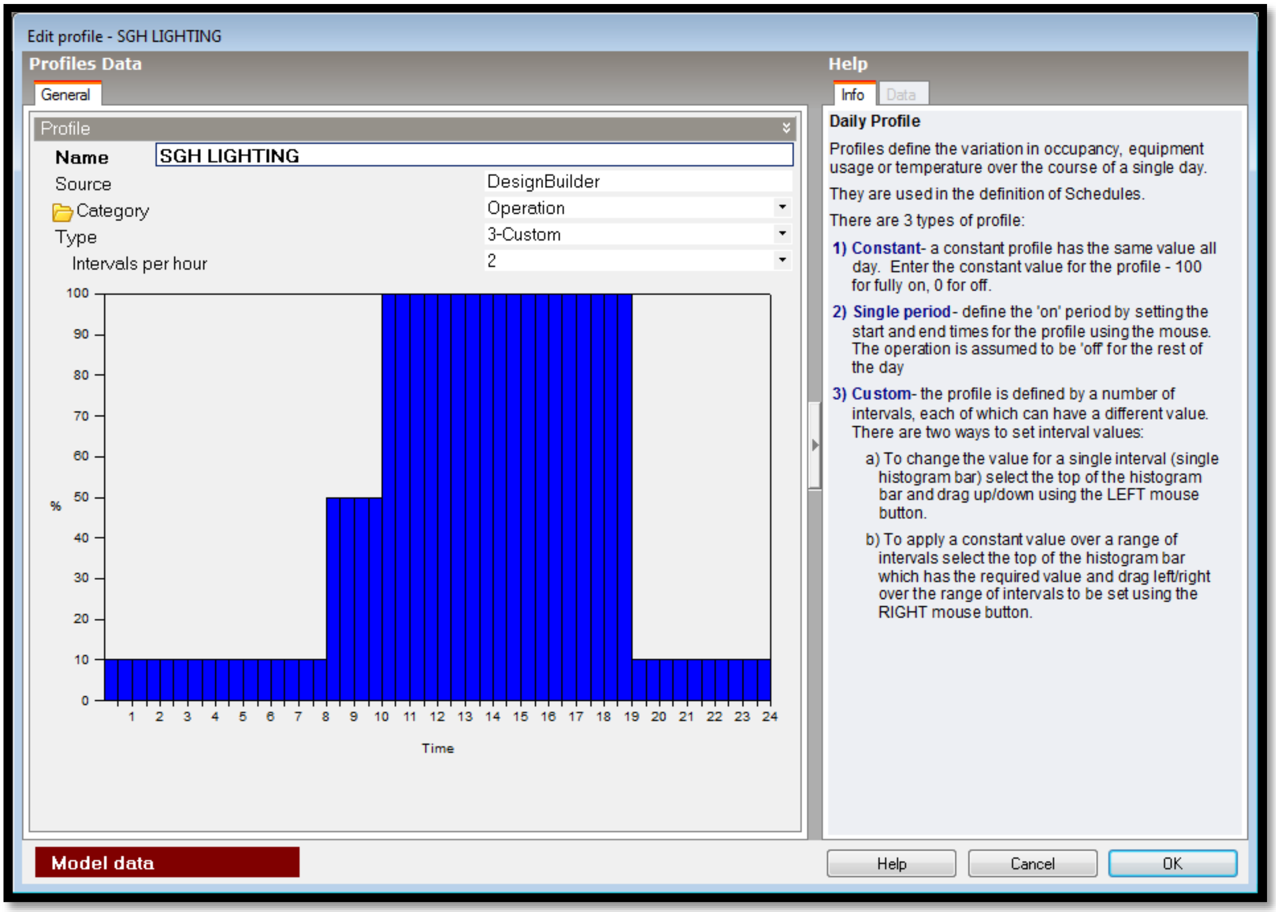

Figure 6.13: Lighting Schedule of SGH Building

The next tab that was modeled was the HVAC control (Figure 6.14). The building's HVAC system, identified to be similar to VAV with fan-assisted terminal reheat, was altered with new HVAC schedule and CoP values identified from Section 5.3.3.3. The SGH HVAC schedule was formulated based on the SGH technician's input (Figure 6.15). For project DHW schedule, we created an SGH Occupant Schedule to find out when the occupants would use hot water in the project building. The schedule, created based on the user survey results from Section 5.4, shows percentage of the occupants present over time (Figure 6.16). The weekday schedule varies from weekend schedule (Figure 6.17 and Figure 6.18). As the majority of the survey participants answered that they rarely come to work on Sundays, the Sunday schedule was modeled as off.

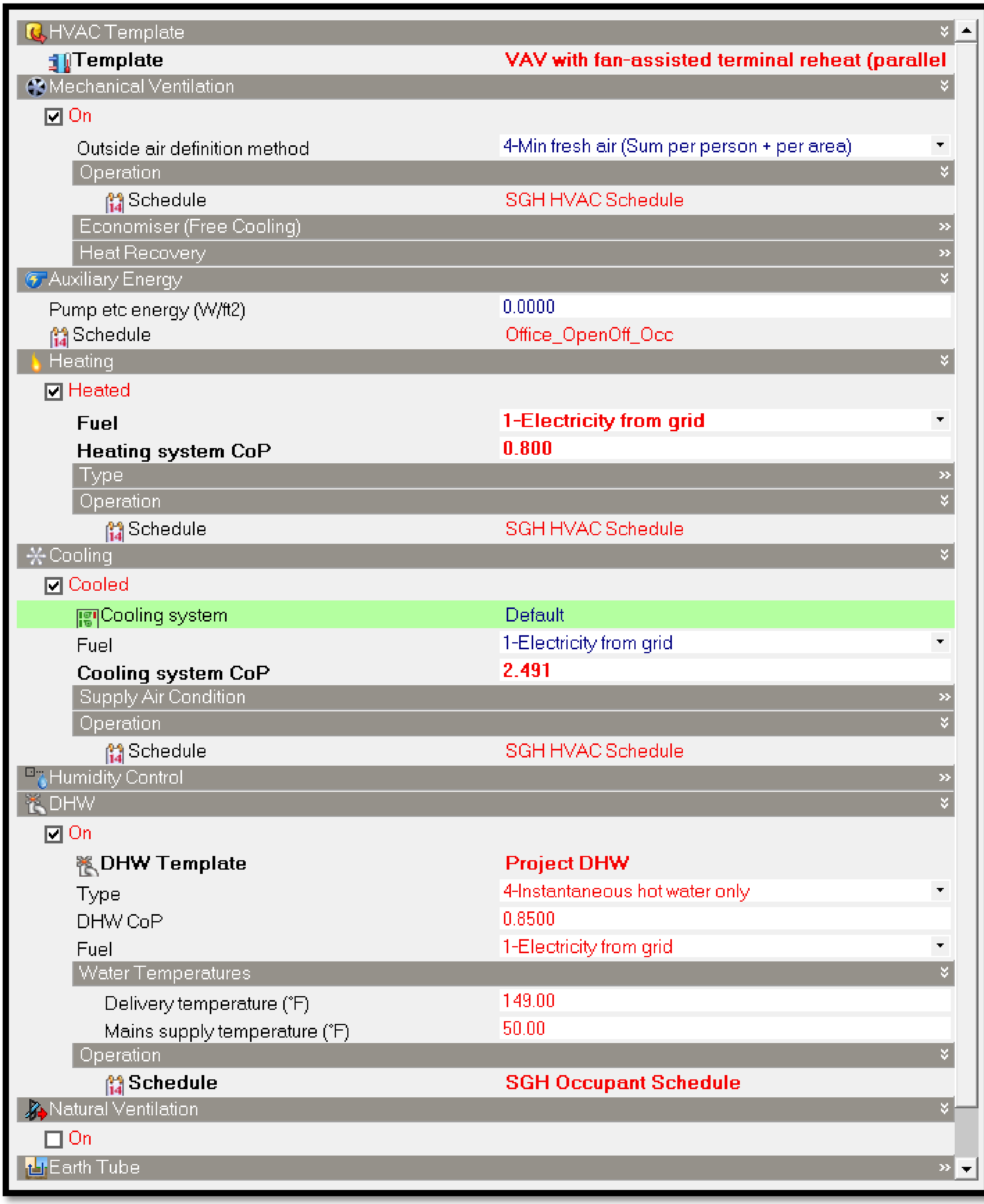

Figure 6.14: HVAC Tab of DesignBuilder

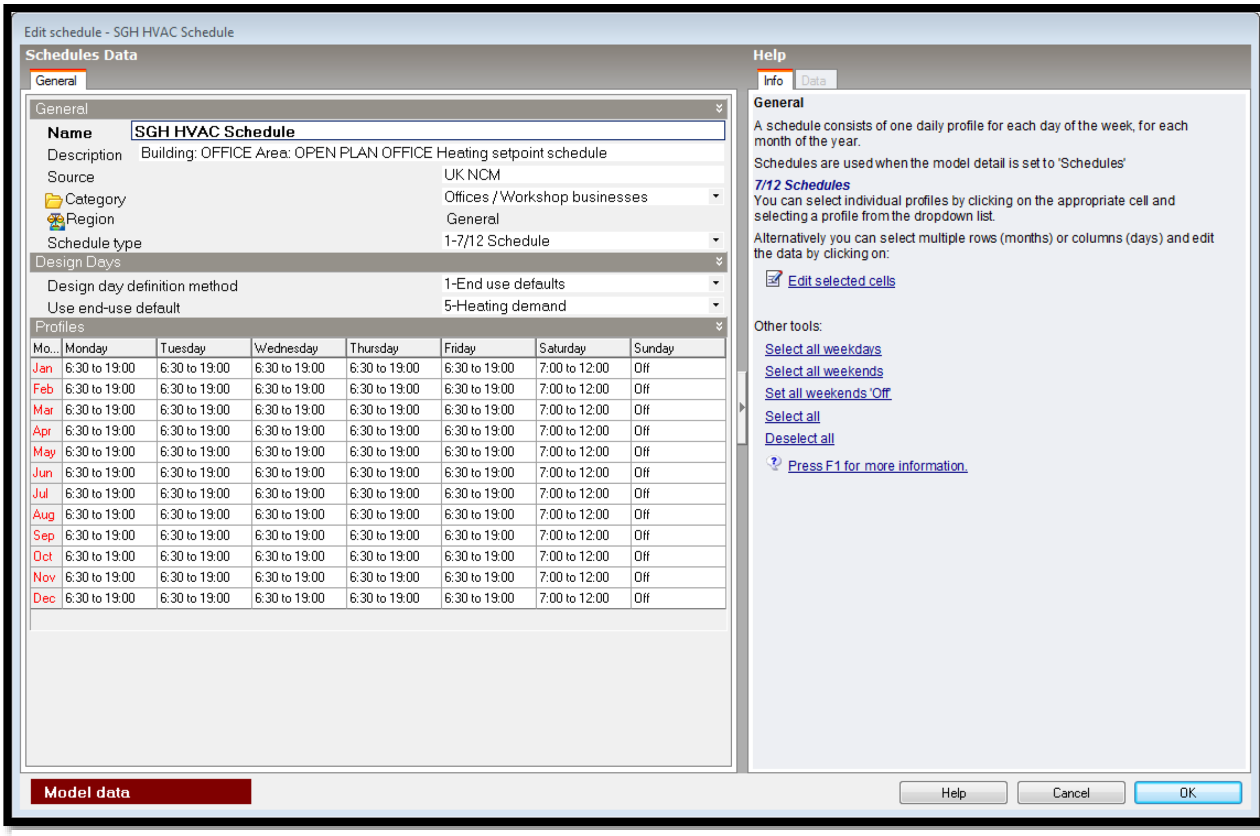

Figure 6.15: SGH's HVAC Schedule for DesignBuilder

The system operates during 6:30 AM to 7:00 PM in weekdays and 7:00 AM to 12:00 PM on Saturday. The system is turned off on Sundays but the employees can override the system if they were to work during the hours HVAC system is turned off.

Profiles

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Jan	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off
Feb	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off
Mar	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off
Apr	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off
May	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off
Jun	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off
Jul	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off
Aug	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off
Sep	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off
Oct	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off
Nov	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off
Dec	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekday	SGH Weekend	Off

Figure 6.16: SGH Occupant Schedule used to determine DHW and Activity Level in Office

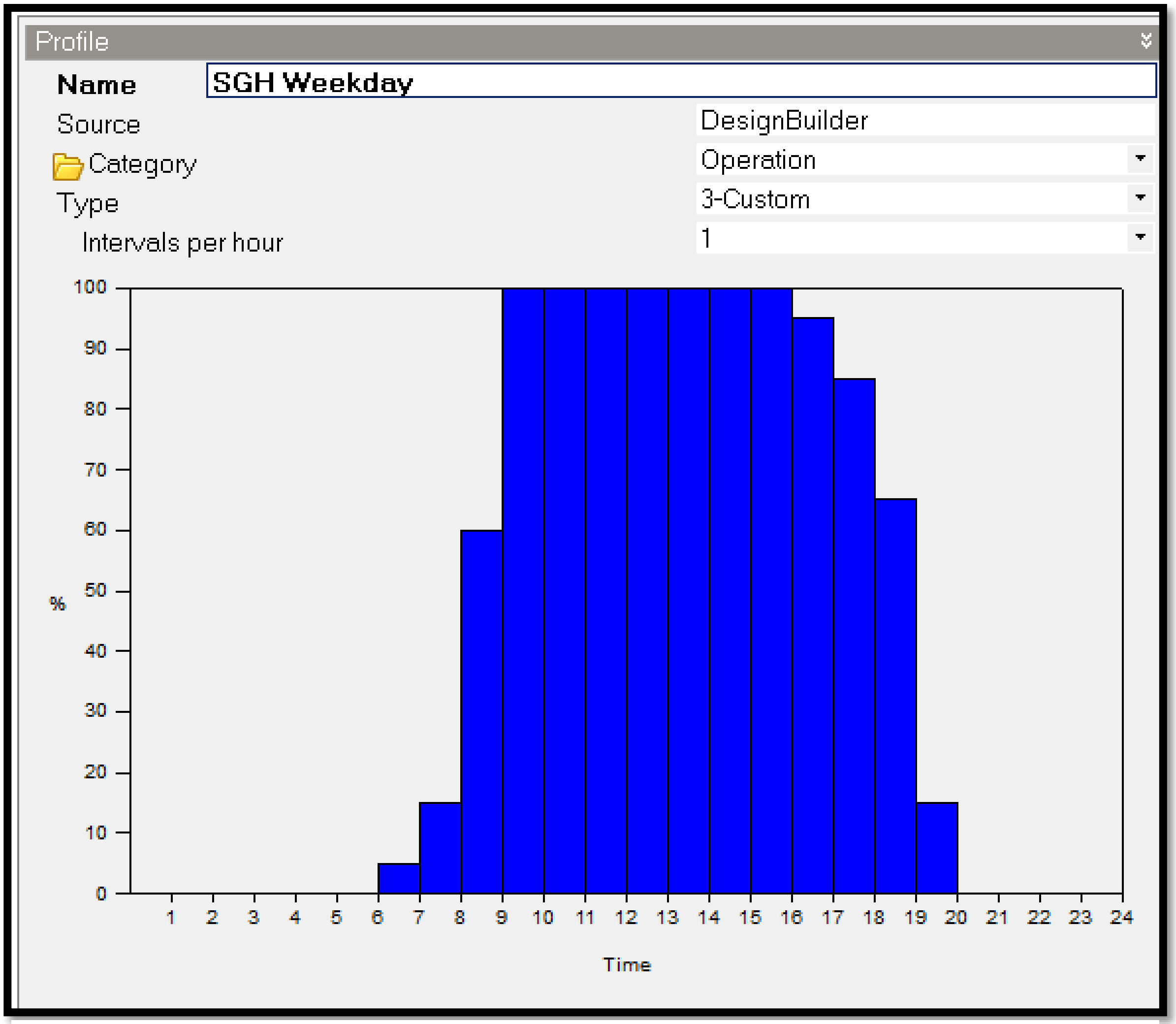

Figure 6.17: SGH Occupant Schedule During a Weekday

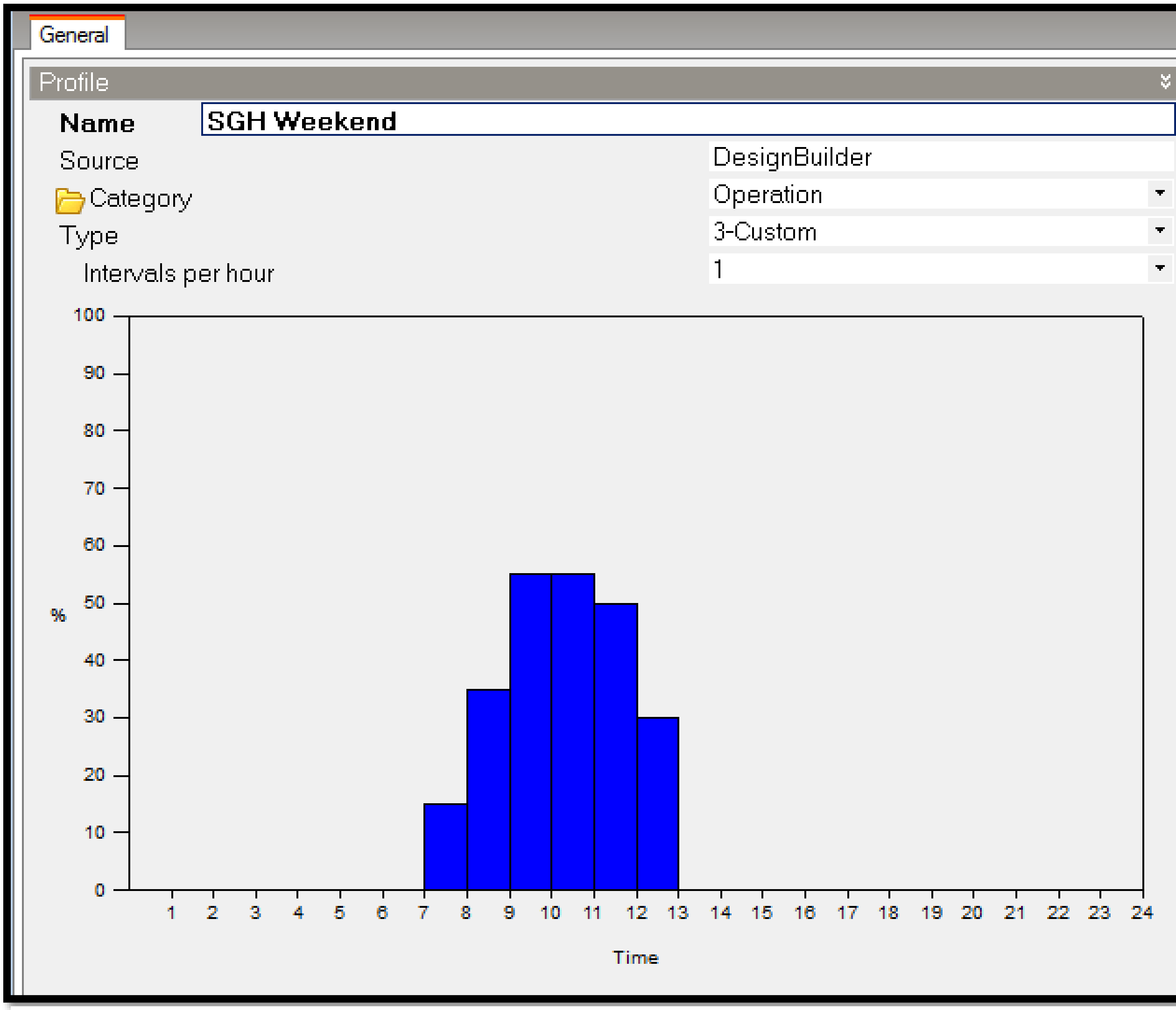

Figure 6.18: SGH Occupant Schedule During the Weekend

Finally, the activity tab of the software was modeled (Figure 6.19). With General Office Area template as a starting point, several options including occupancy, environmental control, and office equipment were modeled. The occupancy density was calculated by dividing the total number of employees by building's total area. The occupancy schedule used for DHW was used again to describe the occupants' activity level. The heating and cooling set point temperatures were inputted based on the building's operation. Lastly, the office equipment input calculated from Section 5.3.2 was modeled.

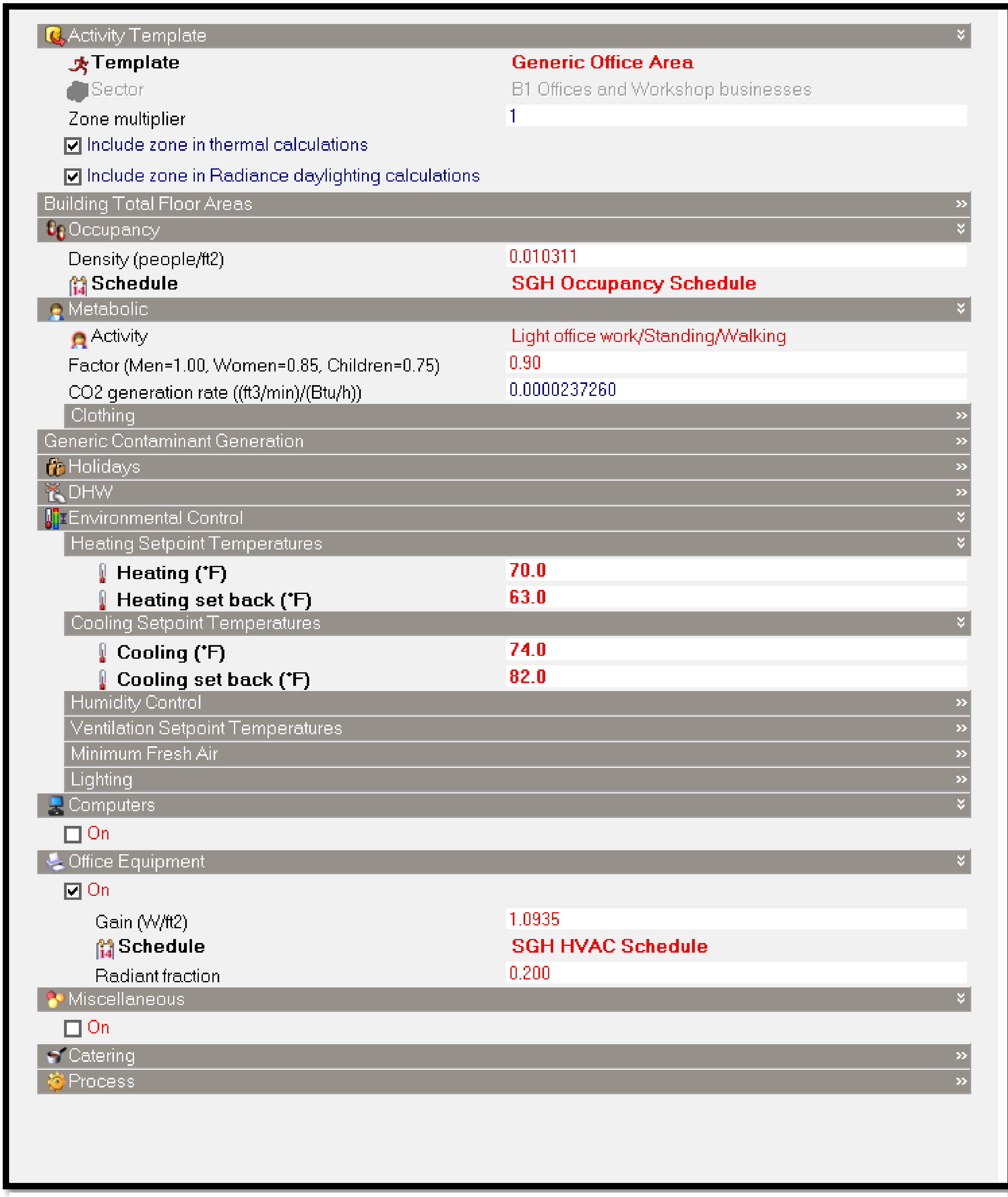

Figure 6.19: Activities Tab of DesignBuilder

6.2 Results

One of the scenarios that we considered when running our simulation was looking at the base building in 2002 and its utility data. The weather file DesignBuilder used to run the simulation was based off of weather data from 2002. Also, for the original building, the utility bill separates the HVAC and plug load energy consumption, allowing us to take a closer look at where the bulk of our error was located. There are only three months of utility data available for the year 2002, and the readings are shown in Table 6.1.

Table 6.1: SGH Energy Consumption (Utility Bill) 2002-2003

Electricity Consumption				
Period	Meter	Prior Reading	Current Reading	kWh Usage
2002 - 2003				
9/10 - 10/10	Dpw 4a2 (HVAC)	145,842	223,201	77,359
	Dpw 4a1	24,111	64,236	40,125
				117,484
10/10 - 11/08	Dpw 4a2 (HVAC)	223,201.0	322,806	99,605
	Dpw 4a1	64,236.0	93,226	28,990
				128,595
11/08 - 12/13	Dpw 4a2 (HVAC)	322,806.0	418,801	95,995
	Dpw 4a1	93,226.0	127,566	34,340
				130,335

We took the full building model as it exists today and used the cut tool to remove the two expansions from the simulation. Then we ran the simulation and recorded the output. What we found was that the overall energy consumption from September 10, 2002 until December 13, 2002 was simulated as 683,296 kBtu, which converts to 217,471 kWh. The utility data readings give a total of 376,414 kWh for the three months. Because we have separate energy consumption data for HVAC and plug loads, we then considered the individual values of the simulation output. For all loads besides heating and cooling, DesignBuilder's output showed 92,694 kWh, versus the 103,455 kWh from the utility (~10.4% difference). DesignBuilder recorded 124,777 kWh for the three months as a result of heating and cooling loads. The utility recorded 272,959 kWh. The difference: approximately 54.3%. The breakdown is shown in Figure 6.20. This supported our findings that the simulated HVAC was not an accurate representation of the actual system; however, it flagged the issue that the HVAC system may not be operating properly, or as intended.

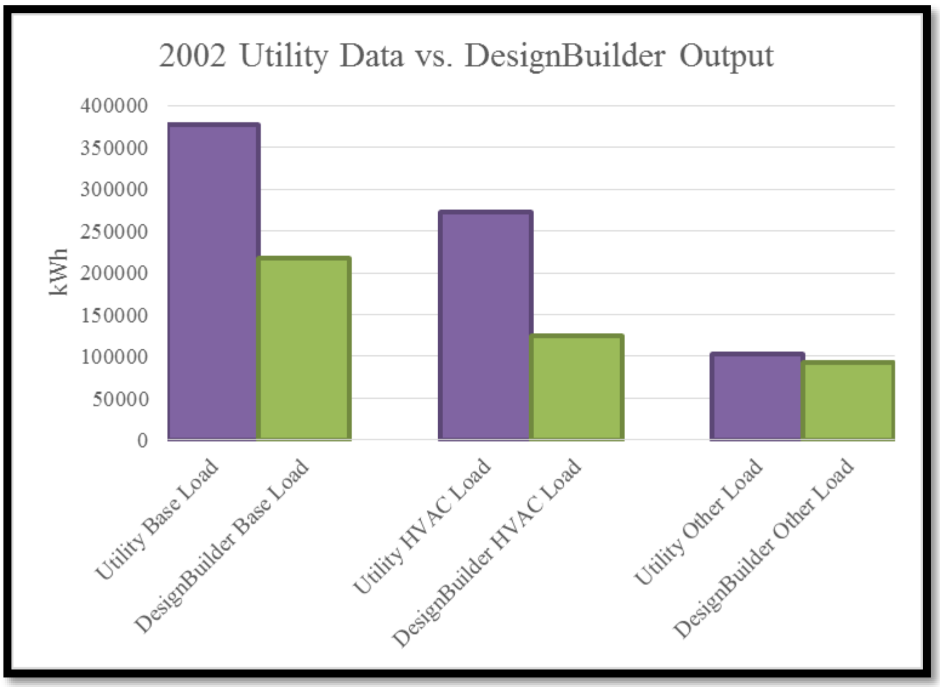

Figure 6.20: 2002 Utility Data vs. DesignBuilder Output

For the main simulation considering the full year, total energy consumption was 6,220,423 kBTU. Though the simulation underpredicts the energy use, especially the HVAC sector, to consider energy conservation measures and model various options, we accepted the values from the simulation results. The energy use breakdown by end uses from the simulation results showed that the majority of the energy consumption was for heating (Table 6.2 and Figure 6.21). With cold New England weather, it was not surprising to see such a high amount of energy spent for heating in a building with a huge volume to surface area ratio like SGH's office building.[84] Compared to the end use of a typical building provided by DOE (Figure 6.22), the SGH building uses a lot of its energy on space heating, As the building heating system skews the SGH's energy use percentage, it is difficult to determine if energy spent on the other sectors are reasonable.[85] Water systems in SGH takes up mere 2 percent of total energy use, which correlates with the 6 percent use in general buildings by percent magnitude. For interior equipment in simulation, electronic (7 percent), refrigeration (4 percent), computers (4 percent), and cooking (2 percent) falls under the category, adding up to 17 percent of total use of an average office building. This percent value correlates with SGH's interior equipment energy use of 17 percent of its total use. Cooling varies slightly by 3 percent difference in magnitude (10 percent in SGH simulation and 13 percent in DOE's data). The lighting takes up significantly less percentage of energy in SGH's building compared to the average commercial building. However, this could be an unfortunate side effect of skewed heating consumption in the SGH building.

Table 6.2: Energy Use Breakdown by End Uses

End Uses	Energy Use (kBTU)
Heating	3524444.4
Cooling	645942.72
Interior Lighting	858007.36
Interior Equipment	1090449.4
Water systems	101579.39
Total	6220423

[84] Behsh, Basam. "Building form as an option for enhancing the indoor thermal conditions." In *Building Physics 2002-6th Nordic Symposium*, 2002.
[85] DOE (U.S. Department of Energy) 2009. 2009 Building Energy Data Book. Available from: http://buildingsdatabook.eren.doe.gov/

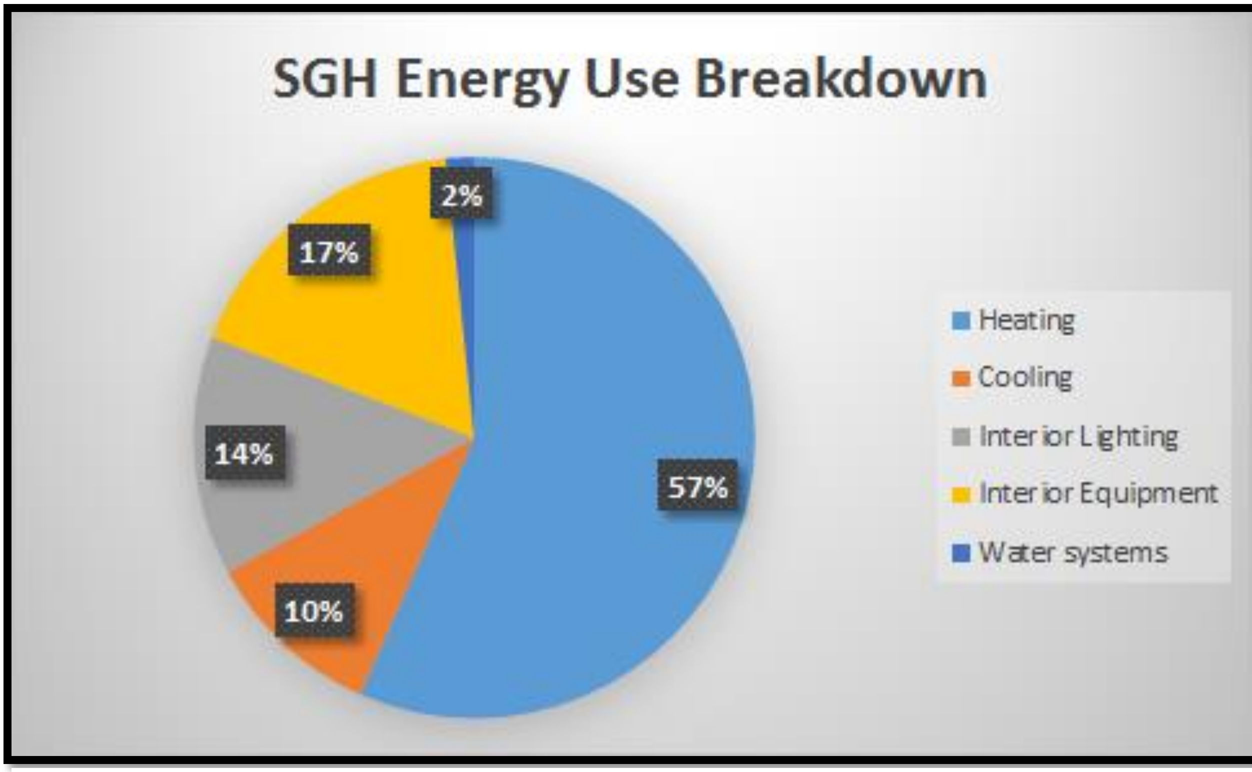

Figure 6.21: Energy Use Breakdown by End Uses Illustrated by Percentage

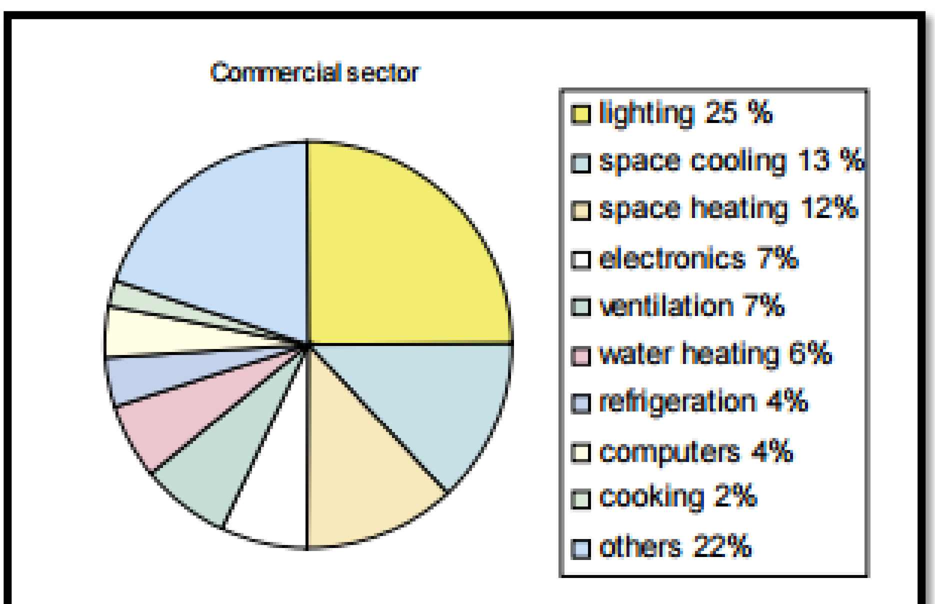

Figure 6.22: Building Site Energy Consumption of a Typical Building by End Use, DOE

From comparing the simulation data with published data from DOE, we established that the overall energy use trend in simulation is acceptable, as our energy simulation results are comparable to the average commercial energy use. To identify the specific cause of the skewed space-heating load, DesignBuilder's heating design was studied (Figure 6.23). From heating design graph, it was identified that the external infiltration was causing significant amount of heat loss in the building. The building was losing –1820.07 kBtu/h due to external infiltration. While the controlled external vent was causing heat loss of –535.61 kBtu/h and conduction through poorly insulated roof was causing –385.18 kBtu/h, the amount of heat loss due to external infiltration was significant. While pressure imposed by building's HVAC system affects some external infiltration, in most cases, the windward face experience wind-driven infiltration.[86] With buildings with huge volume and fenestration like SGH's building, more surface area is exposed to the wind-driven infiltration, causing the significant amount of heat loss due to external infiltration. One of the energy conservation measures was based on the reduction of infiltration to consider how much external infiltration affects heating design.

[86] *Infiltration modeling guidelines for commercial building energy analysis*. USA: Pacific Northwest National Laboratory, 2009.

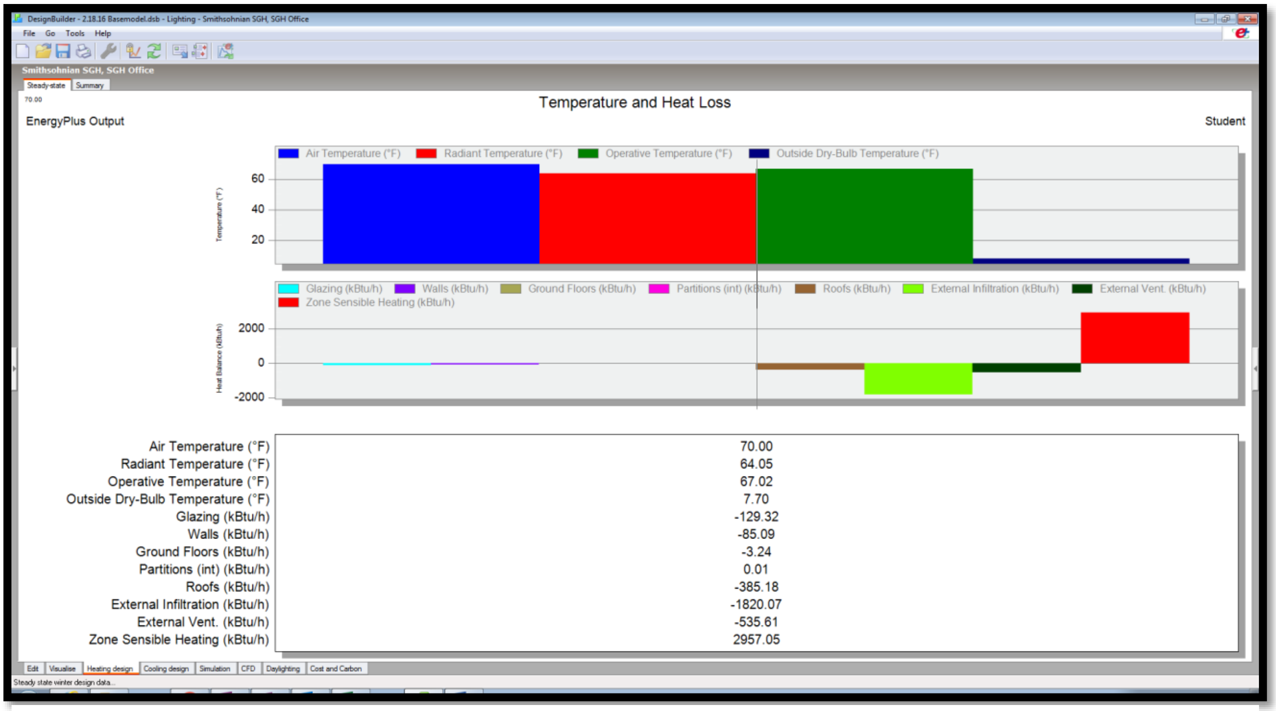

Figure 6.23: Heating Design of the Project from DesignBuilder

7. Proposed Energy Conservation Measures

We considered three energy conservation measures strategies: incorporating weather forecasts into HVAC controls, changing the heating system to radiant floor heating, and increasing air tightness.

7.1 Weather Forecasting

One method to consider for reducing the energy consumption of the building was combining HVAC operation with weather forecasts. That is, if the HVAC operation can be connected to predictive weather data from a local station, then the units can be proactive rather than reactive. Most systems are reactionary: the inside of the building is hot, cold air is supplied. There have been a few studies that have considered this approach.[87] One smaller scale study conducted in Sweden found energy savings up to 20kWh/m^2 (1.86 kWh/ft^2).[88] The technique applied in the project used "equivalent temperature" (ET), which considers a combination of factors: outside air temperature, solar radiation, and wind, and how these factors contribute to the building's indoor environment.

SGH could consider regulating its HVAC system through a similar technique incorporating a smart building automation system, where the HVAC could be controlled by local weather forecasts (and overridden at a local level if needed). When considering the shutdown (November 25-28, 2015) of the mechanical equipment during our investigation, the building

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[87] Frauke Oldewurtel, Allesandra Parisio, Colin N. Jones, et al. "Use of model predictive control and weather forecasts for energy efficient building climate control," *Energy and Buildings* 45, 15-27. http://infoscience.epfl.ch/record/176005/files/frauke_eab_2012.pdf
[88] "Local weather forecasts control building HVAC system," Caddet Energy Efficiency, IEA, 2001. http://gundog.lbl.gov/dirpubs/caddet_weath.pdf
Note: the building in this study did not have a cooling system, so potential savings could be greater.

performed quite well without the assistance of HVAC. The lowest temperatures for the four loggers actively recording during the shutdown were: Logger a [69.22°], Logger B [69.13°], Logger c [65.49°], and Logger D was actually coldest while the HVAC system was active on November 17, at 8:50AM. The outdoor temperature for the days during this shutdown are shown in Table 7.1.

Table 7.1: Weather Data for 11/25-28/2015, WeatherUnderground

Day	High	Low	Average
11-25-2015	51°	28°	38.4°
11-26-2015	63.3°	34.5°	50.1°
11-27-2015	68.5°	54.5°	60.7°
11-28-2015	61.3°	43.5°	52.5°

The average temperatures for these days were below the unoccupied setpoint temperature, although the building still maintained temperatures above the setpoint. If SGH monitored weather forecasts, even if they did not implement an automated building system that regulated HVAC based off of the predictive data, they could manually turn off the system during optimal weather. That is, the user survey showed that many of the occupants were cold throughout the year, regardless of the temperature outside. If the weather were considered more closely, then potential savings could be reached by reducing the chance of overcooling the building. Also, making use of the operable windows during optimal weather and just using fans to move the air could also show energy savings.

7.2 Radiant Floor Heating

We decided to consider radiant floor heating because of the geometry of the building. There is a lot of a floor space, and radiant floor heating could cover this, without necessarily losing heat to the high ceiling along the center of the building. To incorporate radiant floor heating system in the simulation, the template with underfloor heating system and natural ventilation was used. The CoP of the system we modelled was 4.[89] The natural ventilation was set to have 3 ac/h per template. Though the new heating system was much more effective with higher CoP, due to excessive amount of heat loss through uncontrolled natural ventilation with no heat recovery system, the heating load was not reduced by significant amount (Figure 7.1 and Figure 7.2). Furthermore, due to lack of cooling system, temperature control in summer months were at risk. If the separate cooling system were to be installed and maintained, it would offset the pros of the radiant floor heating. Therefore, unless remedies for natural ventilation and cooling is proposed, use of radiant floor heating is not recommended for the system.

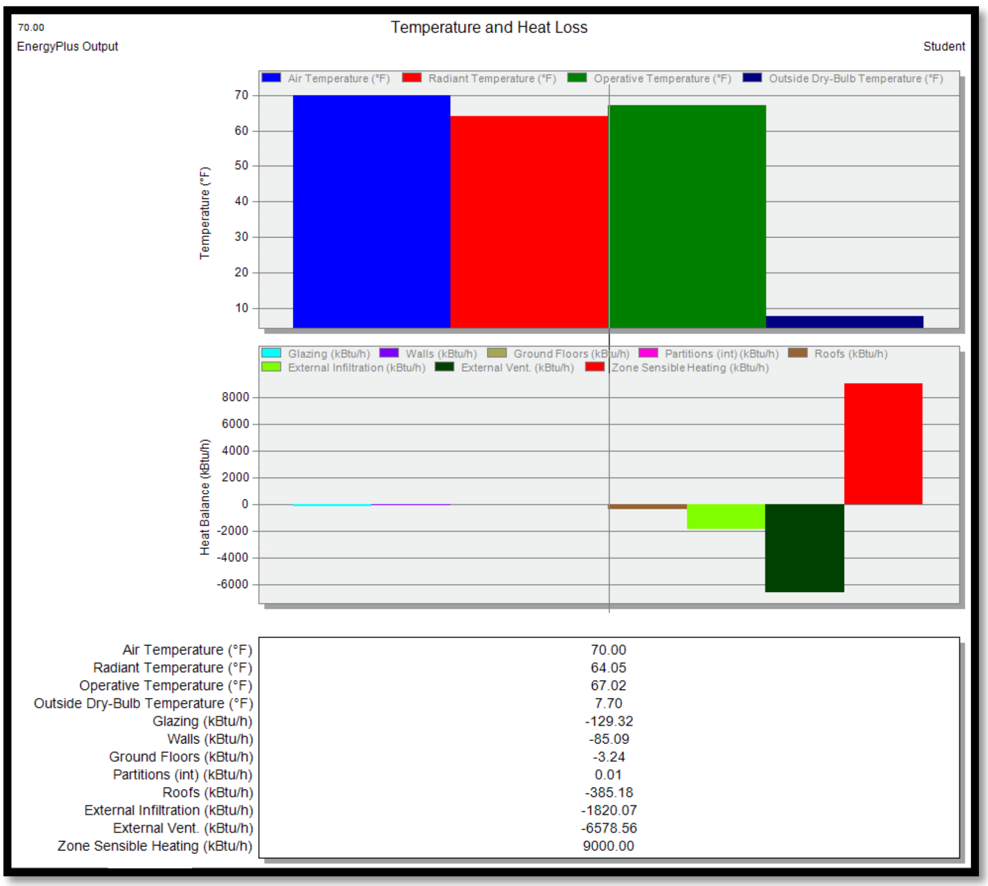

Figure 7.1: The Heating Design Results from DesignBuilder for Radiant Heat Floor HVAC System

89 "Air Tightness to Avoid Structural Damages." Passive House Air Tightness. September 16, 2006. Accessed February 29, 2016. http://passiv.de/former_conferences/Passive_House_E/airtightness_06.html.

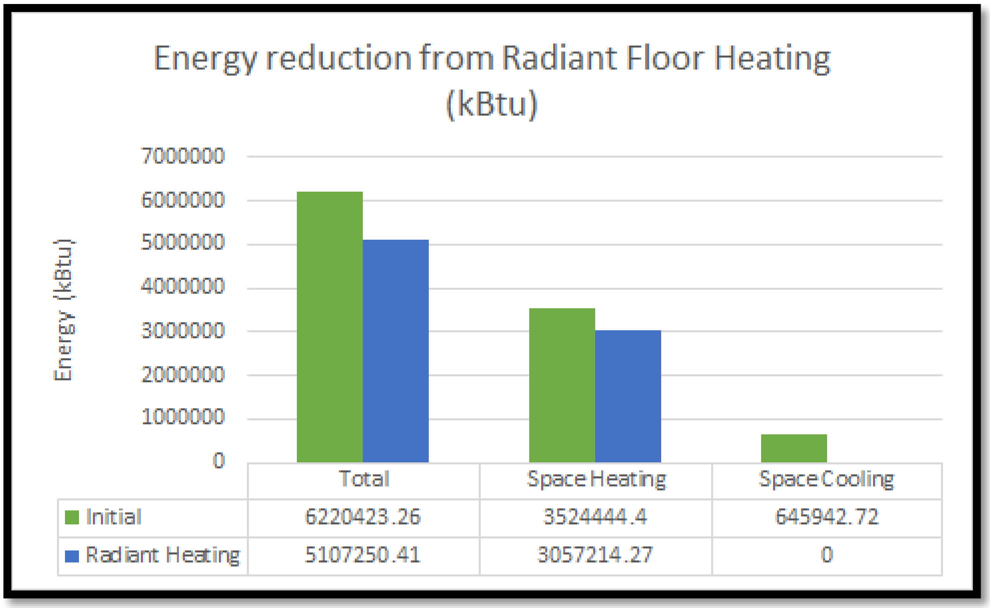

Figure 7.2: Energy Use Comparison Between Initial Results and Radiant Floor Heating Model

7.3 Increased Air Tightness

As pointed out in Section 4.1 Initial Analysis of Results, the external infiltration was a major cause of heat loss in the building. The initial input of 0.83 ach was halved to 0.4 ach to evaluate how much the external infiltration value affect the simulation results. The Heating Design results provided from the simulation showed that the energy lost due to external infiltration was reduced to –877.14 kBtu/h from –1820.07 kBtu/h (Figure 7.3). This reduced the zone sensible heating requirement from 2957.06 kBtu/h to 2014.13 kBtu/h. This reduction in heat loss almost halves the amount of energy used for space heating in the SGH building (Figure 7.4). Any external infiltration values below 0.4 ach is irrational, as 0.6 ach is the passive house requirement for external infiltration.[90] Though 0.4 ach is an impractical value for an office building like SGH's office, the difference in energy consumption for heating between given scenarios highlight the effects infiltration have on the model. Though the cooling load was

[90] "Air Tightness to Avoid Structural Damages." Passive House Air Tightness. September 16, 2006. Accessed February 29, 2016. http://passiv.de/former_conferences/Passive_House_E/airtightness_06.html.

slightly reduced from the infiltration input change, the magnitude of change was insignificant compared to the change in heating load.

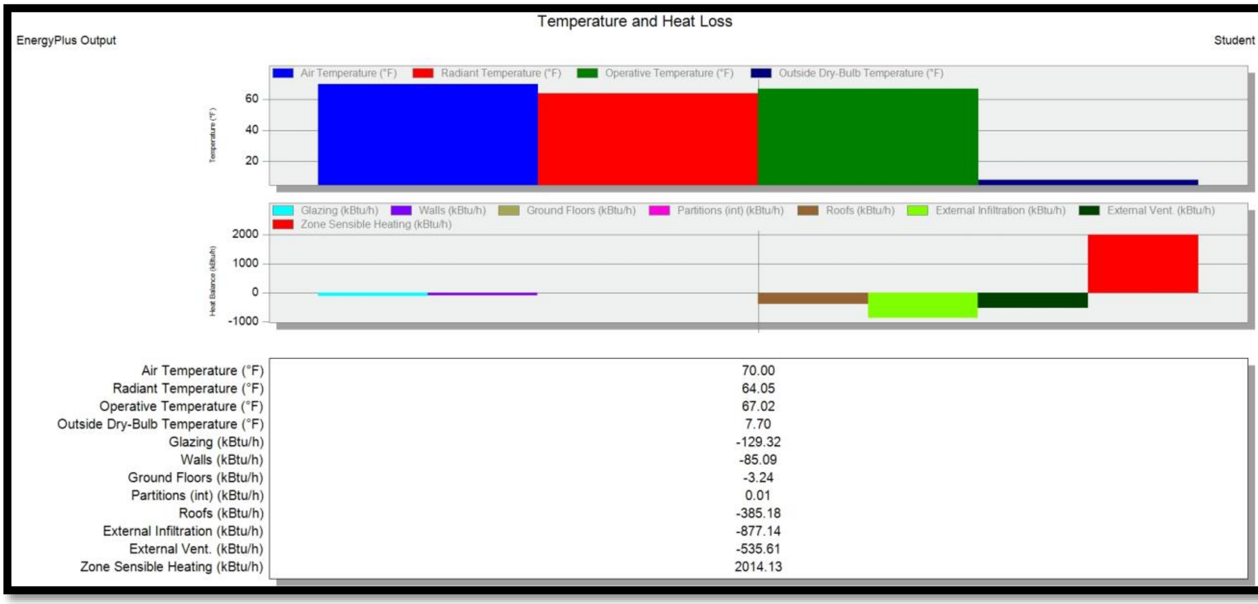

Figure 7.3: Heating Design Results of Air Tight Scenario from DesignBuilder

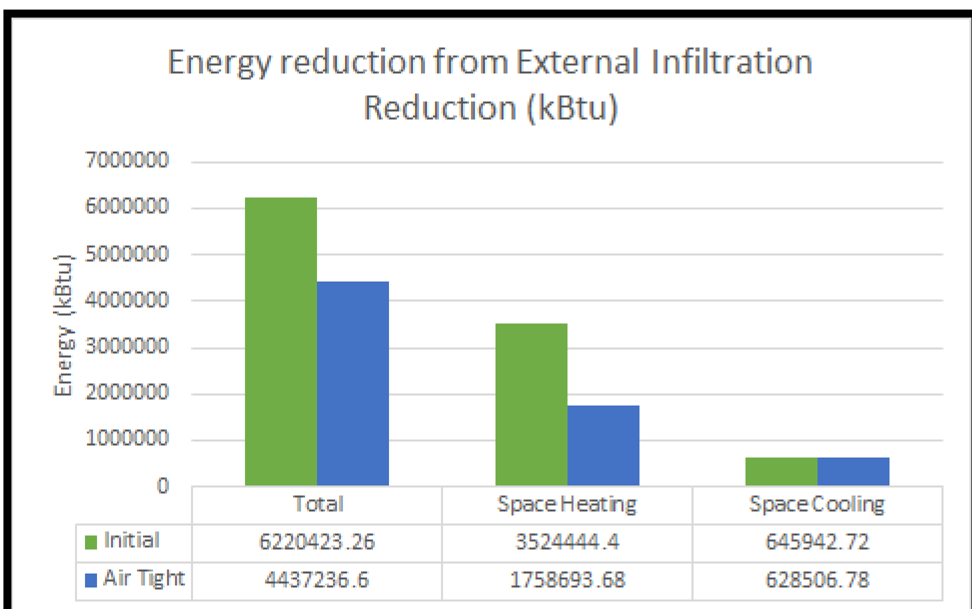

Figure 7.4: Comparison Between Total Energy Use, Heating Energy Use, and Cooling Energy Use of Initial Simulation and Simulation with Higher Air Tightness Value

8. Conclusion

The following section covers the challenges encountered throughout the project, from data collection to simulation. The section is followed by conclusion as well as recommendation for further research.

8.1 Difficulties Encountered

Several challenges were encountered in the study that limited its findings. This section is dedicated to acknowledging these difficulties and the limitations that we experienced as a result.

To begin with, a complete set of as-built drawings for the completed building (included the original renovation, plus the two expansions) were not available. In addition, CAD files with drawings to scale were also not available. This extended the amount of time we dedicated to confirming the building geometry, as well as the building envelope. Because SGH is not the owner of the building, but a tenant, we did not have access to all of the plans, and thus did not have drawings depicting the exterior wall composition, or the roof. We investigated these both, and with the assistance of SGH employees were able to determine the build-up which we implemented into DesignBuilder.

DesignBuilder and our access to computer files, limited our ability to simulate actual weather data from the site, as well as from a year other than 2002. We were unable to use the weather data provided from the SGH weather station, and the closest weather file we could find was located in Bedford, MA. The SGH weather file also did not include a years' worth of data.

Whole building calibrated simulation as a concept in general is difficult to perform and time consuming. According to ASHRAE Guideline 14, one of the minimum requirements for the

Whole Building Calibrated Simulation approach is five years' computer simulation experience and the understanding of simulation data by non-technical personnel is described as "difficult."[91]

Unreliable utility data also proved a difficulty. We were unable to calibrate the model for a variety of reasons, but the utility data was a definite factor. The discrepancies in energy usage from year to year, as well as the lack of sub-metered data made it difficult to determine whether or not the error was located in the simulation or in an irregularity in the utility data.

8.2 Conclusions and Recommendations

In this paper, we have initially reviewed various methods of energy analysis for the project site, SGH office headquarters, located in Waltham. DesignBuilder, a plug-in for EnergyPlus, was concluded to be suitable for the case study. ASHRAE Guideline 14, Measurement of Energy and Demand savings, was used to properly conduct an energy analysis on DesignBuilder. We have collected building data for building geometry, building envelope, lighting, plug loads, HVAC, utility data and spot measurements. Furthermore, a user survey was conducted to ensure better understanding of the occupant behaviors. While inputting the collected data in the software, and calibrating the model to monthly utility data, we observed some irregularity in the office's monthly utility data. Heating Degree Days analysis was conducted on the utility data and it was observed that the building's energy use, especially HVAC operation, did not display any noticeable trend that is expected from buildings located in similar environment.

Though the DesignBuilder model could not be calibrated to the utility data, the closest model produced using measured inputs was used to identify possible energy conservation measures. Out of three considered methods–weather forecasting, radiant floor heating with

[91] ASHRAE Guideline 14-2002, p. 17, 20.

natural ventilation, and increased air tightness–weather forecasting and increased air tightness seemed to be most effective, with weather forecasting being more applicable.

Due to a lack of data and time constraints, we could not further our study in identifying the cause of the oddity in the HVAC system and evaluating energy conservation measures. Therefore, this report recommends further work to:

- collect more information on every HVAC unit with the spot measurement devices
- collect more detailed utility data through sub-metering units
- gain better understanding on the system such as location of thermostats, etc
- research further the claim that increasing air tightness and weather forecasting are effective energy conservation measures.

Establishing the validity of this claim could impact the energy use of SGH's office headquarters in Waltham.

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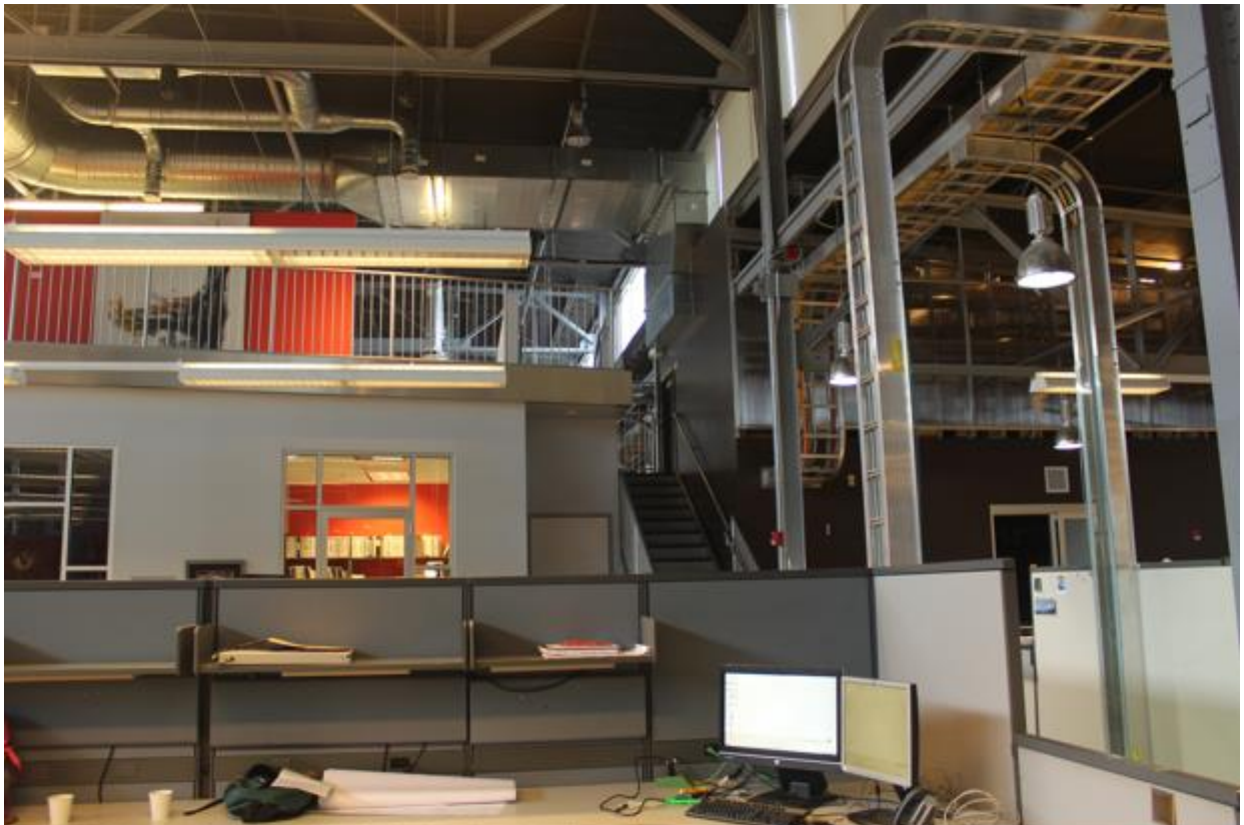
10. Appendix A: Site Photos


Carrier



11. Appendix B: Electricity Consumption Data

Electricity Consumption				
Period	Meter	Prior Reading	Current Reading	kWh Usage
2002 - 2003				
9/10 - 10/10	Dpw 4a2 (HVAC)	145,842	223,201	77,359
	Dpw 4a1	24,111	64,236	40,125
				117,484
10/10 - 11/08	Dpw 4a2 (HVAC)	223,201.0	322,806	99,605
	Dpw 4a1	64,236.0	93,226	28,990
				128,595
11/08 - 12/13	Dpw 4a2 (HVAC)	322,806.0	418,801	95,995
	Dpw 4a1	93,226.0	127,566	34,340
				130,335
2003				
12/13 - 1/10	Dpw 4a2 (HVAC)	418,801.0	480,089	61,288
	Dpw 4a1	127,566.0	154,494	26,928
				88,216
1/10 - 2/13	Dpw 4a2 (HVAC)	480,089.0	565,827	85,738
	Dpw 4a1	154,494.0	190,705	36,211
				121,949
2/13 - 3/12	Dpw 4a2 (HVAC)	565,827.0	621,424	55,597
	Dpw 4a1	190,705.0	218,374	27,669
				83,266
3/12 - 4/10	Dpw 4a2 (HVAC)	621,424.0	664,122	42,698
	Dpw 4a1	218,374.0	247,821	29,447
				72,145
4/10 - 5/9	Dpw 4a2 (HVAC)	664,122.0	706,195	42,073
	Dpw 4a1	247,821.0	275,362	27,541
				69,614
5/9 - 6/10	Dpw 4a2 (HVAC)	706,195	754,095	47,900
	Dpw 4a1	275,362	292,231	16,869
				64,769
6/1 - 7/1	Dpw 4a2 (HVAC)	754,095	803,337	49,242
	Dpw 4a1	292,231	309,422	17,191
				66,433
7/1 - 8/7	Dpw 4a2 (HVAC)	803,337	859,893	56,556
	Dpw 4a1	309,422	329,878	20,456
				77,012
8/7 - 9/11	Dpw 4a2 (HVAC)	859,893	902,579	42,686

	Dpw 4a1	329,878	345,251	15,373
				58,059
9/11 - 10/10	Dpw 4a2 (HVAC)	902,579	944,587	42,008
	Dpw 4a1	345,251	361,496	16,245
				58,253
10/10 - 11/11	Dpw 4a2 (HVAC)	944,587	990,221	45,634
	Dpw 4a1	361,496	377,754	16,258
				61,892
11/11 - 12/12	Dpw 4a2 (HVAC)	990,221	1,039,943	49,722
	Dpw 4a1	377,754	392,658	14,904
				64,626
2004				
12/12/03 - 2/2/04	Dpw 4a2 (HVAC)	1,039,943	1,158,366	118,423
	Dpw 4a1	392,658	421,782	29,124
	Warehouse	0	4,779	4,779
				152,326
2/2- 3/3	Dpw 4a2 (HVAC)	1,158,366	1,214,537	56,171
	Dpw 4a1	421,782	438,069	16,287
	Warehouse	4,779	13,072	8,293
				80,751
3/3-4/6	Dpw 4a2 (HVAC)	1,214,537	1,276,001	61,464
	Dpw 4a1	438,069	451,599	19,530
	Warehouse	13,072	20,951	7,879
				88,873
4/6 -5/4	Dpw 4a2 (HVAC)	1,276,001	1,316,534	40,533
	Dpw 4a1	451,599	473,259	15,660
	Warehouse	20,951	26,280	5,329
				61,522
5/4 - 6/4	Dpw 4a2 (HVAC)	1,316,534	1,316,534	46,386
	Dpw 4a1	473,259	490,027	16,768
	Warehouse	26,280	31,192	4,912
				68,066
6/4 - 7/2	Dpw 4a2 (HVAC)	1,316,534	1,403,865	40,945
	Dpw 4a1	490,027	505,034	15,007
	Warehouse	31,192	35,877	4,685
				60,637
7/2 - 8/10	Dpw 4a2 (HVAC)	1,403,865	1,459,513	55,648
	Dpw 4a1	505,034	525,393	20,359
	Warehouse	35,877	40,411	4,534
				80,541
8/10 - 8/31	Dpw 4a2 (HVAC)	1,459,513	1,491,382	31,869

	Dpw 4a1	525,393	536,279	10,886
	Warehouse	40,411	43,246	2,835
				45,590
8/31- 10/04	Dpw 4a2 (HVAC)	1,491,382	1,540,160	48,778
	Dpw 4a1	536,279	553,815	17,536
	Warehouse	43,246	48,239	4,993
				71,307
10/04 - 11/3	Dpw 4a2 (HVAC)	1,540,160	1,582,868	42,709
	Dpw 4a1	553,815	571,925	18,110
	Warehouse	48,239	53,928	5,689
				66,508
11/3 - 12/01	Dpw 4a2 (HVAC)	1,582,868	1,625,877	43,009
	Dpw 4a1	18924*	35,484	16,560
	Warehouse	53,928	60,694	6,766
				66,335
12/01 - 12/30	Dpw 4a2 (HVAC)	1,625,877	1,682,634	56,757
new meter installed	Dpw 4a1	35,484	79,615	44,131
	Warehouse	60,694	68,918	8,224
				109,112
2005				
12/30 - 1/3	Dpw 4a2 (HVAC)	1,682,634	1,750,152	67,518
	Dpw 4a1	79,615	130,830	51,215
	Warehouse	68,918	78,565	9,647
				128,380
1/31 - 2/28	Dpw 4a2 (HVAC)	1,750,152	1,806,572	56,420
	Dpw 4a1	130,830	179,613	48,783
	Warehouse	78,565	89,191	10,626
				115,829
2/28 - 4/7	Dpw 4a2 (HVAC)	1,806,572	1,866,690	60,118
	Dpw 4a1	179,613	235,993	56,380
	Warehouse	89,191	100,038	10,847
				127,345
4/7 - 5/04	Dpw 4a2 (HVAC)	1,866,690	1,907,278	40,588
	Dpw 4a1	235,993	280,189	44,196
	Warehouse	100,038	107,650	7,612
				92,396
5/4 - 6/30	Dpw 4a2 (HVAC)	1,907,278	1,949,452	42,174
	Dpw 4a1	280,189	325,209	45,020
	Warehouse	107,650	114,944	7,294
				94,488

6/3- 7/8	Dpw 4a2 (HVAC)	1,949,452	2,011,075	61,623
	Dpw 4a1	325,209	380,064	54,855
	Warehouse	114,944	122,854	7,910
				124,388
7/8 - 8/9	Dpw 4a2 (HVAC)	2,011,075	2,074,147	63,072
	Dpw 4a1	380,064	433,073	53,009
	Warehouse	122,854	127,837	4,983
				121,064
8/9- 9/1	Dpw 4a2 (HVAC)	2,074,147	2,116,183	42,036
	Dpw 4a1	433,073	470,391	37,318
	Warehouse	127,837	130,762	2,925
	SGH West (expansion)	0	2	2
				82,281
9/1 - 10/6	Dpw 4a2 (HVAC)	2,116,183	2,174,840	58,657
	Dpw 4a1	470,391	527242	56,851
	Warehouse	130,762	135766	5,004
	SGH West (expansion)	2	2	0
				120,512
10/6 - 11/9	Dpw 4a2 (HVAC)	2,174,840	2,231,398	56,558
	Dpw 4a1	527,242	585,724	58,482
	Warehouse	135,766	141,201	5,435
	SGH West (expansion)	2	4	2
				120,477
11/9 - 12/09	Dpw 4a2 (HVAC)	2,231,398	2,289,669	58,271
	Dpw 4a1	585,724	636,708	50,984
	Warehouse	141,201	145,329	4,128
	SGH West (expansion)	4	4	0
				113,383
12/5 - 12/23	Dpw 4a2 (HVAC)	2,289,669	2,319,176	29,507
	Dpw 4a1	636,708	663,926	27,218
	SGH West (expansion)	4	4	0
	Warehouse	145,329	148,744	3,415
				60,140
2006				
12/23 - 1/31	Dpw 4a2 (HVAC)	2,319,176	2,389,069	69,893
	Dpw 4a1	663,926	732,565	68,639
	SGH West (expansion)	4	12,119	9,184

	Warehouse	148,744	157,928	12,115
				159,831
1/31 - 3/6	Dpw 4a2 (HVAC)	2,389,069	2,452,717	63,648
	Dpw 4a1	732,565	792,173	59,608
	SGH West (expansion)	12,119	85,540	73,421
	Warehouse	157,928	168,220	10,292
				206,969
3/6 - 4/3	Dpw 4a2 (HVAC)	2,452,717	2,498,765	46,048
	Dpw 4a1	792,173	841,883	49,710
	SGH West (expansion)	85,540	141,314	55,774
	Warehouse	168,220	176,245	8,025
				159,557
4/3 - 5/10	Dpw 4a2 (HVAC)	2,498,765	2,559,631	60,866
	Dpw 4a1	841,883	911,056	69,173
	SGH West (expansion)	141,314	214,674	73,360
	Warehouse	176,245	184,859	8,614
				212,013
5/10 - 6/9	Dpw 4a2 (HVAC)	2,559,631	2,605,625	45,994
	Dpw 4a1	911,056	963,573	52,517
	SGH West (expansion)	214,674	273,268	58,594
	Warehouse	184,859	190,934	6,075
				163,180
6/9 - 7/18	Dpw 4a2 (HVAC)	2,605,625	2,681,634	76,009
	Dpw 4a1	963,573	1,036,752	73,179
	SGH West (expansion)	273,268	352,548	79,280
	Warehouse	190,934	197,469	6,535
				235,003
7/18 - 8/7	Dpw 4a2 (HVAC)	2,681,634	2,724,860	43,226
	Dpw 4a1	1,036,752	1,077,000	40,248
	SGH West (expansion)	352,548	393,142	40,594
	Warehouse	197,469	200,362	2,893
				126,961
8/7 - 9/7	Dpw 4a2 (HVAC)	2,724,860	2,786,501	61,641
	Dpw 4a1	1,077,000	1,136,661	59,661
	SGH West (expansion)	393,142	458,169	65,027
	Warehouse	200,362	204,430	4,068
				190,397
9/7 - 10/4	Dpw 4a2 (HVAC)	2,786,501	2,839,262	52,761

	Dpw 4a1	1,136,661	1,185,787	49,126
	SGH West (expansion)	458,169	525,279	67,110
	Warehouse	204,430	207,978	3,548
				172,545
10/4 - 11/3	Dpw 4a2 (HVAC)	2,839,262	2,899,906	60,644
	Dpw 4a1	1,185,787	1,243,595	57,808
	SGH West (expansion)	525,279	614,012	88,733
	Warehouse	207,978	212,296	4,318
				211,503
11/3 - 12/4	Dpw 4a2 (HVAC)	2,899,906	2,953,187	53,281
	Dpw 4a1	1,243,595	1,298,500	54,905
	SGH West (expansion)	614,012	695,653	81,641
	Warehouse	212,296	215,938	3,642
				193,469
12/4 - 1/2	Dpw 4a2 (HVAC)	2,953,187	3,009,526	56,339
	Dpw 4a1	1,298,500	1,351,494	52,994
	SGH West (expansion)	695,653	788,388	92,735
	Warehouse	215,938	220,011	4,073
				206,141
2007				
Jan	Dpw 4a2 (HVAC)	3,009,526	3,087,154	77,628
1/2 - 2/9	Dpw 4a1	1,351,494	1,421,292	69,798
	SGH West (expansion)	788,388	907,615	119,227
	Warehouse	220,011	226,466	6,455
				273,108
Feb	Dpw 4a2 (HVAC)	3,087,154	3,139,387	52,233
2/9 - 3/5	Dpw 4a1	1,421,292	1,465,570	44,278
	SGH West (expansion)	907,615	987,079	79,464
	Warehouse	226,466	230,827	4,361
				180,336
Mar	Dpw 4a2 (HVAC)	3,139,387	3,201,052	61,665
3/5 - 4/4	Dpw 4a1	1,465,570	1,523,698	58,128
	SGH West (expansion)	987,079	1,080,613	93,534
	Warehouse	230,827	236,386	5,559
				218,886
Apr	Dpw 4a2 (HVAC)	3,201,052	3,251,661	50,609
4/4 - 5/1	Dpw 4a1	1,523,698	1,576,600	52,902

	SGH West (expansion)	1,080,613	1,158,259	77,646
	Warehouse	236,386	241,434	5,048
				186,205
May	Dpw 4a2 (HVAC)	3,251,661	3,323,972	72,311
5/1 - 6/5	Dpw 4a1	1,576,600	1,646,454	69,854
	SGH West (expansion)	1,158,259	1,229,168	70,909
	Warehouse	241,434	245,841	4,407
				217,481
Jun	Dpw 4a2 (HVAC)	3,323,972	3,390,650	66,678
6/5 - 7/5	Dpw 4a1	1,646,454	1,708,854	62,400
	SGH West (expansion)	1,229,168	1,277,736	48,568
	Warehouse	245,841	250,132	4,291
				181,937
Jul	Dpw 4a2 (HVAC)	3,390,650	3,462,293	71,643
7/5 - 8/8	Dpw 4a1	1,708,854	1,772,599	63,745
	SGH West (expansion)	1,277,736	1,309,110	31,374
	Warehouse	250,132	254,082	3,950
				170,712
Aug	Dpw 4a2 (HVAC)	3,462,293	3,518,418	56,125
8/8 - 9/5	Dpw 4a1	1,772,599	1,827,936	55,337
	SGH West (expansion)	1,309,110	1,333,951	24,841
	Warehouse	254,082	257,583	3,501
				139,804
Sep	Dpw 4a2 (HVAC)	3,518,418	3,575,587	57,169
9/5 - 10/5	Dpw 4a1	1,827,936	1,888,052	60,116
	SGH West (expansion)	1,333,951	1,359,553	25,602
	Warehouse	257,583	265,419	7,836
				150,723
Oct	Dpw 4a2 (HVAC)	3,575,587	3,633,310	57,723
10/5 - 11/7	Dpw 4a1	1,888,052	1,957,976	69,924
	SGH West (expansion)	1,359,553	1,389,189	29,636
	Warehouse	265,419	270,400	4,981
				162,264
Nov	Dpw 4a2 (HVAC)	3,633,310	3,705,076	71,766
11/7 - 12/20	Dpw 4a1	1,957,976	2,047,669	89,693
	SGH West (expansion)	1,389,189	1,469,423	80,234
	Warehouse	270,400	278,361	7,961

				249,654
Dec	Dpw 4a2 (HVAC)	3,705,076	3,741,382	36,306
12/20 - 1/8	Dpw 4a1	2,047,669	2,090,530	42,861
	SGH West (expansion)	1,469,423	1,514,155	44,732
	Warehouse	278,361	282,897	4,536
				236,579
2008				
Jan	Dpw 4a2 (HVAC)	3,741,382	3,797,732	56,350
1/8 - 2/12	Dpw 4a1	2,090,530	2,158,651	68,121
	SGH West (expansion)	1,514,155	1,593,013	78,858
	Warehouse	282,897	290,606	7,709
				211,038
Feb	Dpw 4a2 (HVAC)	3,797,732	3,857,753	60,021
2/12 - 3/13	Dpw 4a1	2,158,651	2,226,296	67,645
	SGH West (expansion)	1,593,013	1,668,482	75,469
	Warehouse	290,606	297,462	6,856
				209,991
Mar	Dpw 4a2 (HVAC)	3,857,753	3,899,379	41,626
3/13 - 4/11	Dpw 4a1	2,226,296	2,286,340	60,044
	SGH West (expansion)	1,668,482	1,723,262	54,780
	Warehouse	297,462	303,248	5,786
				162,236
Apr	Dpw 4a2 (HVAC)	3,899,379	3,955,247	55,868
4/11 - 5/13	Dpw 4a1	2,286,340	2,356,467	70,127
	SGH West (expansion)	1,723,262	1,777,037	53,775
	Warehouse	303,248	309,392	6,144
				185,914
May	Dpw 4a2 (HVAC)	3,955,247	4,010,008	54,761
5/13 - 6/13	Dpw 4a1	2,356,467	2,420,870	64,403
	SGH West (expansion)	1,777,037	1,788,676	11,639
	Warehouse	309,392	313,076	3,684
Jun				**134,487**
6/13 - 7/14	Dpw 4a2 (HVAC)	4,010,008	4,064,487	54,479
	Dpw 4a1	2,420,870	2,489,265	68,395
	SGH West (expansion)	1,788,676	1,806,507	17,831
	Warehouse	313,076	317,056	3,980
				144,685

Jul	Dpw 4a2 (HVAC)	4,064,487	4,117,224	52,737
	Dpw 4a1	2,489,265	2,554,141	64,876
	SGH West (expansion)	1,806,507	1,825,568	19,061
	Warehouse	317,056	322,017	4,961
				141,635
Aug	Dpw 4a2 (HVAC)	4,117,224	4,171,539	54,315
	Dpw 4a1	2,554,141	2,620,178	66,037
	SGH West (expansion)	1,825,568	1,882,146	56,578
	Warehouse	322,017	326,955	4,938
				181,868
Sep	Dpw 4a2 (HVAC)	4,171,539	4,219,399	47,860
	Dpw 4a1	2,620,178	2,689,170	68,992
	SGH West (expansion)	1,882,146	1,960,581	78,435
	Warehouse	326,955	331,049	4,094
				199,381
Oct	Dpw 4a2 (HVAC)	4,219,399	4,271,732	52,333
	Dpw 4a1	2,689,170	2,760,675	71,505
	SGH West (expansion)	1,960,581	2,068,424	107,843
	Warehouse	331,049	336,380	5,331
				237,012
Nov	Dpw 4a2 (HVAC)	4,271,732	4,321,859	50,127
	Dpw 4a1	2,760,675	2,817,493	56,818
	SGH West (expansion)	2,068,424	2,163,193	94,769
	Warehouse	336,380	342,229	5,849
				207,563
Dec	Dpw 4a2 (HVAC)	4,321,859	4,395,460	73,601
12/15 - 1/20	Dpw 4a1	2,817,493	2,890,908	73,415
	SGH West (expansion)	2,163,193	2,300,935	137,742
	Warehouse	342,229	350,546	8,317
				293,075
2009				
1/20 - 2/9	Dpw 4a2 (HVAC)	4,395,460	4,438,396	42,936
	Dpw 4a1	2,890,908	2,936,928	46,020
	SGH West (expansion)	2,300,935	2,386,264	85,329
	Warehouse	350,546	355,829	5,283
				179,568
2/10 - 3/13	Dpw 4a2 (HVAC)	4,438,396	4,484,273	45,877

	Dpw 4a1	2,936,928	2,996,234	59,306
	SGH West (expansion)	2,386,264	2,482,284	96,020
	Warehouse	355,829	362,510	6,681
				207,884
3/14 - 4/14	Dpw 4a2 (HVAC)	4,484,273	4,532,772	48,499
	Dpw 4a1	2,996,234	3,061,097	64,863
	SGH West (expansion)	2,482,284	2,573,554	91,270
	Warehouse	362,510	369,562	7,052
				211,684
4/15 - 5/19	Dpw 4a2 (HVAC)	4,532,772	4,586,226	53,454
	Dpw 4a1	3,061,097	3,125,701	64,604
	SGH West (expansion)	2,573,554	2,649,751	76,197
	Warehouse	369,562	375,081	5,519
				199,774
5-20 - 6/12	Dpw 4a2 (HVAC)	4,586,226	4,626,473	40,247
	Dpw 4a1	3,125,701	3,173,022	47,321
	SGH West (expansion)	2,649,751	2,703,776	54,025
	Warehouse	375,081	378,741	3,660
				145,253
6/13 - 7/14	Dpw 4a2 (HVAC)	4,626,473	4,684,327	57,854
	Dpw 4a1	3,173,022	3,243,827	70,805
	SGH West (expansion)	2,703,776	2,779,829	76,053
	Warehouse	378,741	383,977	5,236
				209,948
7/15 - 8/19	Dpw 4a2 (HVAC)	4,684,327	4,746,147	61,820
	Dpw 4a1	3,243,827	3,310,610	66,783
	SGH West (expansion)	2,779,829	2,842,771	62,942
	Warehouse	383,977	389,138	5,161
				196,706
8/20 - 9/15	Dpw 4a2 (HVAC)	4,746,147	4,793,556	47,409
	Dpw 4a1	3,310,610	3,363,900	53,290
	SGH West (expansion)	2,842,771	2,897,864	55,093
	Warehouse	389,138	393,568	4,430
				160,222
9/16 - 10/19	Dpw 4a2 (HVAC)	4,793,556	4,845,434	51,878
	Dpw 4a1	3,363,900	3,434,976	71,076
	SGH West (expansion)	2,897,864	2,970,707	72,843

	Warehouse	393,568	399,915	6,347
				202,144
10/20 - 11/17	Dpw 4a2 (HVAC)	4,845,434	4,884,306	38,872
	Dpw 4a1	3,434,976	3,493,060	58,084
	SGH West (expansion)	2,970,707	3,017,576	46,869
	Warehouse	399,915	404,650	4,735
				148,560
11/17 - 12/18	Dpw 4a2 (HVAC)	4,884,306	4,934,569	50,263
	Dpw 4a1	3,493,060	3,555,014	61,954
	SGH West (expansion)	3,017,576	3,068,416	50,840
	Warehouse	404,650	410,365	5,715
				168,772
12/18 - 1/14/10	Dpw 4a2 (HVAC)	4,934,569	4,986,313	51,744
	Dpw 4a1	3,555,014	3,607,554	52,540
	SGH West (expansion)	3,068,416	3,121,989	53,573
	Warehouse	410,365	415,322	4,957
				162,814
2010				
1/15 - 2/17	Dpw 4a2 (HVAC)	4,986,313	5,048,567	62,254
	Dpw 4a1	3,607,554	3,680,728	73,174
	SGH West (expansion)	3,121,989	3,186,001	64,012
	Warehouse	415,322	421,396	6,074
				205,514
2/18 - 3/17	Dpw 4a2 (HVAC)	5,048,567	5,093,258	44,691
	Dpw 4a1	3,680,728	3,767,563	86,835
	SGH West (expansion)	3,186,001	3,228,066	42,065
	Warehouse	421,396	425,938	4,542
				178,133
3/17 - 4/16	Dpw 4a2 (HVAC)	5,093,258	5,142,122	48,864
	Dpw 4a1	3,767,563	3,805,469	37,906
	SGH West (expansion)	3,228,066	3,270,475	42,409
	Warehouse	425,938	430,771	4,833
				134,012
4/16 - 5/13	Dpw 4a2 (HVAC)	5,142,122	5,182,872	40,750
	Dpw 4a1	3,805,469	3,861,827	56,358
	SGH West (expansion)	3,270,475	3,301,529	31,054
	Warehouse	430,771	434,761	3,990

				132,152
5/13 - 6/15	Dpw 4a2 (HVAC)	5,182,872	5,238,347	55,475
	Dpw 4a1	3,861,827	3,932,454	70,627
	SGH West (expansion)	3,301,529	3,342,057	40,528
	Warehouse	434,761	439,868	5,107
				171,737
6/15 - 7/16	Dpw 4a2 (HVAC)	5,238,347	5,301,203	62,856
	Dpw 4a1	3,932,454	3,995,113	62,659
	SGH West (expansion)	3,342,057	3,377,399	35,342
	Warehouse	439,868	442,860	2,992
				163,849
7/16 - 8/13	Dpw 4a2 (HVAC)	5,301,203	5,357,644	56,441
	Dpw 4a1	3,995,113	4,051,683	56,570
	SGH West (expansion)	3,377,399	3,408,789	31,390
	Warehouse	442,860	446,587	3,727
				148,128
8/13 - 9/15	Dpw 4a2 (HVAC)	5,357,644	5,412,059	54,415
	Dpw 4a1	4,051,683	4,116,123	64,440
	SGH West (expansion)	3,408,789	3,449,807	41,018
	Warehouse	446,587	451,097	4,510
				164,383
9/15 - 10/14	Dpw 4a2 (HVAC)	5,412,059	5,454,746	42,687
	Dpw 4a1	4,116,123	4,174,406	58,283
	SGH West (expansion)	3,449,807	3,484,525	34,718
	Warehouse	451,097	456,095	4,998
				140,686
10/14 - 11/15	Dpw 4a2 (HVAC)	5,454,746	5,498,873	44,127
	Dpw 4a1	4,174,406	4,240,241	65,835
	SGH West (expansion)	3,484,525	3,522,593	38,068
	Warehouse	456,095	460,863	4,768
				152,798
11/15 - 12/20	Dpw 4a2 (HVAC)	5,498,873	5,548,838	49,965
	Dpw 4a1	4,240,241	4,309,828	69,587
	SGH West (expansion)	3,522,593	3,567,142	44,549
	Warehouse	460,863	466,845	5,982
				170,083
12/20 - 1/19/11	Dpw 4a2 (HVAC)	5,548,838	5,619,726	70,888
	Dpw 4a1	4,309,828	4,379,242	69,414

	SGH West (expansion)	3,567,142	3,635,563	68,421
	Warehouse	466,845	472,485	5,640
				214,363
2011				
1/19 - 2/16	Dpw 4a2 (HVAC)	5,619,726	5,684,127	64,401
	Dpw 4a1	4,379,242	4,441,275	62,033
	SGH West (expansion)	3,635,563	3,693,905	58,342
	Warehouse	472,485	477,455	4,970
				189,746
2/16 - 3/15	Dpw 4a2 (HVAC)	5,684,127	5,777,082	92,955
	Dpw 4a1	4,441,275	4,495,907	54,632
	SGH West (expansion)	3,693,905	3,738,343	44,438
	Warehouse	477,455	481,743	4,288
				196,313
3/15 - 4/15	Dpw 4a2 (HVAC)	5,777,082	5,831,275	54,193
	Dpw 4a1	4,495,907	4,562,360	66,453
	SGH West (expansion)	3,738,343	3,758,917	20,574
	Warehouse	481,743	486,708	4,965
				146,185
4/15 - 5/16	Dpw 4a2 (HVAC)	5,831,275	5,873,756	42,481
	Dpw 4a1	4,562,360	4,628,299	65,939
	SGH West (expansion)	3,758,917	3,777,387	18,470
	Warehouse	486,708	489,827	3,119
				130,009
5/16-6/20	Dpw 4a2 (HVAC)	5,873,756	5,930,937	57,181
	Dpw 4a1	4,628,299	4,703,960	75,661
	SGH West (expansion)	3,777,387	3,800,054	22,667
	Warehouse	489,827	495,550	5,723
				161,232
6/20 - 7/18	Dpw 4a2 (HVAC)	5,930,937	5,983,347	52,410
	Dpw 4a1	4,703,960	4,764,392	60,432
	SGH West (expansion)	3,800,054	3,815,370	15,316
	Warehouse	495,550	498,774	3,224
				131,382
7/18 - 8/24	Dpw 4a2 (HVAC)	5,983,347	6,048,249	64,902
	Dpw 4a1	4,764,392	4,844,258	79,866
	SGH West (expansion)	3,815,370	3,843,569	28,199

	Warehouse	498,774	502,594	3,820
				176,787
8/24 - 9/16	Dpw 4a2 (HVAC)	6,048,249	6,077,652	29,403
	Dpw 4a1	4,844,258	4,893,507	49,249
	SGH West (expansion)	3,843,569	3,864,100	20,531
	Warehouse	502,594	506,010	3,416
				102,599
9/16 - 10/17	Dpw 4a2 (HVAC)	6,077,652	6,111,160	33,508
	Dpw 4a1	4,893,507	4,962,551	69,044
	SGH West (expansion)	3,864,100	3,894,311	30,211
	Warehouse	506,010	510,947	4,937
				137,700
10/17 - 11/17	Dpw 4a2 (HVAC)	6,111,160	6,138,910	27,750
	Dpw 4a1	4,962,551	5,126,481	163,930
	SGH West (expansion)	3,894,311	3,922,590	28,279
	Warehouse	510,947	516,423	5,476
				225,435
11/17 - 12/16	Dpw 4a2 (HVAC)	6,138,910	6,166,977	28,067
	Dpw 4a1	5,126,481	5,195,994	69,513
	SGH West (expansion)	3,922,590	3,963,912	41,322
	Warehouse	516,423	520,797	4,374
				143,276
2012				
12/16 - 1/17/12	Dpw 4a2 (HVAC)	6,166,977	6,213,134	46,157
	Dpw 4a1	5,195,994	5,220,607	24,613
	SGH West (expansion)	3,963,912	4,008,227	44,315
	Expansion II		12,385	12,385
	Warehouse	520,797	526,636	5,839
				133,309
1/17 - 2/17	Dpw 4a2 (HVAC)	6,213,134	6,253,247	40,113
	Dpw 4a1	5,220,607	5,237,351	16,744
	SGH West (expansion)	4,008,227	4,048,101	39,874
	Expansion II	12,385	52,507	40,122
	Warehouse	526,636	531,333	4,697
				141,550
2/17 - 3/16	Dpw 4a2 (HVAC)	6,253,247	6,293,734	40,487
	Dpw 4a1	5,237,351	5,298,748	61,397

	SGH West (expansion)	4,048,101	4,088,234	40,133
	Expansion II	52,507	88,746	36,239
	Warehouse	531,333	535,319	3,986
				182,242
3/16 - 4/18	Dpw 4a2 (HVAC)	6,293,734	6,336,561	42,827
	Dpw 4a1	5,298,748	5,372,591	73,843
	SGH West (expansion)	4,088,234	4,134,559	46,325
	Expansion II	88,746	130,146	41,400
	Warehouse	535,319	539,757	4,438
				208,833
4/18 - 5/18	Dpw 4a2 (HVAC)	6,336,561	6,371,895	35,334
	Dpw 4a1	5,372,591	5,436,666	64,075
	SGH West (expansion)	4,134,559	4,174,378	39,819
	Expansion II	130,146	163,251	33,105
	Warehouse	539,757	544,666	4,909
				177,242
5/18 - 6/18	Dpw 4a2 (HVAC)	6,371,895	6,414,623	42,728
	Dpw 4a1	5,436,666	5,509,274	72,608
	SGH West (expansion)	4,174,378	4,214,152	39,774
	Expansion II	163,251	200,756	37,505
	Warehouse	544,666	549,506	4,840
				197,455
6/18 - 7/18	Dpw 4a2 (HVAC)	6,414,623	6,472,990	58,367
	Dpw 4a1	5,509,274	5,575,982	66,708
	SGH West (expansion)	4,214,152	4,242,683	28,531
	Expansion II	200,756	235,495	34,739
	Warehouse	549,506	553,691	4,185
				192,530
7/18 - 8/17	Dpw 4a2 (HVAC)	6,472,990	6,536,742	63,752
	Dpw 4a1	5,575,982	5,657,755	81,773
	SGH West (expansion)	4,242,683	4,272,246	29,563
	Expansion II	235,495	273,840	38,345
	Warehouse	553,691	558,331	4,640
				218,073
8/17 - 9/19	Dpw 4a2 (HVAC)	6,536,742	6,594,987	58,245
	Dpw 4a1	5,657,755	5,740,198	82,443
	SGH West (expansion)	4,272,246	4,303,413	31,167
	Expansion II	273,840	311,424	37,584

	Warehouse	558,331	562,666	4,335
				213,774
9/19-10/19	Dpw 4a2 (HVAC)	6,594,987	6,637,948	42,961
	Dpw 4a1	5,740,198	5,808,505	68,307
	SGH West (expansion)	4,303,413	4,338,187	34,774
	Expansion II	311,424	348,532	37,108
	Warehouse	562,666	567,643	4,977
				188,127
10/19-11/16	Dpw 4a2 (HVAC)	6,637,948	6,682,544	44,596
	Dpw 4a1	5,808,505	5,864,811	56,306
	SGH West (expansion)	4,338,187	4,364,450	26,263
	Expansion II	348,532	381,723	33,191
	Warehouse	567,643	573,549	5,906
				166,262
11/16-12/19	Dpw 4a2 (HVAC)	6,682,544	6,738,519	55,975
	Dpw 4a1	5,864,811	5,934,090	69,279
	SGH West (expansion)	4,364,450	4,403,169	38,719
	Expansion II	381,723	421,423	39,700
	Warehouse	573,549	581,442	7,893
				211,566
2013				
12/19- 1/17	Dpw 4a2 (HVAC)	6,738,519	6,793,384	54,865
	Dpw 4a1	5,934,090	5,991,746	57,656
	SGH West (expansion)	4,403,169	4,440,306	37,137
	Expansion II	421,423	458,953	37,530
	Warehouse	581,442	588,071	6,629
				193,817
1/17-2/1	Dpw 4a2 (HVAC)	6,793,384	6,820,828	27,444
	Dpw 4a1	5,991,746	6,020,835	29,089
	SGH West (expansion)	4,440,306	4,458,769	18,463
	Expansion II	458,953	481,618	22,665
	Warehouse	588,071	591,932	3,861
				101,522
2/1-2/15	Dpw 4a2 (HVAC)	6,820,828	6,850,233	29,405
	Dpw 4a1	6,020,835	6,052,002	31,167
	SGH West (expansion)	4,458,769	4,478,551	19,782
	Expansion II	481,618	505,901	24,283
	Warehouse	591,932	593,068	1,136

				105,773
2/15 - 3/15	Dpw 4a2 (HVAC)	6,850,233	6,900,073	49,840
	Dpw 4a1	6,052,002	6,110,148	58,146
	SGH West (expansion)	4,478,551	4,511,497	32,946
	Expansion II	505,901	548,492	42,591
	Warehouse	593,068	604,517	11,449
				194,972
3/15-4/18	Dpw 4a2 (HVAC)	6,900,073	6,953,707	53,634
	Dpw 4a1	6,110,148	6,183,054	72,906
	SGH West (expansion)	4,511,497	4,550,010	38,513
	Expansion II	548,492	592,007	43,515
	Warehouse	604,517	614,408	9,891
				218,459
4/18 - 5/18	Dpw 4a2 (HVAC)	6,953,707	6,996,753	43,046
	Dpw 4a1	6,183,054	6,246,254	63,200
	SGH West (expansion)	4,550,010	4,581,624	31,614
	Expansion II	592,007	625,628	33,621
	Warehouse	614,408	620,801	6,393
				177,874
5/18 - 6/17	Dpw 4a2 (HVAC)	6,996,753	7,048,243	51,490
	Dpw 4a1	6,246,254	6,317,819	71,565
	SGH West (expansion)	4,581,624	4,614,249	32,625
	Expansion II	625,628	661,664	36,036
	Warehouse	620,801	627,168	6,367
				198,083
6/17-7/16	Dpw 4a2 (HVAC)	7,048,243	7,116,336	68,093
	Dpw 4a1	6,317,819	6,386,787	68,968
	SGH West (expansion)	4,614,249	4,640,080	25,831
	Expansion II	661,664	698,136	36,472
	Warehouse	627,168	631,907	4,739
				204,103
7/16-8/16	Dpw 4a2 (HVAC)	7,116,336	7,175,469	59,133
	Dpw 4a1	6,386,787	6,455,701	68,914
	SGH West (expansion)	4,640,080	4,664,690	24,610
	Expansion II	698,136	733,287	35,151
	Warehouse	631,907	638,001	6,094
				193,902

8/16-9/19	Dpw 4a2 (HVAC)	7,175,469	7,240,470	65,001
	Dpw 4a1	6,455,701	6,531,756	76,055
	SGH West (expansion)	4,664,690	4,688,809	24,119
	Expansion II	733,287	774,437	41,150
	Warehouse	638,001	645,256	7,255
				213,580
9/19-10/17	Dpw 4a2 (HVAC)	7,240,470	7,290,304	49,834
	Dpw 4a1	6,531,756	6,597,198	65,442
	SGH West (expansion)	4,688,809	4,709,441	20,632
	Expansion II	774,437	808,969	34,532
	Warehouse	645,256	650,194	4,938
				175,378
10/17-11/19	Dpw 4a2 (HVAC)	7,290,304	7,348,473	58,169
	Dpw 4a1	6,597,198	6,672,326	75,128
	SGH West (expansion)	4,709,441	4,742,842	33,401
	Expansion II	808,969	844,413	35,444
	Warehouse	650,194	655,842	5,648
				207,790
11/19-12/19	Dpw 4a2 (HVAC)	7,348,473	7,419,399	70,926
	Dpw 4a1	6,672,326	6,738,038	65,712
	SGH West (expansion)	4,742,842	4,784,046	41,204
	Expansion II	844,413	866,086	21,673
	Warehouse	655,842	660,978	5,136
				204,651
2014				
12/19-1/17	Dpw 4a2 (HVAC)	7,419,399	7,484,918	65,519
	Dpw 4a1	6,738,038	6,801,247	63,209
	SGH West (expansion)	4,784,046	4,826,273	42,227
	Expansion II	866,086	925,886	59,800
	Warehouse	660,978	665,242	4,264
				235,019
1/17-2/18	Dpw 4a2 (HVAC)	7,484,918	7,556,397	71,479
	Dpw 4a1	6,801,247	6,880,245	78,998
	SGH West (expansion)	4,826,273	4,867,901	41,628
	Expansion II	925,886	968,039	42,153
	Warehouse	665,242	672,489	7,247
				241,505
2/18-3/18	Dpw 4a2 (HVAC)	7,556,397	7,613,936	57,539

	Dpw 4a1	6,880,245	6,948,675	68,430
	SGH West (expansion)	4,867,901	4,900,975	33,074
	Expansion II	968,039	1,003,965	35,926
	Warehouse	672,489	679,812	7,323
				202,292
3/18-4/18	Dpw 4a2 (HVAC)	7,613,936	7,672,093	58,157
	Dpw 4a1	6,948,675	7,021,709	73,034
	SGH West (expansion)	4,900,975	4,932,433	31,458
	Expansion II	1,003,965	1,041,055	37,090
	Warehouse	679,812	687,084	7,272
				207,011
4/18-5/20	Dpw 4a2 (HVAC)	7,672,093	7,731,125	59,032
	Dpw 4a1	7,021,709	7,089,016	67,307
	SGH West (expansion)	4,932,433	4,959,495	27,062
	Expansion II	1,041,055	1,074,705	33,650
	Warehouse	687,084	691,872	4,788
				191,839
5/20-6/13	Dpw 4a2 (HVAC)	7,731,125	7,777,982	46,857
	Dpw 4a1	7,089,016	7,141,569	52,553
	SGH West (expansion)	4,959,495	4,977,450	17,955
	Expansion II	1,074,705	1,102,683	27,978
	Warehouse	691,872	695,051	3,179
				148,522
6/13-7/15	Dpw 4a2 (HVAC)	7,777,982	7,836,079	58,097
	Dpw 4a1	7,141,569	7,212,739	71,170
	SGH West (expansion)	4,977,450	4,998,384	20,934
	Expansion II	1,102,683	1,148,671	45,988
	Warehouse	695,051	699,195	4,144
				200,333
7/15-8/15	Dpw 4a2 (HVAC)	7,836,079	7,882,512	46,433
	Dpw 4a1	7,212,739	7,283,566	70,827
	SGH West (expansion)	4,998,384	5,019,305	20,921
	Expansion II	1,148,671	1,199,298	50,627
	Warehouse	699,195	703,401	4,206
				193,014
	storage 431	5	6	1
	storage 432	233	463	230
	storage 433			0

8/15-9/12	Dpw 4a2 (HVAC)	7,882,512	7,921,260	38,748
	Dpw 4a1	7,283,566	7,343,429	59,863
	SGH West (expansion)	5,019,305	5,037,181	17,876
	Expansion II	1,199,298	1,239,262	39,964
	Warehouse	703,401	707,356	3,955
	storage 431	6	6	0
	storage 432	463	616	153
	storage 433			
				160,559
9/12-10/14	Dpw 4a2 (HVAC)	7,921,260	7,961,893	40,633
	Dpw 4a1	7,343,429	7,415,679	72,250
	SGH West (expansion)	5,037,181	5,062,024	24,843
	Expansion II	1,239,262	1,288,351	49,089
	Warehouse	707,356	712,914	5,558
	storage 431	6	6	0
	storage 432	616	789	173
	storage 433		557	557
				193,103
10/14-11/17	Dpw 4a2 (HVAC)	7,961,893	8,006,319	44,426
	Dpw 4a1	7,415,679	7,490,016	74,337
	SGH West (expansion)	5,062,024	5,093,774	31,750
	Expansion II	1,288,351	1,332,849	44,498
	Warehouse	712,914	718,143	5,229
	storage 431	6	8	2
	storage 432	789	997	208
	storage 433	557	1,165	608
				201,058
11/17-12/12	Dpw 4a2 (HVAC)	8,006,319	8,048,382	42,063
	Dpw 4a1	7,490,016	7,546,794	56,778
	SGH West (expansion)	5,093,774	5,120,972	27,198
	Expansion II	1,332,849	1,361,332	28,483
	Warehouse	718,143	722,722	4,579
	storage 431	8	8	0
	storage 432	997	1,138	141
	storage 433	1,165	1,946	781
				160,023
2015				
12/12-1/14	Dpw 4a2 (HVAC)	8,048,382	8,100,540	52,158

	Dpw 4a1	7,546,794	7,612,700	65,906
	SGH West (expansion)	5,120,972	5,158,761	37,789
	Expansion II	1,361,332	1,394,509	33,177
	Warehouse	722,722	728,517	5,795
	storage 431	8	9	1
	storage 432	1,138	1,308	170
	storage 433	1,946	3,656	1,710
				196,706
1/14-2/16	Dpw 4a2 (HVAC)	8,100,540	8,165,629	65,089
	Dpw 4a1	7,612,700	7,683,241	70,541
	SGH West (expansion)	5,158,761	5,199,210	40,449
	Expansion II	1,394,509	1,436,172	41,663
	Warehouse	728,517	734,851	6,334
	storage 431	9	9	0
	storage 432	1,308	1,493	185
	storage 433	3,656	7,023	3,367
				227,628
2/16-3/16	Dpw 4a2 (HVAC)	8,165,629	8,223,068	57,439
	Dpw 4a1	7,683,241	7,744,225	60,984
	SGH West (expansion)	5,199,210	5,230,597	31,387
	Expansion II	1,436,172	1,467,512	31,340
	Warehouse	734,851	739,898	5,047
	storage 431	9	9	0
	storage 432	1,493	1,638	145
	storage 433	7,023	9,169	2,146
				188,488
3/16-4/14	Dpw 4a2 (HVAC)	8,223,068	8,282,013	58,945
	Dpw 4a1	7,744,225	7,807,969	63,744
	SGH West (expansion)	5,230,597	5,264,655	34,058
	Expansion II	1,467,512	1,497,053	29,541
	Warehouse	739,898	745,052	5,154
	storage 431	9	9	0
	storage 432	1,638	1,797	159
	storage 433	9,169	10,629	1,460
				193,061
4/14-5/15	Dpw 4a2 (HVAC)	8,282,013	8,334,754	52,741
	Dpw 4a1	7,807,969	7,874,056	66,087
	SGH West (expansion)	5,264,655	5,289,588	24,933
	Expansion II	1,497,053	1,525,780	28,727

	Warehouse	745,052	750,483	5,431
	storage 431	9	10	1
	storage 432	1,797	1,972	175
	storage 433	10,629	11,597	968
				179,063
5/15-6/15	Dpw 4a2 (HVAC)	8,334,754	8,383,870	49,116
	Dpw 4a1	7,874,056	7,942,709	68,653
	SGH West (expansion)	5,289,588	5,309,708	20,120
	Expansion II	1,525,780	1,553,570	27,790
	Warehouse	750,483	755,759	5,276
	storage 431	10	0	-10
	storage 432	1,972	2,128	156
	storage 433	11,597	12,509	912
				172,013
6/15-7/20	Dpw 4a2 (HVAC)	8,383,870	8,446,169	62,299
	Dpw 4a1	7,942,709	8,022,768	80,059
	SGH West (expansion)	5,309,708	5,333,271	23,563
	Expansion II	1,553,570	1,590,429	36,859
	Warehouse	755,759	761,440	5,681
	storage 431	0	10	10
	storage 432	2,128	2,301	173
	storage 433	12,509	13,532	1,023
				209,667
7/20-8/21	Dpw 4a2 (HVAC)	8,446,169	8,494,358	48,189
	Dpw 4a1	8,022,768	8,086,877	64,109
	SGH West (expansion)	5,333,271	5,355,705	22,434
	Expansion II	1,590,429	1,620,746	30,317
	Warehouse	761,440	766,722	5,282
	storage 431	10	10	0
	storage 432	2,301	2,446	145
	storage 433	13,532	14,318	786
				171,262
8/17-9/21	Dpw 4a2 (HVAC)	8,494,358	8,551,983	57,625
	Dpw 4a1	8,086,877	8,167,391	80,514
	SGH West (expansion)	5,355,705	5,385,127	29,422
	Expansion II	1,620,746	1,659,384	38,638
	Warehouse	766,722	774,432	7,710
	storage 431	10	10	0
	storage 432	2,446	2,608	162

	storage 433	14,318	15,313	995
				215,066

12. Appendix C: Spot Measurements

Due to space constraints, and the sheer volume of data, we have only included a select portion of the data collected from the loggers. Please contact smithsohnian@wpi.edu or svandessel@wpi.edu in order to retrieve the complete Excel and other data files.

PHASE	LOGGER	LOCATION	START DATE	END DATE
PHASE 2	1	Front Desk	09-24-2015	10-28-2015
	2	Large Cafeteria	09-24-2015	10-28-2015
	3	Office Space	09-24-2015	10-28-2015
	4	*HVAC Damper	09-24-2015	10-28-2015
PHASE 3	A	Conference Room	11-04-2015	12-06-2015
	B	Truss in Front Bay	11-11-2015	12-06-2015
	C	Window Sill	11-04-2015	12-06-2015
	D	Seminar Room B	11-04-2015	12-06-2015
PHASE 4	a	Slab by Lab	11-25-2015	11-30-2015
	c	Slab in Office Space	11-25-2015	11-28-2015
PHASE 5	i	HR Office	12-21-2015	02-10-2016
	ii	Office Space	12-21-2015	02-10-2016
	iii	Truss in Back Bay	12-21-2015	02-10-2016
	iv	*HVAC Damper	12-21-2015	02-10-2016
	v	SGH RTU-4	12-21-2015	02-10-2016

The following tables depict the high and low temperature values recorded at each of the 15 logger locations. Weather data collected from Weather Underground (wunderground.com) recorded from a nearby station (KMAWALTH6) were added to the tables.

Logger	High Temp (°F)	Time	Day	Outside Weather (°F)
1	86.22	2:30 PM	9/27/2015	74.8
2	78.09	2:10 PM	9/24/2015	57.5
3	77.96	5:30 PM	9/27/2015	70.1
4	82.45	6:00 PM	9/27/2015	70.0
A	79.62	3:00 PM	11/6/2015	76.0
B	78.17	2:40 PM	11/20/2015	62.0
C	76.65	9:50 AM	11/5/2015	70.6
D	73.09	4:40 PM	11/5/2015	74.4
a	72.96	5:00 PM	11/25/2015	45.9
c	69.78	5:00 PM	11/25/2015	45.9
i	75.66	10:50 AM	12/21/2015	52.0
ii	76.01	11:09 AM	12/21/2015	52.3
iii	74.73	11:18 AM	12/21/2015	52.3
iv	90.17	6:58 AM	12/28/2015	37.9
v	105.43	8:35 AM	1/24/2016	35.0

Logger	Low Temp (°F)	Time	Day	Outside Weather (°F)
1	67.93	5:50:00 AM	10/19/2015	33.9
2	68.06	6:30:00 AM	10/19/2015	34.1
3	68.15	5:40:00 AM	10/19/2015	34.1
4	67.55	5:30:00 AM	10/27/2015	35.9
A	70.08	5:20:00 AM	11/25/2015	29.1
B	69.13	7:20:00 AM	11/26/2015	41.8
C	53.04	4:10:00 AM	12/1/2015	31.2
D	63.14	8:50:00 AM	11/17/2015	39.6
a	69.22	8:00:00 AM	11/26/2015	43.5
c	65.49	5:00:00 PM	11/25/2015	45.6
i	67.66	5:10:00 AM	1/5/2016	11.1
ii	67.67	3:29:00 AM	1/12/2016	26.1
iii	66.25	4:38:00 AM	1/28/2016	27.4
iv	57.64	12:38:00 PM	1/20/2016	32.2
v	19.92	4:15:00 AM	1/5/2016	11.4

Another point of interest is the range of temperature experienced by each logger. This is detailed in the following table. Most of the loggers experienced a range of 10°F or less, though some were greater. Logger iv and v’s ranges should not be of great concern, as both of these locations experienced varying conditions: iv is affected by the supply air, and v is subject to outside conditions.

Logger	Range (°F)
1	18.29
2	10.03
3	9.81
4	14.90
A	9.54
B	9.04
C	23.61
D	9.95
a	3.74
c	4.29
i	8.00
ii	8.34
iii	8.48
iv	32.53
v	85.51

13. Appendix D: RTU Nameplate Data

MODEL	48TMD028---		SERIES		600AA		SERIAL	5001F28141			FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	1	460	3	60	10	75	26.8 LBS	12.2 KG	R-22	HI	410 PSI	2827 kPa
COMPR	1	460	3	60	19.6	125			R-22	LO	150 PSI	1034 kPa
COMPR	1	460	3	60	19.6	125	25.6 LBS	11.6 KG				
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	6	460	1	60	0.85		0.5	0.4	MIN CIRCUIT AMPS		64	
INDOOR									MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
Pwrexh	1	460	3	60	14.6		10	7.5	80 FUSE OR HACR BKR			
Outlet									PERMISSIBLE VOLTAGE AT UNIT		506 MAX	414 MIN
COMBUST	1	460	1	60	0.3		0.06	0	EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-14			INPUT MIN			INPUT MAX		OUTPUT CAP		THERMAL EFFICIENCY		
		Btu/Hr	206,000			275,000		223,000				
		Kw	60.3			80.5		65.3		81%		

MODEL	48AKD040---		SERIES		600ED		SERIAL	4901F26996			FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	1	460	3	60	25.6	120	51.5 LBS	23.4 KG	R-22	HI	410 PSI	2827 kPa
COMPR	1	460	3	60	28.8	173	49.5 LBS	22.5 KG	R-22	LO	150 PSI	1034 kPa
COMPR												
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	4	460	3	60	2.7		1	0.75	MIN CIRCUIT AMPS		112	
OUTDOOR									MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
INDOOR	1	460	3	60	27		20	14.9	125 FUSE OR HACR BKR			
OTHER	4	460	1	60	3.2		1	0.75	PERMISSIBLE VOLTAGE AT UNIT		508 MAX	414 MIN
COMBUST	2	460	1	60	0.25		0.06	0.05	EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-13			INPUT MIN			INPUT MAX		OUTPUT CAP		THERMAL EFFICIENCY		
		Btu/Hr	300,000			400,000		324,000				
		Kw	87.93			117.24		94.96		81%		

MODEL	48TFD012---		SERIES		601GA		SERIAL	4501G04684			FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	1	460	3	60	7.9	64	7.4 LBS	3.3 KG	R-22	HI	401 PSI	2761 kPa
COMPR	1	460	3	60	7.9	64	8.0 LBS	3.6 KG	R-22	LO	150 PSI	1034 kPa
COMPR												
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	2	460	1	60	0.7				MIN CIRCUIT AMPS		22.6	
OUTDOOR									MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
INDOOR	1	460	3	60	3.4				125 FUSE OR HACR BKR			
OTHER									PERMISSIBLE VOLTAGE AT UNIT		508 MAX	414 MIN
COMBUST	1	460	1	60	0.3				EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-05			INPUT MIN			INPUT MAX		OUTPUT CAP		THERMAL EFFICIENCY		
		Btu/Hr	120,000			180,000		96,000/144,000				
		Kw	35.2			52.7		28.1/42.2		80%		

MODEL	48AKD040---		SERIES	600ED		SERIAL	4901F26989			FACTORY CHARGED		
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	1	460	3	60	25.6	120	51.5 LBS	23.4 KG	R-22	HI	410 PSI	2827 kPa
COMPR	1	460	3	60	28.8	173	49.5 LBS	22.5 KG	R-22	LO	150 PSI	1034 kPa
COMPR												
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	4	460	3	60	2.7		1	0.75	MIN CIRCUIT AMPS	112		
OUTDOOR									MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
INDOOR	1	460	3	60	27		20	14.9	125 FUSE OR HACR BKR			
OTHER	4	460	1	60	3.2		1	0.75	PERMISSIBLE VOLTAGE AT UNIT		508 MAX	414 MIN
COMBUST	2	460	1	60	0.25		0.06	0.05	EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-01			INPUT MIN			INPUT MAX		OUTPUT CAP		THERMAL EFFICIENCY		
		Btu/Hr	300,000			400,000		324,000				
		Kw	87.93			117.24		94.96		81%		

MODEL	48AKD025-P		SERIES	611HM		SERIAL	1305F11244			FACTORY CHARGED		
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	1	460	3	60	11	90	33.5 LBS	15.2 KG	R-22	HI	410 PSI	2827 kPa
COMPR	1	460	3	60	13.5	95	17.5 LBS	7.9 KG	R-22	LO	150 PSI	1034 kPa
COMPR	1	460	3	60	13.5	95						
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	2	460	3	60	3.3		1	0.75	MIN CIRCUIT AMPS	87		
INDOOR	1	460	3	60	21		15	11.19	MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
Pwrexh	4	460	1	60	3.15		1	0.75	100 FUSE OR HACR BKR			
Outlet	1	115	1	60	3.5				PERMISSIBLE VOLTAGE AT UNIT		506 MAX	414 MIN
COMBUST	2	115	1	60	1.1		0.1	0.07	EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-06			INPUT MIN			INPUT MAX		OUTPUT CAP		THERMAL EFFICIENCY		
		Btu/Hr	262,500			350,000		283,500				
		Kw	76.9			102.6		83.1		81%		

MODEL	48A3S020A1		SERIES		611HK		SERIAL	0510U02028			FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	2	460	3	60	10.6	75	26.2 LBS	11.9 KG	R-410A	HI	650 PSI	4482 kPa
COMPR	1	460	3	60	14.7	95	18.8 LBS	8.5 KG	R-410A	LO	477 PSI	3289 kPa
COMPR												
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	2	460	3	60	3.3		1	0.75	MIN CIRCUIT AMPS		73	
INDOOR	1	460	3	60	14		10	7.46	MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
Pwrexh	4	460	1	60	3.15		1	0.75	80 FUSE OR HACR BKR			
Outlet									PERMISSIBLE VOLTAGE AT UNIT		506 MAX	414 MIN
COMBUST	2	115	1	60	1.1		0.1	0.07	EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-02			INPUT MIN		INPUT MAX		OUTPUT CAP			THERMAL EFFICIENCY		
		Btu/Hr	262,500		350,000		283,500					
		Kw	76.9		102.6		83.1			81%		

MODEL	48HCRB07A2A6A0F5CO		SERIES				SERIAL	4411G10237			FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	1	460	3	60	9.7	62	22.5 LBS	10.2 KG	R-410A	HI	650 PSI	4482 kPa
COMPR		460	3	60					R-410A	LO	450 PSI	3103 kPa
COMPR		460	3	60								
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	2	460	3	60	0.8				MIN CIRCUIT AMPS			
INDOOR	1	460	3	60	3.4				MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
Pwrexh									80 FUSE OR HACR BKR			
OTHER	1	115	1	60	2.2				PERMISSIBLE VOLTAGE AT UNIT		506 MAX	414 MIN
COMBUST	1	460	1	60	0.25				EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-07			INPUT MIN		INPUT MAX		OUTPUT CAP			THERMAL EFFICIENCY		
		Btu/Hr	90,000		125,000		103,000					
		Kw	26.4		36.6		30.2			82%		

MODEL	48HCRB07A2A6A0F5C0		SERIES				SERIAL	4411G10236			FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	1	460	3	60	9.7	62	22.5 LBS	10.2 KG	R-410A	HI	650 PSI	4482 kPa
COMPR		460	3	60					R-410A	LO	450 PSI	3103 kPa
COMPR		460	3	60								
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	2	460	3	60	0.8				MIN CIRCUIT AMPS			
INDOOR	1	460	3	60	3.4				MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
Pwrexh									80 FUSE OR HACR BKR			
OTHER	1	115	1	60	2.2				PERMISSIBLE VOLTAGE AT UNIT		506 MAX	414 MIN
COMBUST	1	460	1	60	0.25				EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-09			INPUT MIN			INPUT MAX		OUTPUT CAP		THERMAL EFFICIENCY		
		Btu/Hr	90,000			125,000		103,000				
		Kw	26.4			36.6		30.2		82%		

MODEL	48A3S020A1		SERIES		611HK		SERIAL	0510U02029			FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	2	460	3	60	10.6	75	26.2 LBS	11.9 KG	R-410A	HI	650 PSI	4482 kPa
COMPR	1	460	3	60	14.7	95	18.8 LBS	8.5 KG	R-410A	LO	477 PSI	3289 kPa
COMPR												
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	2	460	3	60	3.3		1	0.75	MIN CIRCUIT AMPS		73	
INDOOR	1	460	3	60	14		10	7.46	MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
Pwrexh	4	460	1	60	3.15		1	0.75	80 FUSE OR HACR BKR			
Outlet									PERMISSIBLE VOLTAGE AT UNIT		506 MAX	414 MIN
COMBUST	2	115	1	60	1.1		0.1	0.07	EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-11			INPUT MIN			INPUT MAX		OUTPUT CAP		THERMAL EFFICIENCY		
		Btu/Hr	262,500			350,000		283,500				
		Kw	76.9			102.6		83.1		81%		

MODEL	48A3S020A1		SERIES		611HK		SERIAL		0510U02030		FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	2	460	3	60	10.6	75	26.2 LBS	11.9 KG	R-410A	HI	650 PSI	4482 kPa
COMPR	1	460	3	60	14.7	95	18.8 LBS	8.5 KG	R-410A	LO	477 PSI	3289 kPa
COMPR												
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	2	460	3	60	3.3		1	0.75	MIN CIRCUIT AMPS		73	
INDOOR	1	460	3	60	14		10	7.46	MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
Pwrexh	4	460	1	60	3.15		1	0.75	80 FUSE OR HACR BKR			
Outlet									PERMISSIBLE VOLTAGE AT UNIT		506 MAX	414 MIN
COMBUST	2	115	1	60	1.1		0.1	0.07	EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-12			INPUT MIN		INPUT MAX		OUTPUT CAP		THERMAL EFFICIENCY			
	Btu/Hr		262,500		350,000		283,500					
	Kw		76.9		102.6		83.1		81%			

MODEL	48A3S020A1		SERIES		611HK		SERIAL		0510U02027		FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	2	460	3	60	10.6	75	26.2 LBS	11.9 KG	R-410A	HI	650 PSI	4482 kPa
COMPR	1	460	3	60	14.7	95	18.8 LBS	8.5 KG	R-410A	LO	477 PSI	3289 kPa
COMPR												
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	2	460	3	60	3.3		1	0.75	MIN CIRCUIT AMPS		73	
INDOOR	1	460	3	60	14		10	7.46	MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
Pwrexh	4	460	1	60	3.15		1	0.75	80 FUSE OR HACR BKR			
Outlet									PERMISSIBLE VOLTAGE AT UNIT		506 MAX	414 MIN
COMBUST	2	115	1	60	1.1		0.1	0.07	EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-10			INPUT MIN		INPUT MAX		OUTPUT CAP		THERMAL EFFICIENCY			
	Btu/Hr		262,500		350,000		283,500					
	Kw		76.9		102.6		83.1		81%			

MODEL	48AKD025-P		SERIES		611HM		SERIAL	1305F11247			FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	1	460	3	60	11	90	33.5 LBS	15.2 KG	R-22	HI	410 PSI	2827 kPa
COMPR	1	460	3	60	13.5	95	17.5 LBS	7.9 KG	R-22	LO	150 PSI	1034 kPa
COMPR	1	460	3	60	13.5	95						
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	2	460	3	60	3.3		1	0.75	MIN CIRCUIT AMPS		87	
INDOOR	1	460	3	60	21		15	11.19	MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
Pwrexh	4	460	1	60	3.15		1	0.75	100 FUSE OR HACR BKR			
Outlet	1	115	1	60	3.5				PERMISSIBLE VOLTAGE AT UNIT		506 MAX	414 MIN
COMBUST	2	115	1	60	1.1		0.1	0.07	EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-08			INPUT MIN			INPUT MAX		OUTPUT CAP		THERMAL EFFICIENCY		
		Btu/Hr	262,500			350,000		283,500				
		Kw	76.9			102.6		83.1		81%		

MODEL	48AKD040---		SERIES		600ED		SERIAL	4901F26995			FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	1	460	3	60	25.6	120	51.5 LBS	23.4 KG	R-22	HI	410 PSI	2827 kPa
COMPR	1	460	3	60	28.8	173	49.5 LBS	22.5 KG	R-22	LO	150 PSI	1034 kPa
COMPR												
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	4	460	3	60	2.7		1	0.75	MIN CIRCUIT AMPS		112	
OUTDOOR									MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
INDOOR	1	460	3	60	27		20	14.9	125 FUSE OR HACR BKR			
OTHER	4	460	1	60	3.2		1	0.75	PERMISSIBLE VOLTAGE AT UNIT		508 MAX	414 MIN
COMBUST	2	460	1	60	0.25		0.06	0.05	EQUIPPED FOR USE WITH		NATURAL GAS	
SGU RTU-04			INPUT MIN			INPUT MAX		OUTPUT CAP		THERMAL EFFICIENCY		
		Btu/Hr	300,000			400,000		324,000				
		Kw	87.93			117.24		94.96		81%		

MODEL	48AKD040---		SERIES		600ED		SERIAL	4901F26991			FACTORY CHARGED	
	QTY	VOLTS AC	PH	HZ	RLA	LRA	REFRIGERANT/SYSTEM			TEST PRESSURE GAGE		
COMPR	1	460	3	60	25.6	120	51.5 LBS	23.4 KG	R-22	HI	410 PSI	2827 kPa
COMPR	1	460	3	60	28.8	173	49.5 LBS	22.5 KG	R-22	LO	150 PSI	1034 kPa
COMPR												
FAN MTRS	QTY	VOLTS AC	PH	HZ	FLA		HP	kWout	POWER SUPPLY	460 V	3 PH	60 HZ
OUTDOOR	4	460	3	60	2.7		1	0.75	MIN CIRCUIT AMPS		112	
OUTDOOR									MAX OVERCURRENT PROTECTIVE DEVICE AMPS			
INDOOR	1	460	3	60	27		20	14.9	125 FUSE OR HACR BKR			
OTHER	4	460	1	60	3.2		1	0.75	PERMISSIBLE VOLTAGE AT UNIT		508 MAX	414 MIN
COMBUST	2	460	1	60	0.25		0.06	0.05	EQUIPPED FOR USE WITH		NATURAL GAS	

SGU RTU-03		INPUT MIN	INPUT MAX	OUTPUT CAP	THERMAL EFFICIENCY
	Btu/Hr	300,000	400,000	324,000	
	Kw	87.93	117.24	94.96	81%

14. Appendix E: User Survey results

Participant #	What part of the office do you spend majority of your time in?	Are you within 15 feet of an exterior wall?	Please rate the overall thermal comfort in your workspace during hot weather	Please rate the overall thermal comfort in your workspace during cold weather	If you experience thermal discomfort, which time of the day do you feel the discomfort in?	Do you ever use the mechanized shades?	If you experience discomfort with the HVAC system, what is the cause of the discomfort?	What time do you typically come into the office?	What time do you typically leave the office?	Are you able to control the thermostat?	What other issues have you experienced regarding thermal discomfort in your workspace?	How satisfied are you with the amount of light in your workspace?	Do you work in a open or enclosed office?	Do you prefer to use a personal desk lamp?	How satisfied are you with the visual comfort of the lighting?	In a typical week, how many hours do you spend in your work space?	Please describe your activity level in the office
1	BB	No	2	3	Afternoon	No		Before 6:30	6:30	No		3	Open office	Yes	1	50	4
2	BB	Yes	4	3	Afternoon	No	Workspace hotter than other sections of the office, lack of ventilation	7:00	6:30	No	lack of ventilation	3	Enclosed office	No	2	30	2
3	BB	No	3	2	Morning	No		7:45	5:45	No		5	Open office	No, but I would if I had one	4	40	3
4	BB	No	1	2	Always	No	Vented air being too cold	8:00	6:00	No		4	Open office	No	3	45	2
5	BB	No	1	1	Morning	No	Vented air being too cold	8:00	5:00	No	the seminar rooms are freezing	6	Open office	No	6	40	0

6	BB	No	3	3		No		8:00	5:00	No		2	Open office	No, but I would if I had one	1	45	1
7	BB	No	1	0	Always	I would	Workspace colder than other sections of the office	8:15	6:00	No		2	Open office	No, but I would if I had one	2	25	2
8	BB	Yes	1	0	Morning	No	Vented air being too cold, Workspace colder than other sections of the office	9:00	6:00	No		3	Open office	No	4	35	0
9	BB	No	1	3		No		9:00	After 6:30	No	None	5	Open office	No, but I would if I had one	5	40	2
10	BB	No	1	1	I haven't noticed a trend	No		9:00	After 6:30	No	I am often chilly, need a polarfleece in the office even in summer	3	Open office	No	5	35	2
11	BB	No	3	3	Morning, Weekends	No		7:15	5:30	No	Certain conference rooms / seminar rooms will be extremely hot or cold.	4	Open office	No	4	45	4
12	BB	Yes	1	1	Always	No	Vented air being too cold	8:30	After 6:30	No		2	Open office	No	2	50-60	3

13	BB	No	1	1	Always	No	Workspace colder than other sections of the office	8:30	6:30	No		3	Open office	No, but I would if I had one	2		3
14	BB	Yes	1	0	Always	No	Workspace colder than other sections of the office	6:45	5:30	No	overall setpoint seems too cold - i always wear sweaters or a jacket in the office - year round	2	Enclosed office	No	2	50	2
15	BB	No	1	2	Afternoon	No	Vented air being too cold	7:30	5:45	No		3	Open office	No	3	45	3
16	BB	No	0	0	Afternoon	No	Vented air being too cold	7:30	6:00	No		5	Open office	No	3	35	2
17	BB	Yes	4	1	often during cold months	No	Workspace colder than other sections of the office	6:30	5:00	No	I sit at back wall, my feet are near the bottom if the wall and are usually cold	5	Open office	No	5	35	1
18	BB	No	1	1	Always	No	Vented air being too cold, Workspace colder than other sections of the office	7:30	6:00	No		3	Open office	No	2		1
19	BB	Yes	3	2		No		7:30	5:00	No		5	Open office	No, but I would if I had one	5	30+	2

2 0	BB	No	2	2	Always, Except during times of direct sunlight (approx. 20 mins each AM and PM)	We do not have them in the back	Vented air being too cold	7:30	6:15	No		5	Open office	No	5	25	3
2 1	BB	No	3	3		No		9:00	6:00	No		3	Open office	Yes	2	40	2
2 2	FB	No	3	2		No		7:00	5:30	No		6	Enclosed office	No, but I would if I had one	2	30	3
2 3	FB	Yes	0	0	Always	No	Too much air movement , Vented air being too cold	6:30	5:15	No	needing to wear jacket/labcoa t	2	Open office	Yes	1	too many . 50+/-	1
2 4	FB	No	1	0	Afternoon	Yes	Vented air being too cold	Before 6:30	3:30	No		2	Open office	No	2	40	1
2 5	FB	No	0	0	Always	No	Vented air being too cold, Noise	8:00	After 6:30	No		1	Open office	No	2	50	4
2 6	FB	No	2	3		Yes		7:45	After 6:30	No	Seminar rooms are very VERY cold	5	Open office	No	5	55	1
2 7	FB	No	3	3		Yes		6:45	6:00	No		3	Open office	No	3	40	4

28	FB	Yes	3	2	Afternoon	No	Vented air being too cold	7:45	5:30	No		4	Open office	Yes	2	40+	2
29	FB	No	1	1	Morning, Afternoon	Yes		8:00	5:00	No		0	Open office	No	1	35	1
30	FB	No	1	2	Morning, Holidays, Monday Mornings, Evenings	No	Vented air being too cold, air too dry and noise	7:30	6:30	No		0	Open office	Yes	3	35	1
31	FB	No	6	0	Always	No		7:15	4:30	No	Constant sneezing only at office	5	Open office	No	5	43	2
32	FB	No	1	0	Always	No	Vented air being too cold	8:15	6:30	No		3	Open office	No, but I would if I had one	3	45-50	3
33	FB	No	2	2	Always	No	Vented air being too cold	8:00	6:00	No		6	Open office	No	6	50	
34	FB	No	2	2		No		8:30	5:45	No		3	Open office	No	3	44	1
35	FB	No	3	3		No		8:30	5:30	No		2	Open office	No	4	45	2
36	FB	Yes	2	2		No	noise	8:45	After 6:30	No		5	Open office	No	2	35	2

37	FB	Yes	0	1	Afternoon	No	Vented air being too cold	9:00	6:15	No	The air conditioning is much too cold in the summer time	6	Open office	No	5	40	2
38	FB	Yes	1	1	Afternoon	Yes		9:00	4:30	No	Sometimes I am very cold, but it depends on the day.	6	Open office	No	5	6 Hours	1
39	FB	No	4	3	Weekends	No	Workspace hotter than other sections of the office	8:00	6:00	No	stale air in enclosed office	1	Enclosed office	No, but I would if I had one	1	50	0
40	FB	No	3	3		No		9:00	6:00	No		4	Enclosed office	No	5	40	5
41	FB	No	1	2	Always	No	Vented air being too cold	9:00	6:00	No		3	Open office	Yes	3	42	2
42	FB	No	3	3		No	Too much air movement, Vented air being too cold	8:30	6:30	No		1	Enclosed office	Yes	1	20	0
43	FB	No	2	2	Afternoon	No	Noise	8:00	6:30	No		3	Enclosed office	No	3	50	2
44	FB	No	0	0	Always	No	Too much air movement, Vented air being too cold	8:00	After 6:30	No		0	Enclosed office	No	2	70	1
45	FB	No	0	1	Always	Yes	Too much air movement	9:00	6:30	No	cold feet	4	Open office	No	2	30-40	0

46	FB	No	0	0	Always	I would	Too much air movement, Vented air being too cold	9:00	After 6:30	No		3	Open office	No	2	50-60	2
47	FB	No	2	3		No		8:00	5:30	No		4	Enclosed office	No	4	40	2
48	FB	Yes	2	2	Afternoon	No	Vented air being too cold	9:00	6:00	No		2	Open office	No, but I would if I had one	3	25	1
49	FB	No	1	1	Always	No	Workspace colder than other sections of the office	8:30	6:00	No	Not always, but most of the time it's cold. Especially summer - why do I need a sweatshirt in summer.	2	Open office	No, but I would if I had one	4	35	3
50	FB	No	2	1	Not a predictable pattern	No	Too much air movement, Vented air being too cold, Workspace colder than other sections of the office	9:00	5:00	No	Inconsistent and hard to predict	3	Open office	No, but I would if I had one	2	30	4
51	FB	Yes	3	3		No	The heat due to sunlight	8:00	5:30	No		5	Open office	No	5	40	1

52	FB	No	2	2	Always	No	I find the temperature maintained too cool for activity level but wear a fleece jacket to stay warm	7:00	5:30	No		3	Open office	No	3	35 to 45 hours	1
53	HR	No	1	1	Always	No	Too much air movement, I've had the blower above my workspace turned off because it blows out too strong	7:30	3:00	No	FYI - many of us in the HR suite use a space heater	3	Open office	No	6	30	0
54	HR	No	3	1	Morning	No	Workspace colder than other sections of the office	8:00	5:30	No		3	open cube in HR suite (partially enclosed)	No	4	42-45	4

55	Lab	Yes	0	0	Always		Too much air movement, Vented air being too cold	6:30	5:15	Yes	one room of the lab has its own ac system due to equipment in the room. folks are always messing with the controls becuase of unbalanced equipment heat generation and the high velocity air coming from the ac unit. the system is a bad idea.		Open office			too much	2
56	Lab	Yes	4	1	Morning	No	Too much air movement, Vented air being too hot, Vented air being too cold	8:45	6:00	No		3	Open office	No	3		4
57	Lab	Yes	1	5	Monday Mornings	No	The heat due to office equipment	7:00		Yes		5	Open office	No	5	5	6
58	MB	No	3	3		No		8:30	5:30	No		2	Open office	No, but I would if I had one	5	40	4
59	MB	No	3	2	Morning, Afternoon, Monday Mornings	No	Workspace colder than other sections of the office	6:45	4:00	No		5	Open office	No, but I would if I had one	2	45-50	5

60	MB	No	2	2	Morning, Always	No	Vented air being too cold	7:30	4:30	No		3	Open office	No	3	40	3
61	MB	No	0	1	Morning, Afternoon	No	Vented air being too cold	7:30	5:00	No		5	Open office	No, but I would if I had one	5	30	1
62	MB	Yes	3	1	Always	No	Workspace colder than other sections of the office	8:00	4:30	No		3	Enclosed office	No, but I would if I had one	3	32+	1
63	MB	Yes	2	2		No		8:00	5:30	No	Meeting rooms very cold	2	Open office	No	2	45	3
64	MB	No	2	2	Morning, Afternoon	No	Vented air being too cold, Workspace colder than other sections of the office	8:00	5:00	No	Temperature in Conference Rooms A and B is way too low. Lunch talks are uncomfortable.	6	Open office	No	6	40	3
65	MB	No	1	2	Always	No	Vented air being too cold	7:45	4:45	No	Cold in Seminar Rooms A & B	5	Open office	No	5	42	3
66	MB	No	0	0	Always	No	Vented air being too cold	7:30	4:00	No		1	Open office	No, but I would if I had one	1	43	2
67	MB	Yes	1	1	Afternoon		Vented air being too cold	8:00	5:00	No	its generally just cold in the office	6	Open office	No	6	25 to 30	2

68	MB	No	2	2	Morning		Workspace colder than other sections of the office	8:30	5:00	No		4	Open office	No, but I would if I had one	3	37-40	5
69	MB	Yes	1	3	Morning	No	Workspace colder than other sections of the office	7:30	6:30	No		1	Enclosed office	No, but I would if I had one	2	8-Jul	2
70	MB	No	3	3	When I walk around it's cold	No	I need a sweater when I walk somewhere else		6:00	No	I'm fine in my workspace, but need a sweater to walk anywhere	1	Open office	No	1	30-40 hours	2
71	MB	No	0	0	Always	No	Vented air being too cold, Workspace colder than other sections of the office	9:00	6:00	No	Hands stiff due to cold	6	Open office	No	6	45	2
72	MB	No	1	0	Afternoon, Always	No	Vented air being too cold, Workspace colder than other sections of the office	9:00	After 6:30	No		3	Open office	No	5	40	1
73	MB	Yes	3	1	Always	No	Workspace colder than other sections of the office	8:00	4:30	No		3	Enclosed office	No, but I would if I had one	3	32+	1

74	FB	Yes	3	3		No		9:00	6:00	No	none	5	Open office	No	5	30	4
75	Library	No	1	1	Morning	No	Too much air movement	7:45	5:00	No		3	Open office	No	5	40	3
76	MB	No	3	3		No		8:30	5:30	No		2	Open office	No	5	40 hrs	2
77	MB	No	1	1	Always	No	Workspace colder than other sections of the office	6:30	3:30	No		3		Yes	3	45	3
78	FB	No	2	2		No		6:30	3:00	No		5	Enclosed office	No	5	24	1
79	IT	No	3	4	Afternoon	Yes		7:45	5:30	Yes		5	Open office	No, but I would if I had one	5	30	4
80	FB	No	3	3	Morning	No	Too much air movement	7:15	5:30	No		5	Open office	No	5	20	4
81	FB	No	1	4	Morning, Afternoon	No	Workspace hotter than other sections of the office, Workspace colder than other sections of the office	9:00	6:30	No		2	Open office	No	3	40	2

82	MB	No	5	3	Morning	We don't have them where I sit.	The heat due to sunlight, Workspace hotter than other sections of the office, Asymmetrical heating (one side of body warmer than other)	7:00	6:00	No		3	Open office	No	2	30	0
83	BB	No	4	1	Morning, Afternoon, Weekends	No		8:30	6:30	No		3	Open office	Yes	2	45	4

15. Appendix F. DesignBuilder results

Program Version:**EnergyPlusDLL-32 8.1.0.009, 2/28/2016 5:31 PM** Table of Contents

Tabular Output Report in Format: **HTML**

Building: **Building**

Environment: **SMITHSOHNIAN SGH ** Boston MA USA TMY--94701 WMO#=725090**

Simulation Timestamp: **2016-02-28 17:32:06**

Report: **Annual Building Utility Performance Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-28 17:32:06**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kBtu]	Energy Per Total Building Area [kBtu/ft2]	Energy Per Conditioned Building Area [kBtu/ft2]
Total Site Energy	6220423.26	72.00	72.00
Net Site Energy	6220423.26	72.00	72.00
Total Source Energy	19954695.37	230.97	230.97
Net Source Energy	19954695.37	230.97	230.97

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [ft2]
Total Building Area	86394.85
Net Conditioned Building Area	86394.85
Unconditioned Building Area	0.00

End Uses

	Electricity [kBtu]	Natural Gas [kBtu]	Additional Fuel [kBtu]	District Cooling [kBtu]	District Heating [kBtu]	Water [gal]
Heating	0.00	0.00	0.00	0.00	3524444.40	0.00
Cooling	0.00	0.00	0.00	645942.72	0.00	0.00
Interior Lighting	858007.36	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	1090449.40	0.00	0.00	0.00	0.00	0.00

Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	101579.39	123066.21
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	1948456.76	0.00	0.00	645942.72	3626023.79	465.86

Note: District heat appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [kBtu]	Natural Gas [kBtu]	Additional Fuel [kBtu]	District Cooling [kBtu]	District Heating [kBtu]	Water [gal]
Heating	General	0.00	0.00	0.00	0.00	3524444.40	0.00
Cooling	General	0.00	0.00	0.00	645942.72	0.00	0.00
Interior Lighting	ELECTRIC EQUIPMENT#NWMain:FrontBay#GeneralLights	402404.12	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LargeCafeteria#GeneralLights	3995.55	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#GeneralLights	139431.48	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#GeneralLights	211256.23	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#GeneralLights	44021.06	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LabBathroom#GeneralLights	2898.85	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:FrontBayBathroom#GeneralLights	7611.84	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:BackBayBathroom#GeneralLights	8538.07	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#GeneralLights	209.53	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#GeneralLights	2978.78	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Seminar#GeneralLights	34661.86	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	ELECTRIC EQUIPMENT#NWMain:FrontBay#05	525533.82	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#05	182095.45	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#05	275897.51	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#05	57490.86	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#05	273.64	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#05	3890.25	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Seminar#05	45267.88	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	DHW NWMain:FrontBay	0.00	0.00	0.00	0.00	44671.22	54120.41
	DHW NWMain:LargeCafeteria	0.00	0.00	0.00	0.00	8889.43	10769.79

	DHW NWMain:MiddleBay	0.00	0.00	0.00	0.00	15478.41	18752.51
	DHW NWMain:BackBay	0.00	0.00	0.00	0.00	23451.73	28412.42
	DHW NWMain:Lab	0.00	0.00	0.00	0.00	4886.82	5920.51
	DHW Entry:Zone1	0.00	0.00	0.00	0.00	23.26	28.18
	DHW CenterMain:Server	0.00	0.00	0.00	0.00	330.68	400.62
	DHW CenterMain:Seminar	0.00	0.00	0.00	0.00	3847.84	4661.77
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [kBtu/ft2]	Natural Gas Intensity [kBtu/ft2]	Additional Fuel Intensity [kBtu/ft2]	District Cooling Intensity [kBtu/ft2]	District Heating Intensity [kBtu/ft2]	Water Intensity [gal/ft2]
Lighting	9.93	0.00	0.00	0.00	0.00	0.00
HVAC	0.00	0.00	0.00	7.48	41.97	1.42
Other	12.62	0.00	0.00	0.00	0.00	0.00
Total	22.55	0.00	0.00	7.48	41.97	0.01

Utility Use Per Total Floor Area

	Electricity Intensity [kBtu/ft2]	Natural Gas Intensity [kBtu/ft2]	Additional Fuel Intensity [kBtu/ft2]	District Cooling Intensity [kBtu/ft2]	District Heating Intensity [kBtu/ft2]	Water Intensity [gal/ft2]
Lighting	9.93	0.00	0.00	0.00	0.00	0.00
HVAC	0.00	0.00	0.00	7.48	41.97	1.42
Other	12.62	0.00	0.00	0.00	0.00	0.00
Total	22.55	0.00	0.00	7.48	41.97	0.01

Electric Loads Satisfied

	Electricity [kBtu]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	1948456.76	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	1948456.76	100.00
Total On-Site and Utility Electric Sources	1948456.76	100.00
Total Electricity End Uses	1948456.76	100.00

On-Site Thermal Sources

	Heat [kBtu]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	

Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [gal]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	123066.21	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	123066.21	100.00
Total Water End Uses	123066.21	100.00

Setpoint Not Met Criteria

	Degrees [deltaF]
Tolerance for Zone Heating Setpoint Not Met Time	0.36
Tolerance for Zone Cooling Setpoint Not Met Time	0.36

Comfort and Setpoint Not Met Summary

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	18.00
Time Setpoint Not Met During Occupied Cooling	1034.50
Time Not Comfortable Based on Simple ASHRAE 55-2004	2638.50

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

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Report: **Input Verification and Results Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-28 17:32:06**

General

	Value
Program Version and Build	EnergyPlusDLL-32 8.1.0.009, 2/28/2016 5:31 PM
RunPeriod	SMITHSOHNIAN SGH

Weather File	Boston MA USA TMY--94701 WMO#=725090
Latitude [deg]	42.35
Longitude [deg]	-71.1
Elevation [ft]	19.69
Time Zone	-5.0
North Axis Angle [deg]	310.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Above Ground Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Window Opening Area [ft2]	9472.01	0.00	3809.96	1869.97	3792.08
Gross Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02
Above Ground Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Above Ground Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Window Opening Area [ft2]	9472.01	0.00	3809.96	1869.97	3792.08
Gross Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02
Above Ground Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02

Skylight-Roof Ratio

	Total
Gross Roof Area [ft2]	88508.71
Skylight Area [ft2]	0.00
Skylight-Roof Ratio [%]	0.00

PERFORMANCE

Zone Summary

	Area [ft2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [ft3]	Multipliers	Gross Wall Area [ft2]	Window Glass Area [ft2]	Lighting [Btu/h-ft2]	People [ft2 per person]	Plug and Process [Btu/h-ft2]
SHAFT:ZONE1	550.37	Yes	Yes	6498.71	1.00	1972.12	0.00	0.0000		0.0000
SHAFT.1:ZONE1	19.33	Yes	Yes	80.24	1.00	968.74	276.78	0.0000		0.0000
NWMAIN:FRONTBAY	39963.98	Yes	Yes	823470.66	1.00	14578.57	4236.05	3.4117	96.98	3.7306
NWMAIN:LARGECAFETERIA	1120.99	Yes	Yes	18721.42	1.00	637.71	21.18	3.4117	37.26	0.0000
NWMAIN:MIDDLEBAY	13847.37	Yes	Yes	279059.37	1.00	3898.54	967.64	3.4117	96.98	3.7306
NWMAIN:BACKBAY	20980.50	Yes	Yes	401605.79	1.00	11272.26	1668.23	3.4117	96.98	3.7306
NWMAIN:LAB	4371.87	Yes	Yes	73013.72	1.00	2351.65	63.55	3.4117	96.98	3.7306
NWMAIN:LABBATHROOM	271.10	Yes	Yes	4527.59	1.00	0.00	0.00	3.4117	95.74	0.0000
SEMAIN:FRONTBAYBATHROOM	711.86	Yes	Yes	11888.60	1.00	0.00	0.00	3.4117	95.74	0.0000
SEMAIN:BACKBAYBATHROOM	798.48	Yes	Yes	13335.23	1.00	0.00	0.00	3.4117	95.74	0.0000
ENTRY:ZONE1	20.81	Yes	Yes	193.08	1.00	193.64	123.76	3.4117	96.98	3.7305
CENTERMAIN:SERVER	295.83	Yes	Yes	7854.71	1.00	0.00	0.00	3.4117	96.98	3.7306

CENTERMAIN:SEMINAR	3442.38	Yes	Yes	91399.53	1.00	0.00	0.00	3.4117	96.98	3.7306
Total	86394.85			1731648.67		35873.22	7357.19	3.3892	95.60	3.5806
Conditioned Total	86394.85			1731648.67		35873.22	7357.19	3.3892	95.60	3.5806
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

Report: **Demand End Use Components Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-28 17:32:06**

End Uses

	Electricity [kBtuh]	Natural Gas [kBtuh]	Propane [kBtuh]	District Cooling [kBtuh]	District Heating [kBtuh]	Water [gal/min]
Time of Peak	01-JAN-11:30	-	-	19-AUG-05:00	16-DEC-07:30	01-JAN-12:30
Heating	0.00	0.00	0.00	0.00	3118.81	0.00
Cooling	0.00	0.00	0.00	2755.15	0.00	0.00
Interior Lighting	293.01	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	309.57	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	4.85	0.88
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	602.58	0.00	0.00	2755.15	3123.66	0.88

End Uses By Subcategory

	Subcategory	Electricity [kBtuh]	Natural Gas [kBtuh]	Propane [kBtuh]	District Cooling [kBtuh]	District Heating [kBtuh]	Water [gal/min]
Heating	General	0.00	0.00	0.00	0.00	3118.81	0.00
Cooling	General	0.00	0.00	0.00	2755.15	0.00	0.00
Interior Lighting	ELECTRIC EQUIPMENT#NWMain:FrontBay#GeneralLights	136.44	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LargeCafeteria#GeneralLights	3.83	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#GeneralLights	47.28	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#GeneralLights	71.63	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#GeneralLights	14.93	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LabBathroom#GeneralLights	0.93	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:FrontBayBathroom#GeneralLights	2.43	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:BackBayBathroom#GeneralLights	2.73	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#GeneralLights	0.07	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#GeneralLights	1.01	0.00	0.00	0.00	0.00	0.00
	ELECTRIC						

	EQUIPMENT#CenterMain:Seminar#GeneralLights	11.75	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	ELECTRIC EQUIPMENT#NWMain:FrontBay#05	149.19	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#05	51.69	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#05	78.32	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#05	16.32	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#05	0.08	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#05	1.10	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Seminar#05	12.85	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	DHW NWMain:FrontBay	0.00	0.00	0.00	0.00	2.34	0.31
	DHW NWMain:LargeCafeteria	0.00	0.00	0.00	0.00	0.00	0.23
	DHW NWMain:MiddleBay	0.00	0.00	0.00	0.00	0.81	0.11
	DHW NWMain:BackBay	0.00	0.00	0.00	0.00	1.23	0.17
	DHW NWMain:Lab	0.00	0.00	0.00	0.00	0.26	0.03
	DHW Entry:Zone1	0.00	0.00	0.00	0.00	0.00	0.00
	DHW CenterMain:Server	0.00	0.00	0.00	0.00	0.02	0.00
	DHW CenterMain:Seminar	0.00	0.00	0.00	0.00	0.20	0.03
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Report: **Climatic Data Summary**

Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-28 17:32:06**

SizingPeriod:DesignDay

	Maximum Dry Bulb [F]	Daily Temperature Range [deltaF]	Humidity Value	Humidity Type	Wind Speed [ft/min]	Wind Direction
SUMMER DESIGN DAY IN SMITHSOHNIAN SGH JUL	90.86	15.30	73.04	Wetbulb [F]	0.00	0.00
WINTER DESIGN DAY IN SMITHSOHNIAN SGH	7.70	0.00	7.70	Wetbulb [F]	2874.16	0.00

16. Appendix G. DesignBuilder ECM results

16.1 Infiltration Model

Program Version:**EnergyPlusDLL-32 8.1.0.009, 2/28/2016 5:51 PM** Table of Contents

Tabular Output Report in Format: **HTML**

Building: **Building**

Environment: **SMITHSOHNIAN SGH ** Boston MA USA TMY--94701 WMO#=725090**

Simulation Timestamp: **2016-02-28 17:51:27**

Report: **Annual Building Utility Performance Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-28 17:51:27**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kBtu]	Energy Per Total Building Area [kBtu/ft2]	Energy Per Conditioned Building Area [kBtu/ft2]
Total Site Energy	4437236.60	51.36	51.36
Net Site Energy	4437236.60	51.36	51.36
Total Source Energy	13556042.88	156.91	156.91
Net Source Energy	13556042.88	156.91	156.91

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [ft2]
Total Building Area	86394.85
Net Conditioned Building Area	86394.85
Unconditioned Building Area	0.00

End Uses

	Electricity [kBtu]	Natural Gas [kBtu]	Additional Fuel [kBtu]	District Cooling [kBtu]	District Heating [kBtu]	Water [gal]
Heating	0.00	0.00	0.00	0.00	1758693.68	0.00
Cooling	0.00	0.00	0.00	628506.78	0.00	0.00
Interior Lighting	858007.36	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	1090449.40	0.00	0.00	0.00	0.00	0.00

Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	101579.39	123066.21
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	1948456.76	0.00	0.00	628506.78	1860273.06	465.86

Note: District heat appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [kBtu]	Natural Gas [kBtu]	Additional Fuel [kBtu]	District Cooling [kBtu]	District Heating [kBtu]	Water [gal]
Heating	General	0.00	0.00	0.00	0.00	1758693.68	0.00
Cooling	General	0.00	0.00	0.00	628506.78	0.00	0.00
Interior Lighting	ELECTRIC EQUIPMENT#NWMain:FrontBay#GeneralLights	402404.12	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LargeCafeteria#GeneralLights	3995.55	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#GeneralLights	139431.48	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#GeneralLights	211256.23	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#GeneralLights	44021.06	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LabBathroom#GeneralLights	2898.85	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:FrontBayBathroom#GeneralLights	7611.84	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:BackBayBathroom#GeneralLights	8538.07	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#GeneralLights	209.53	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#GeneralLights	2978.78	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Seminar#GeneralLights	34661.86	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	ELECTRIC EQUIPMENT#NWMain:FrontBay#05	525533.82	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#05	182095.45	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#05	275897.51	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#05	57490.86	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#05	273.64	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#05	3890.25	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Seminar#05	45267.88	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	DHW NWMain:FrontBay	0.00	0.00	0.00	0.00	44671.22	54120.41
	DHW NWMain:LargeCafeteria	0.00	0.00	0.00	0.00	8889.43	10769.79

	DHW NWMain:MiddleBay	0.00	0.00	0.00	0.00	15478.41	18752.51
	DHW NWMain:BackBay	0.00	0.00	0.00	0.00	23451.73	28412.42
	DHW NWMain:Lab	0.00	0.00	0.00	0.00	4886.82	5920.51
	DHW Entry:Zone1	0.00	0.00	0.00	0.00	23.26	28.18
	DHW CenterMain:Server	0.00	0.00	0.00	0.00	330.68	400.62
	DHW CenterMain:Seminar	0.00	0.00	0.00	0.00	3847.84	4661.77
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [kBtu/ft2]	Natural Gas Intensity [kBtu/ft2]	Additional Fuel Intensity [kBtu/ft2]	District Cooling Intensity [kBtu/ft2]	District Heating Intensity [kBtu/ft2]	Water Intensity [gal/ft2]
Lighting	9.93	0.00	0.00	0.00	0.00	0.00
HVAC	0.00	0.00	0.00	7.27	21.53	1.42
Other	12.62	0.00	0.00	0.00	0.00	0.00
Total	22.55	0.00	0.00	7.27	21.53	0.01

Utility Use Per Total Floor Area

	Electricity Intensity [kBtu/ft2]	Natural Gas Intensity [kBtu/ft2]	Additional Fuel Intensity [kBtu/ft2]	District Cooling Intensity [kBtu/ft2]	District Heating Intensity [kBtu/ft2]	Water Intensity [gal/ft2]
Lighting	9.93	0.00	0.00	0.00	0.00	0.00
HVAC	0.00	0.00	0.00	7.27	21.53	1.42
Other	12.62	0.00	0.00	0.00	0.00	0.00
Total	22.55	0.00	0.00	7.27	21.53	0.01

Electric Loads Satisfied

	Electricity [kBtu]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	1948456.76	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	1948456.76	100.00
Total On-Site and Utility Electric Sources	1948456.76	100.00
Total Electricity End Uses	1948456.76	100.00

On-Site Thermal Sources

	Heat [kBtu]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	

Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [gal]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	123066.21	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	123066.21	100.00
Total Water End Uses	123066.21	100.00

Setpoint Not Met Criteria

	Degrees [deltaF]
Tolerance for Zone Heating Setpoint Not Met Time	0.36
Tolerance for Zone Cooling Setpoint Not Met Time	0.36

Comfort and Setpoint Not Met Summary

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	40.50
Time Setpoint Not Met During Occupied Cooling	1067.00
Time Not Comfortable Based on Simple ASHRAE 55-2004	2553.50

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

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Report: **Input Verification and Results Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-28 17:51:27**

General

	Value
Program Version and Build	EnergyPlusDLL-32 8.1.0.009, 2/28/2016 5:51 PM
RunPeriod	SMITHSOHNIAN SGH

Weather File	Boston MA USA TMY--94701 WMO#=725090
Latitude [deg]	42.35
Longitude [deg]	-71.1
Elevation [ft]	19.69
Time Zone	-5.0
North Axis Angle [deg]	310.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Above Ground Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Window Opening Area [ft2]	9472.01	0.00	3809.96	1869.97	3792.08
Gross Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02
Above Ground Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Above Ground Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Window Opening Area [ft2]	9472.01	0.00	3809.96	1869.97	3792.08
Gross Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02
Above Ground Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02

Skylight-Roof Ratio

	Total
Gross Roof Area [ft2]	88508.71
Skylight Area [ft2]	0.00
Skylight-Roof Ratio [%]	0.00

PERFORMANCE

Zone Summary

	Area [ft2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [ft3]	Multipliers	Gross Wall Area [ft2]	Window Glass Area [ft2]	Lighting [Btu/h-ft2]	People [ft2 per person]	Plug and Process [Btu/h-ft2]
SHAFT:ZONE1	550.37	Yes	Yes	6498.71	1.00	1972.12	0.00	0.0000		0.0000
SHAFT.1:ZONE1	19.33	Yes	Yes	80.24	1.00	968.74	276.78	0.0000		0.0000
NWMAIN:FRONTBAY	39963.98	Yes	Yes	823470.66	1.00	14578.57	4236.05	3.4117	96.98	3.7306
NWMAIN:LARGECAFETERIA	1120.99	Yes	Yes	18721.42	1.00	637.71	21.18	3.4117	37.26	0.0000
NWMAIN:MIDDLEBAY	13847.37	Yes	Yes	279059.37	1.00	3898.54	967.64	3.4117	96.98	3.7306
NWMAIN:BACKBAY	20980.50	Yes	Yes	401605.79	1.00	11272.26	1668.23	3.4117	96.98	3.7306
NWMAIN:LAB	4371.87	Yes	Yes	73013.72	1.00	2351.65	63.55	3.4117	96.98	3.7306
NWMAIN:LABBATHROOM	271.10	Yes	Yes	4527.59	1.00	0.00	0.00	3.4117	95.74	0.0000
SEMAIN:FRONTBAYBATHROOM	711.86	Yes	Yes	11888.60	1.00	0.00	0.00	3.4117	95.74	0.0000
SEMAIN:BACKBAYBATHROOM	798.48	Yes	Yes	13335.23	1.00	0.00	0.00	3.4117	95.74	0.0000
ENTRY:ZONE1	20.81	Yes	Yes	193.08	1.00	193.64	123.76	3.4117	96.98	3.7305
CENTERMAIN:SERVER	295.83	Yes	Yes	7854.71	1.00	0.00	0.00	3.4117	96.98	3.7306

CENTERMAIN:SEMINAR	3442.38	Yes	Yes	91399.53	1.00	0.00	0.00	3.4117	96.98	3.7306
Total	86394.85			1731648.67		35873.22	7357.19	3.3892	95.60	3.5806
Conditioned Total	86394.85			1731648.67		35873.22	7357.19	3.3892	95.60	3.5806
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

Report: **Demand End Use Components Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-28 17:51:27**

End Uses

	Electricity [kBtuh]	Natural Gas [kBtuh]	Propane [kBtuh]	District Cooling [kBtuh]	District Heating [kBtuh]	Water [gal/min]
Time of Peak	01-JAN-11:30	-	-	19-AUG-06:30	28-JAN-08:30	01-JAN-12:30
Heating	0.00	0.00	0.00	0.00	1941.64	0.00
Cooling	0.00	0.00	0.00	2339.30	0.00	0.00
Interior Lighting	293.01	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	309.57	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	19.38	0.88
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	602.58	0.00	0.00	2339.30	1961.02	0.88

End Uses By Subcategory

	Subcategory	Electricity [kBtuh]	Natural Gas [kBtuh]	Propane [kBtuh]	District Cooling [kBtuh]	District Heating [kBtuh]	Water [gal/min]
Heating	General	0.00	0.00	0.00	0.00	1941.64	0.00
Cooling	General	0.00	0.00	0.00	2339.30	0.00	0.00
Interior Lighting	ELECTRIC EQUIPMENT#NWMain:FrontBay#GeneralLights	136.44	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LargeCafeteria#GeneralLights	3.83	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#GeneralLights	47.28	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#GeneralLights	71.63	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#GeneralLights	14.93	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LabBathroom#GeneralLights	0.93	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:FrontBayBathroom#GeneralLights	2.43	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:BackBayBathroom#GeneralLights	2.73	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#GeneralLights	0.07	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#GeneralLights	1.01	0.00	0.00	0.00	0.00	0.00
	ELECTRIC						

	EQUIPMENT#CenterMain:Seminar#GeneralLights	11.75	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	ELECTRIC EQUIPMENT#NWMain:FrontBay#05	149.19	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#05	51.69	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#05	78.32	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#05	16.32	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#05	0.08	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#05	1.10	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Seminar#05	12.85	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	DHW NWMain:FrontBay	0.00	0.00	0.00	0.00	9.34	0.31
	DHW NWMain:LargeCafeteria	0.00	0.00	0.00	0.00	0.00	0.23
	DHW NWMain:MiddleBay	0.00	0.00	0.00	0.00	3.24	0.11
	DHW NWMain:BackBay	0.00	0.00	0.00	0.00	4.90	0.17
	DHW NWMain:Lab	0.00	0.00	0.00	0.00	1.02	0.03
	DHW Entry:Zone1	0.00	0.00	0.00	0.00	0.00	0.00
	DHW CenterMain:Server	0.00	0.00	0.00	0.00	0.07	0.00
	DHW CenterMain:Seminar	0.00	0.00	0.00	0.00	0.80	0.03
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Report: **Climatic Data Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-28 17:51:27**

SizingPeriod:DesignDay

	Maximum Dry Bulb [F]	Daily Temperature Range [deltaF]	Humidity Value	Humidity Type	Wind Speed [ft/min]	Wind Direction
SUMMER DESIGN DAY IN SMITHSOHNIAN SGH JUL	90.86	15.30	73.04	Wetbulb [F]	0.00	0.00
WINTER DESIGN DAY IN SMITHSOHNIAN SGH	7.70	0.00	7.70	Wetbulb [F]	2874.16	0.00

16.2 Radiant Floor Heating Model

Program Version:**EnergyPlusDLL-32 8.1.0.009, 2/29/2016 4:10 PM**

Table of Contents

Tabular Output Report in Format: **HTML**

Building: **Building**

Environment: **SMITHSOHNIAN SGH ** Boston MA USA TMY--94701 WMO#=725090**

Simulation Timestamp: **2016-02-29 16:10:34**

Report: **Annual Building Utility Performance Summary**

Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-29 16:10:34**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kBtu]	Energy Per Total Building Area [kBtu/ft2]	Energy Per Conditioned Building Area [kBtu/ft2]
Total Site Energy	5107250.41	59.12	59.12
Net Site Energy	5107250.41	59.12	59.12
Total Source Energy	17584536.95	203.54	203.54
Net Source Energy	17584536.95	203.54	203.54

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [ft2]
Total Building Area	86394.85
Net Conditioned Building Area	86394.85
Unconditioned Building Area	0.00

End Uses

	Electricity [kBtu]	Natural Gas [kBtu]	Additional Fuel [kBtu]	District Cooling [kBtu]	District Heating [kBtu]	Water [gal]
Heating	0.00	0.00	0.00	0.00	3057214.27	0.00
Cooling	0.00	0.00	0.00	0.00	0.00	0.00
Interior Lighting	858007.36	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	1090449.40	0.00	0.00	0.00	0.00	0.00

Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	101579.39	123066.21
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	1948456.76	0.00	0.00	0.00	3158793.65	465.86

Note: District heat appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [kBtu]	Natural Gas [kBtu]	Additional Fuel [kBtu]	District Cooling [kBtu]	District Heating [kBtu]	Water [gal]
Heating	General	0.00	0.00	0.00	0.00	3057214.27	0.00
Cooling	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Lighting	ELECTRIC EQUIPMENT#NWMain:FrontBay#GeneralLights	402404.12	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LargeCafeteria#GeneralLights	3995.55	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#GeneralLights	139431.48	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#GeneralLights	211256.23	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#GeneralLights	44021.06	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LabBathroom#GeneralLights	2898.85	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:FrontBayBathroom#GeneralLights	7611.84	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:BackBayBathroom#GeneralLights	8538.07	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#GeneralLights	209.53	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#GeneralLights	2978.78	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Seminar#GeneralLights	34661.86	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	ELECTRIC EQUIPMENT#NWMain:FrontBay#05	525533.82	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#05	182095.45	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#05	275897.51	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#05	57490.86	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#05	273.64	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#05	3890.25	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Seminar#05	45267.88	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	Ventilation (simple)	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	DHW NWMain:FrontBay	0.00	0.00	0.00	0.00	44671.22	54120.41
	DHW NWMain:LargeCafeteria	0.00	0.00	0.00	0.00	8889.43	10769.79

	DHW NWMain:MiddleBay	0.00	0.00	0.00	0.00	15478.41	18752.51
	DHW NWMain:BackBay	0.00	0.00	0.00	0.00	23451.73	28412.42
	DHW NWMain:Lab	0.00	0.00	0.00	0.00	4886.82	5920.51
	DHW Entry:Zone1	0.00	0.00	0.00	0.00	23.26	28.18
	DHW CenterMain:Server	0.00	0.00	0.00	0.00	330.68	400.62
	DHW CenterMain:Seminar	0.00	0.00	0.00	0.00	3847.84	4661.77
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [kBtu/ft2]	Natural Gas Intensity [kBtu/ft2]	Additional Fuel Intensity [kBtu/ft2]	District Cooling Intensity [kBtu/ft2]	District Heating Intensity [kBtu/ft2]	Water Intensity [gal/ft2]
Lighting	9.93	0.00	0.00	0.00	0.00	0.00
HVAC	0.00	0.00	0.00	0.00	36.56	1.42
Other	12.62	0.00	0.00	0.00	0.00	0.00
Total	22.55	0.00	0.00	0.00	36.56	0.01

Utility Use Per Total Floor Area

	Electricity Intensity [kBtu/ft2]	Natural Gas Intensity [kBtu/ft2]	Additional Fuel Intensity [kBtu/ft2]	District Cooling Intensity [kBtu/ft2]	District Heating Intensity [kBtu/ft2]	Water Intensity [gal/ft2]
Lighting	9.93	0.00	0.00	0.00	0.00	0.00
HVAC	0.00	0.00	0.00	0.00	36.56	1.42
Other	12.62	0.00	0.00	0.00	0.00	0.00
Total	22.55	0.00	0.00	0.00	36.56	0.01

Electric Loads Satisfied

	Electricity [kBtu]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	1948456.76	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	1948456.76	100.00
Total On-Site and Utility Electric Sources	1948456.76	100.00
Total Electricity End Uses	1948456.76	100.00

On-Site Thermal Sources

	Heat [kBtu]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	

Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [gal]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	123066.21	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	123066.21	100.00
Total Water End Uses	123066.21	100.00

Setpoint Not Met Criteria

	Degrees [deltaF]
Tolerance for Zone Heating Setpoint Not Met Time	0.36
Tolerance for Zone Cooling Setpoint Not Met Time	0.36

Comfort and Setpoint Not Met Summary

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	33.00
Time Setpoint Not Met During Occupied Cooling	0.00
Time Not Comfortable Based on Simple ASHRAE 55-2004	2915.00

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

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Report: **Input Verification and Results Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-29 16:10:34**

General

	Value
Program Version and Build	EnergyPlusDLL-32 8.1.0.009, 2/29/2016 4:10 PM
RunPeriod	SMITHSOHNIAN SGH

Weather File	Boston MA USA TMY--94701 WMO#=725090
Latitude [deg]	42.35
Longitude [deg]	-71.1
Elevation [ft]	19.69
Time Zone	-5.0
North Axis Angle [deg]	310.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Above Ground Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Window Opening Area [ft2]	9472.01	0.00	3809.96	1869.97	3792.08
Gross Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02
Above Ground Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Above Ground Wall Area [ft2]	35322.85	4116.01	13547.06	4125.76	13534.02
Window Opening Area [ft2]	9472.01	0.00	3809.96	1869.97	3792.08
Gross Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02
Above Ground Window-Wall Ratio [%]	26.82	0.00	28.12	45.32	28.02

Skylight-Roof Ratio

	Total
Gross Roof Area [ft2]	88508.71
Skylight Area [ft2]	0.00
Skylight-Roof Ratio [%]	0.00

PERFORMANCE

Zone Summary

	Area [ft2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [ft3]	Multipliers	Gross Wall Area [ft2]	Window Glass Area [ft2]	Lighting [Btu/h-ft2]	People [ft2 per person]	Plug and Process [Btu/h-ft2]
SHAFT:ZONE1	550.37	Yes	Yes	6498.71	1.00	1972.12	0.00	0.0000		0.0000
SHAFT.1:ZONE1	19.33	Yes	Yes	80.24	1.00	968.74	276.78	0.0000		0.0000
NWMAIN:FRONTBAY	39963.98	Yes	Yes	823470.66	1.00	14578.57	4236.05	3.4117	96.98	3.7306
NWMAIN:LARGECAFETERIA	1120.99	Yes	Yes	18721.42	1.00	637.71	21.18	3.4117	37.26	0.0000
NWMAIN:MIDDLEBAY	13847.37	Yes	Yes	279059.37	1.00	3898.54	967.64	3.4117	96.98	3.7306
NWMAIN:BACKBAY	20980.50	Yes	Yes	401605.79	1.00	11272.26	1668.23	3.4117	96.98	3.7306
NWMAIN:LAB	4371.87	Yes	Yes	73013.72	1.00	2351.65	63.55	3.4117	96.98	3.7306
NWMAIN:LABBATHROOM	271.10	Yes	Yes	4527.59	1.00	0.00	0.00	3.4117	95.74	0.0000
SEMAIN:FRONTBAYBATHROOM	711.86	Yes	Yes	11888.60	1.00	0.00	0.00	3.4117	95.74	0.0000
SEMAIN:BACKBAYBATHROOM	798.48	Yes	Yes	13335.23	1.00	0.00	0.00	3.4117	95.74	0.0000
ENTRY:ZONE1	20.81	Yes	Yes	193.08	1.00	193.64	123.76	3.4117	96.98	3.7305
CENTERMAIN:SERVER	295.83	Yes	Yes	7854.71	1.00	0.00	0.00	3.4117	96.98	3.7306

CENTERMAIN:SEMINAR	3442.38	Yes	Yes	91399.53	1.00	0.00	0.00	3.4117	96.98	3.7306
Total	86394.85			1731648.67		35873.22	7357.19	3.3892	95.60	3.5806
Conditioned Total	86394.85			1731648.67		35873.22	7357.19	3.3892	95.60	3.5806
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

Report: **Demand End Use Components Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-29 16:10:34**

End Uses

	Electricity [kBtuh]	Natural Gas [kBtuh]	Propane [kBtuh]	District Cooling [kBtuh]	District Heating [kBtuh]	Water [gal/min]
Time of Peak	01-JAN-11:30	-	-	-	16-DEC-06:00	01-JAN-12:30
Heating	0.00	0.00	0.00	0.00	2651.05	0.00
Cooling	0.00	0.00	0.00	0.00	0.00	0.00
Interior Lighting	293.01	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	309.57	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	1.62	0.88
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	602.58	0.00	0.00	0.00	2652.66	0.88

End Uses By Subcategory

	Subcategory	Electricity [kBtuh]	Natural Gas [kBtuh]	Propane [kBtuh]	District Cooling [kBtuh]	District Heating [kBtuh]	Water [gal/min]
Heating	General	0.00	0.00	0.00	0.00	2651.05	0.00
Cooling	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Lighting	ELECTRIC EQUIPMENT#NWMain:FrontBay#GeneralLights	136.44	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LargeCafeteria#GeneralLights	3.83	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#GeneralLights	47.28	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#GeneralLights	71.63	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#GeneralLights	14.93	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:LabBathroom#GeneralLights	0.93	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:FrontBayBathroom#GeneralLights	2.43	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#SEMain:BackBayBathroom#GeneralLights	2.73	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#GeneralLights	0.07	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#GeneralLights	1.01	0.00	0.00	0.00	0.00	0.00
	ELECTRIC						

	EQUIPMENT#CenterMain:Seminar#GeneralLights	11.75	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	ELECTRIC EQUIPMENT#NWMain:FrontBay#05	149.19	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:MiddleBay#05	51.69	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:BackBay#05	78.32	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#NWMain:Lab#05	16.32	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#Entry:Zone1#05	0.08	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Server#05	1.10	0.00	0.00	0.00	0.00	0.00
	ELECTRIC EQUIPMENT#CenterMain:Seminar#05	12.85	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	Ventilation (simple)	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	DHW NWMain:FrontBay	0.00	0.00	0.00	0.00	0.78	0.31
	DHW NWMain:LargeCafeteria	0.00	0.00	0.00	0.00	0.00	0.23
	DHW NWMain:MiddleBay	0.00	0.00	0.00	0.00	0.27	0.11
	DHW NWMain:BackBay	0.00	0.00	0.00	0.00	0.41	0.17
	DHW NWMain:Lab	0.00	0.00	0.00	0.00	0.09	0.03
	DHW Entry:Zone1	0.00	0.00	0.00	0.00	0.00	0.00
	DHW CenterMain:Server	0.00	0.00	0.00	0.00	0.01	0.00
	DHW CenterMain:Seminar	0.00	0.00	0.00	0.00	0.07	0.03
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Report: **Climatic Data Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2016-02-29 16:10:34**

SizingPeriod:DesignDay

	Maximum Dry Bulb [F]	Daily Temperature Range [deltaF]	Humidity Value	Humidity Type	Wind Speed [ft/min]	Wind Direction
SUMMER DESIGN DAY IN SMITHSONIAN SGH JUL	90.86	15.30	73.04	Wetbulb [F]	0.00	0.00
WINTER DESIGN DAY IN SMITHSONIAN SGH	7.70	0.00	7.70	Wetbulb [F]	2874.16	0.00