2013-07-11

A Comparative Analysis of Energy ModelingMethods for Commercial Buildings

Spencer Mark Salmon
Brigham Young University - Provo

BYU ScholarsArchive Citation

Salmon, Spencer Mark, "A Comparative Analysis of Energy ModelingMethods for Commercial Buildings" (2013). *Theses and Dissertations*. 3703.
https://scholarsarchive.byu.edu/etd/3703

A Comparative Analysis of Energy Modeling

Methods for Commercial Buildings

Spencer Salmon

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Kevin R. Miller, Chair
Jeffery L. Campbell
Kevin L. Burr
Jay P. Christofferson

School of Technology

Brigham Young University

July 2013

ABSTRACT

A Comparative Analysis of Energy Modeling Methods for Commercial Buildings

Spencer Salmon
School of Technology, BYU
Master of Science

This thesis researched the accuracy of measured energy data in comparison to estimated hand calculation data and estimated building energy performance simulation data.

In the facility management industry, there is minimal evidence that building energy performance software is being used as a benchmark against measured energy usage within a building. Research was conducted to find examples of measured energy data compared to simulated data. The study examined the accuracy of a simulation software and hand calculations to measured energy data.

Data suggests that comparisons may be made between building energy performance simulated data and measured data, though comparisons are solely based on each individual case. Data suggests that heating load simulation data is more accurate for benchmarks than cooling load simulation data.

Importing models into Autodesk Green Building Studio (GBS) was not as successful as was expected. When only four of the initial ten building models chosen imported successfully, the remaining twenty-five other building models were imported. Only two of the twenty-five models successfully imported into GBS. The sample size of this research changed from ten to six.

The results of this study show that GBS simulated data was close to actual data for the heating loads. For the cooling loads, however, GBS simulated data was consistently low in comparison to the actual data.

The results of this study show that hand calculations were consistently low and not as close as GBS simulated data when compared to the actual data for the heating loads. The opposite was true with the cooling loads as hand calculations were consistently high in comparison to actual data.

Keywords: Spencer Salmon, energy analysis, building energy performance, building information modeling, energy modeling

ACKNOWLEDGEMENTS

A heartfelt thanks to my thesis committee chair, Kevin Miller for the time he spent mentoring and providing direction. A special thanks to the thesis committee, Kevin Burr, Jeff Campbell, and Jay Christofferson, who took time out of their busy schedule to provide feedback that allowed this thesis paper to come together. And, a very special thanks to Amy and Maxwell, my wife and son, for their support and encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Background of the Problem

Building Information Modeling has provided owners, designers, and facility managers the ability to forecast the energy efficiencies of their facilities. Based on writings from Claridge, whole building simulation has increased significantly for the design of a building's heating, ventilation, and air conditioning (HFAC) systems in the past several years (Claridge, 2011). It is a common occurrence in the design phase that building information models be combined with energy analysis software to perform environmental and energy analysis' because of the object information richness within the 3-D models (Eastman et al, 2008). Though useful in design, there is greater benefit to continue the use of simulation as a benchmark through a building's lifecycle. The vision of simulating energy analysis through a building's lifecycle has not been frequently used to help optimize its operation after construction has been completed and the accuracy of simulated energy analysis is in question (Claridge, 2011).

Eastman, Teicholz, Sacks, and Liston state that Building Information Modeling (BIM) is an advantageous technological advancement over 2-D models because 3-D models have more object information that can be used to perform energy analysis for increased efficiency. When a 3-D model is linked to building energy performance analysis tools, the abundant object information provided by the model generates an estimation of energy use data (Eastman et al, 2008).

Hodges and Elvey indicate that for every square foot of operation costs, average energy costs are between \$1.50-\$2.00. With a building that is approximately 100,000 square feet, the energy costs run from \$150,000 to \$200,000 annually. The amount of money spent on energy is not easily overlooked (Eastman et al, 2008).

Though not a frequent practice, Claridge has identified one case study where simulation results in output errors were 50% or more when compared with actual building performance. The case study Claridge identified was Texas A&M University's Harrington Tower (Claridge, 2011). The figure below shows the daily measured and simulated heating usage.

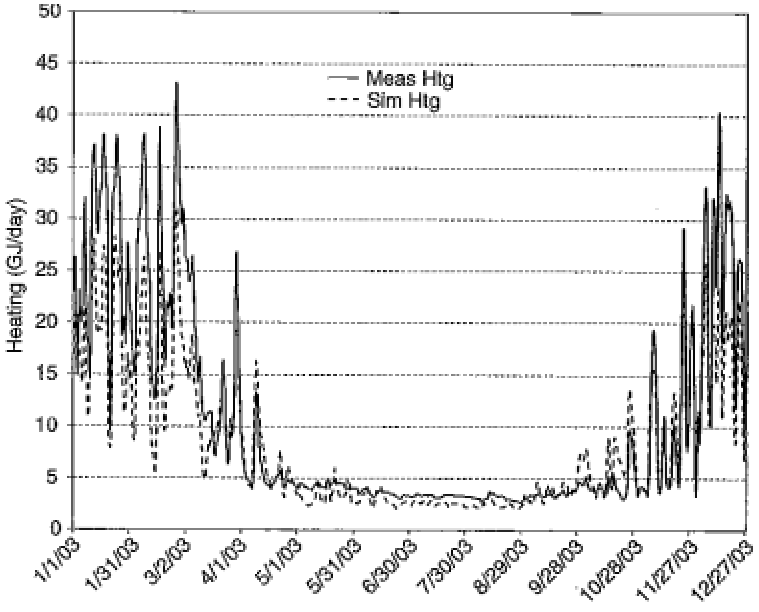


Figure 1-1: Harrison Tower 2003 Simulated and Measured Heating Usage

Claridge stated that from this case study, "a simulation may not accurately reflect the performance of the buildings" (Claridge, 2011). Figure1-1 shows the truth of Claridge's statement because the measured heating usage is greater than the simulated heating throughout most of the year. More studies should be performed to better understand what the accuracy is of measured data from constructed buildings to simulated data (Hensen & Lamberts, 2011).

Brigham Young University's (BYU) physical plant has used CAD drawings for as-built documents. BYU is converting this documentation to Building Information Models or BIM. BIM has the potential to contain parametric data and perform analysis with various types of information about buildings. Some information that is important to the BYU Physical Facilities division includes floor types, ceiling types, area, square footage, and energy usage.

BYU has tracked energy consumption of individual building spaces, and capital needs for each building on campus for several decades. BYU is one of many universities that has not benchmarked and compared their measured data to energy simulation data.

1.2 **Research Problem and Purpose**

The research problem is; users of energy modeling are uncertain of the accuracy of their models.

The purpose of the research was to determine the accuracy of energy modeling data and hand calculated energy data against historical data using comparison measurements of Million British Thermal Units (mmBtu).

Research questions that are intended to be answered are: How accurate is hand calculation data compared to measured data and how accurate is energy modeling data compared to measured data.

1.3 **Limitations and Assumptions**

The weather in the Utah region is a steppe climate and has four seasons. Utah has a dry climate, but humidity is higher during the summer than it is during the winter. Winter weather is cold; spring weather is warm; summer weather is hot; and fall weather is warm. See Figure 1-2 below for the average Utah weather and seasons (WeatherSpark, "Temperature"):

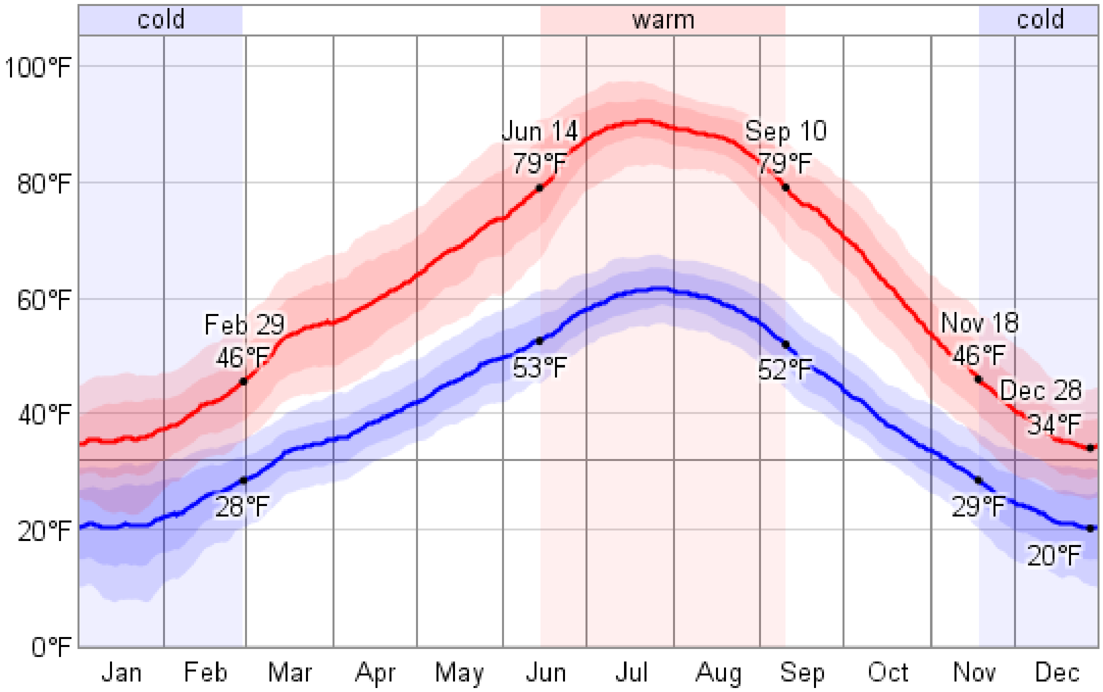


Figure 1-2: Average Seasonal Weather for Provo, Utah

The red lines in Figure 1-2 represent the average temperature high while the blue lines represent that average temperature low. The red shading represents the warmest period of time and the blue shading represents the coldest period of time.

Autodesk's Green Building Studio (GBS) has a built-in weather program that allows the user to select the city in closest proximity to the project. The weather database is an assembly of averages over decades. For the study, the weather station in Provo, Utah was selected because it is approximately 1.3 miles away from the projects' location.

The six building models used in this research have their own metering systems to measure the actual energy consumed. These same six models were created by Brigham Young University's BIM manager and were verified through two-dimensional architectural drawings and on-site inspections.

All objects-e.g. windows, doors, and walls-were modeled based on dimensions. Objects either came from the Autodesk Revit selection of object families, or were created within Autodesk Revit. These components were spatially accurate and used the correct materials, but may have lacked information on the age, manufacturing type, and insulation factors.

Models exported to gbXML and uploaded into GBS were solely based on building envelope materials. Green Building Studio did ask for models to include mechanical and electrical systems to more accurately calculate energy use.

1.4 **Definitions**

Building Information Modeling (BIM)-a digital representation of physical and functional characteristics of a facility that serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle.

Leadership in Energy and Environmental Design (LEED)-a rating system for the design, construction and operation of high performance sustainable buildings.

Metering-the use of an instrument to measure and record the quantity of utilities (water, gas, electricity) used at a specific location.

XML-an extension to HTML, the language used to send information over the web. It is an alternative way to exchange data.

2 LITERATURE REVIEW

This literature review provided a context on BIM, energy metering, hand energy modeling calculations, and building energy performance software.

2.1 **Building Information Modeling – BIM**

The National Building Information Modeling Standard Committee has defined building information modeling (BIM) as “a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward” (Leite, 2010). Numerous architecture, construction, engineering, and facility management companies incorporated BIM, and used it for applications like design reviews, commissioning, constructability analysis, life-cycle costs, and clash detections (Leite, 2010). Government organizations also supported and used BIM. Some examples were the US General Services Administration (GSA) and the US Army Corps of Engineers (USACE). In 2005, the GSA inquired about suggestions on the use of BIM technology from vendors, sub-contractors, general contractors, and design consultants (Levy, 2012).

2.1.1 Advantages of BIM

The value of BIM was still underutilized for its use in construction projects with companies in the AEC/FM (architect, engineer, construction, and facilities management) industries. This in part, was due to the fact that BIM is not a seamless practice currently in every stage of a construction project. Several articles were written about the benefits of BIM in industry and several methods were used to identify the benefits and benchmark them. Some examples where BIM can add value to a project were quantifying space in a facility, quantifying rooms, time and accuracy improvements with cost estimates, Requests for Information (RFI), and contractor initiated change order reduction were all examples of value added by BIM (Leite, 2010).

For the architectural and engineering industries, BIM provided the ability to identify design conflicts, geometric representation accuracy of the facility and all its parts. For the construction industry, BIM provided less rework, prefabrication of any components before construction, fewer change orders (both contractor and owner initiated), fewer Requests for Information (RFIs), increased marketing satisfaction of customers because of visualization, productivity improvement with phasing and scheduling, and increased effective construction management leadership (Leite, 2010). It also provided contractors access to digitally record their progress on any given project and simplified their supply estimates with quantity take-off automation (Weygant, 2011). For the facility management industry, there was greater control over life-cycle costs and total cost of ownership, accurate and rapid change updates through a software medium, and as-built information (Leite, 2010).

2.1.2 Level of Detail

An important component of BIM was 'Level of Detail.' Level of Detail (LOD) within a BIM model was an important factor to consider when determining its value (Leite, 2010). Research indicated that the American Institute of Architects (AIA) has created a document outlining the different levels of design. They proceeded with five basic levels: LOD 100-500. LOD 100 was intended to be used during the pre-design phase and represented just the general masses of the project. For example, this may be just the building and general shape. LOD 200 was more specified as it represented approximate sizes, shapes, and quantities. For example, ceilings, floors, walls, openings in walls for windows and doors are LOD 200 material. LOD 300 was the beginning of more detailed work and was usually the level of construction documents. At this level, quantities may have been estimated, but there was a lack of detail with regards to installation or maintenance. LOD 400 contained the information to create shop and fabrication documents. LOD 400 contained a greater amount of information within each object. LOD 500 was the highest level of detail and usually was a high, digital representation of the desired product. So much information was contained within a project at this level that current systems used to support these projects were overloaded (Weygant, 2011).

It was essential to standardize information within a BIM project so that a consistent LOD was maintained among all materials. Without this, the detail of materials and level of information may have crossed different levels and created confusion for software simulations. BIM Projects were no longer interoperable when material details crossed different levels (Weygant, 2011).

2.1.3 BIM Standards

The US National Institute for Standards and Technology has indicated that the failure of not providing interoperability was costing the US Capital Facilities industry an estimated $15.8 billion per year. Because of this, the GSA has strongly pushed the National Building Information Modeling Standard for new initiatives. Through a web survey study, a study of BIM and Virtual Design and Construction indicated that BIM and Virtual Design and Construction were used frequently in all design and construction stages of projects. This study also noted that the participants' positive perception about BIM increased the value even though these participants couldn't quantify any benefits (Howard & Bjork, 2008).

Bjork and Howard conducted a study in which architect, engineering, construction, and IT experts from several countries were asked if it was "possible to create comprehensive BIMs?" Responses from these different experts resulted in half saying 'no, but…' and the other half saying 'yes, but…' In effect, each expert responded with their own definition of BIM. Bjork and Howard also asked about standards within the definition of BIM. They reported that the experts responded to the belief of standards but could not agree upon the formality, observation, or what should be standardized. When the respondents were asked about existing standards, they indicated that BIM standards were incomplete and poorly marked. Those surveyed indicated that the experts in the construction industry should develop the standards and software companies should implement the standards. Respondents indicated that if the standards of BIM were to match industry procedures, this would assist the BIM effort to provide the greatest benefits to those involved in any stage of a project (Howard & Bjork, 2008).

Howard and Bjork have summarized common themes from the surveys. One of the common BIM themes included an idealistic goal to create a building model that would be able to be used throughout the entire process of a project. Another theme that came to light is that standards are appreciated, but only a handful of people might apply them all. A third theme indicated that BIM has many relevant standards, but none are aimed at the single building model. A fourth theme from the survey questions was to create an information manager on the project teams of companies who would be able to coordinate and communicate model information with other companies and partners (Howard & Bjork, 2008).

There have been many examples from architects and engineers integrating BIM standards into the initial design and building phases, yet authors collected little experience or feedback from property/facility owners. Experts across the industries agreed that the building requirements should be integrated and standardized through modeling so that the data is represented in a way that does not delay the design and construction phases. Although BIM strived for greater standardization, current BIM practices fell short of these goals (Howard & Bjork 2008).

Pramod Reddy put to rest some of the common BIM themes that Howard and Bjork list above. Reddy stated that the focus of standards should not be on the model itself; the focus should be in the information within the model. This was significant. The standards should organize the information in a format where any party could use the information to best meet their needs without eliminating any contractual liabilities. BIM standards should focus on industry information standards such as the National Institute of Standards and Technology's UNIFORMAT II and OmniClass Construction Classification System (Reddy, 2011).

2.1.4 BIM Influences in Construction Industry

BIM has expanded into the construction industry in recent years. BIM provided dynamic decision-making information throughout a project's lifecycle. BIM was causing traditional construction practices to experience a paradigm shift as the industry enhanced the practice of communication, processes, culture and business models. With all this expansion, BIM had not been fully embraced into the industry and several questions were to be more fully explored and answered (Wilson & Heng, 2010).

BIM turned construction projects into virtual environments for the construction industry because it allowed construction companies to virtually build the project beforehand and access it as it is physically constructed. An example of this was a construction company using a thorough model to produce shop drawings. This was advantageous since shop drawings have been produced independently. Now, shop drawing information was connected to the model. If there were further questions about the shop drawings, they could be answered by accessing the information within the model. Visually, the model was the beginning point of a construction schedule and further enhanced the industry's understanding (Kymmell, 2008).

2.1.5 BIM Concerns

Building owners had a difficult time justifying the use of funds for overall BIM. It is seen as an additional cost with no return on investment (Wilson & Heng, 2010). The AEC industries were working with owners to realize the benefits of using BIM (Wilson & Heng, 2010).

It is estimated that $15.8 billion dollars could be saved annually by increasing the interoperability of systems within buildings (RICS, "Interoperability"). Support was increasing from architectural, engineering, construction and facility management industries to utilize BIM in order to improve a project's life-cycle performance, project communication during construction and increase efficiency in construction processes. Each year, more AEC/FM companies initiated and continued to utilize BIM to help reduce these unneeded costs (Leite, 2010).

The early phases of the building design and preconstruction were very important. During this time, critical decisions concerning sustainable features such as construction materials and site locations were made. CAD and other traditional design options lacked the energy and sustainability analysis for the early phases of design development. Architectural designs and construction documents for a project were usually produced before performance analyses are conducted on the building. Irregular sustainability analysis during the design process could cause inefficient results, not achieving pre-established performance criteria. To understand and accurately analyze sustainable measures during the design phase, it was essential to have proper building, materials, and mechanical-electrical-plumbing (MEP) systems. Building Information Modeling (BIM) contained information that communicated with various software packages to provide sustainable measures and processes (Azhar et al, 2011).

2.1.6 BIM and Sustainability

In a study by Nies and Kriegel, they identified means by which BIM assists in sustainable design. First, BIM assisted in building orientation and daylighting. Daylighting was an energy analysis tool used to determine the amount of day light a building will receive. Second, BIM assisted with the building envelope and size. Third, BIM contributed to water harvesting, energy modeling, and recycled or reduced materials. Fourth, BIM helped to layout and organize the construction site. In a survey by these authors, design and construction companies reported that they are experiencing ‘some-to-significant’ cost savings and time using BIM-based sustainable analysis when compared to traditional sustainable methods (Azhar et al, 2011).

A McGraw-Hill Construction study found that in retrospect, green construction enhanced the use of BIM among companies. In 2010, slightly less than half of green BIM projects used sustainable analysis tools in only half of their projects. Seventy-eight percent of the study's respondents indicated that they were preparing to use these same tools within the next three years. McGraw-Hill also found that firms specialized in sustainability projects were more likely to use the full spectrum of tools provided by BIM than other construction companies. These firms used more than three-quarters of the available tools BIM provides for green objectives (Wroblaski & Morton, 2010).

2.1.7 BIM and LEED

Building Information Modeling was a digital representation of physical and functional characteristics of a facility that serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle. A building information model was sufficiently rich in information to produce documentation for receiving sustainable LEED credits. For example, BIM provided building component schedules that included the material percentages' used, salvaged, and recycled content. BIM also allowed for several designs to be saved to track and review sustainability. Architects were able to run sustainable site analysis based on spatial information input to help the design team analyze the related issues of resources, location, climate, and surroundings (Azhar et al, 2011). The design team was also able to take each design and evaluate its location, impact on the site, solar orientation efficiency, and daylighting analysis. BIM more efficiently generated drawings to support the documentation of each LEED credit. BIM also was of great benefit when changes occurred in the design because each drawing was linked to all other drawings. When changes were made, all drawings were updated instantaneously. This cut back the labor of any worker to update all drawings which was required in more traditional drafting or 2D CAD designs (Azhar et al, 2011).

One case study by Azhar sought to verify that 17 total LEED credits and two prerequisites may be achieved using BIM during the design phase. From the published article, BIM was only able to contribute sufficient data, information, or analysis to verify five LEED credits and one prerequisite. Using BIM during the design phase resulted in the most potential LEED credits earned. Fewer LEED credits may be earned during the construction phase and substantially fewer LEED credits may be earned during the pre-design phase (Azhar et al, 2011). In another study published more recently, Kubba said that up to 20 LEED credits can now be confirmed and documented through the use of BIM (Kubba, 2012).

Brown and Azhar found that the software used, Virtual Environment (VE) and Revit, lacked LEED integration characteristics and that there was not a one-to-one relationship between LEED certification process and sustainability analysis of BIM software. One observation that Brown and Azhar made about BIM was the ability of BIM to generate instantaneous results. Traditional means, such as paper and pencil, yielded results weeks and months after calculations (Azhar et al, 2011).

In another case study, Yoders researched information on the relocation project of the New York Police Academy that the Bloomberg administration announced in 2008. Cal Smith, a technical director at Perkins+Will stated that without BIM, this building would not have been designed the way it is designed currently, nor could the team attempt to achieve the LEED Silver Certification. BIM enhanced the ease of the design of a building in order to accumulate the greatest amount of LEED credits (Yoders, 2010).

2.2 **Energy Metering**

Campus environments with cooling systems, central heating, or cogeneration had some of the best methods of energy metering. Energy metering systems traced the energy used in a building. Oftentimes, the only metering in these systems was at the entrance of the utility plant gate. Some institutions had instituted sub-metering for the individual buildings on campus. McBride (2002) published that some campuses had energy costs in the millions of dollars passing through the campus plants with minimal understanding of energy use downstream. Metering was a tool used by energy companies and customers to track the quantity of energy passing through a meter. The information could then be analyzed to understand how and where the energy was being consumed and look for means to reduce the amount of energy being consumed (McBride, 2002).

To achieve energy savings, thoughtful planning took place. The essentials of knowing what needs to be metered and how something is going to meter were the first steps of energy savings (McBride, 2002). The advantages of several small meters were that it created a more accurate trace of energy use, provided a better break-down of where energy is being used, and produced easier billing if multiple entities use a specific building. The disadvantages for going from a few meters to several small meters included numerous upfront costs for the several small meters, individual metered service charges, and if peak demand is billed separately, cost increases for same period (Energy Star, 2002).

2.2.1 Sub-Metering

Sub-Metering was the use of additional meters located near a building utility meter. Sub-Meters may have included individual building metering on centrally metered campuses or individual utility loads metered within a building (McBride, 2002). Mid- to large size campuses would have the most to benefit from sub-metering compared to small campuses. These benefits included the separation of buildings using different funding sources, facilitating college and department responsibility, identifying performance improvements, creating baseline energy use and quick response, and improving accountability for energy consumption (Energy Star, 2002).

Sub-Metering helped to separate costs to specific funding sources. For example, many universities were funded through multiple sources, such as a state, a donor, or an auxiliary fund. If sub-metering was implemented on a campus, then each building would track its specific amount of energy used. The energy used translated into energy costs and was allocated to the specific funding types. Private donors knew their exact costs for the buildings that they funded and the state knew their exact costs for the buildings that they funded. Sub-Meters prevented inaccurate accounting of energy usage and eliminated the use of approximate percentages of energy use per building (Energy Star, 2002).

In a large research university study, sub-meters may be used to estimate loads for new buildings. Sub-metering also provided the University with the option of connecting individual utility company accounts to one or more sub-meters because the cost of electricity can be calculated on an account by account basis. This study also demonstrated another benefit that sub-meters accurately verified utility meter readings of energy use of entire buildings (Energy Star, 2002).

In one case study of two universities, facility managers of higher education were interviewed. The survey results revealed that electrical costs at universities consumed the majority of the energy budget exceeding costs for steam, natural gas, chilled water, and other resources. Electrical sub-meters were generally installed before any other energy source sub-meter. Sub-Metering was an increasing trend for electrical usage and a significant amount of college campuses were sub-metering energy. Through the use of sub-metering, facility managers more easily knew where high energy use was occurring and were able to focus on energy efficiency improvements in those areas to lower costs (Energy Star, 2002).

Sub-Metering allowed energy use comparisons among similar buildings with various categories. Buildings were heavily categorized by their use, whether they were dormitories, offices, laboratories, classroom spaces, dining halls, and gymnasiums. If campuses had not sub-metered yet, priority for sub-metering may be given to those buildings that were dormitories with laboratories, offices, and classroom spaces because these spaces consumed the most energy (Energy Star, 2002).

2.3 **Building Energy Performance Software**

Attia, Beltran, Herde, and Hansen tracked building simulation back to the United States government in the 1960s. They first used it in a project to assess the thermal environments of shelters (Attia, et al, 2009). For more than 50 years, people and companies developed hundreds of building energy metering programs and many are still in use today. Key building performance indicators had been the focus of these whole-building energy programs. Key indicators used by the industry included energy costs, energy use and demand, humidity, and temperature (Crawley, et al., 2008). With the improvement of technology, building simulation improved and evolved into an industry that produced tools that are validated internationally and scientifically (Attia et al, 2009).

Companies that develop building performance simulation (BPS) tools knew of the importance of energy performance decisions and costs all the way back in the early 1980s and started developing these tools to assist designers that allowed them to create a more energy efficient building. Not until the 1990s did the BPS field grow with architects and designers who used virtual environment and CAD tools. The 1990s increased the use of BPS tools with designers. Many found that the BPS tools were too complicated and complex. Technical researchers, scientists, or engineers developed these BPS tools and the literature reported a growing gap between architects and BPS tools. To narrow the gap between users and developers, the user interface needed to encompass the abilities and needs of the end-user and not just analytical calibration and verification. Human interaction with the computer enriched the human experience with the building simulation program. One opportunity to narrow this gap was through the use of BIM because it directly linked the design and building performance system tools. This opportunity to overcome differences between reality and logical models came with the chance to improve alliances and integration in the AEC industry (Attia et al, 2009).

Though the importance of building energy simulations increased in new building design, importance also grew for assessing possible energy efficiencies in existing buildings. David Claridge stated that “simulations can be valuable tools in many applications, such as calculating energy savings from proposed or implemented retrofits, existing building and new building commissioning fault detection and diagnosis, and program evaluation” (Hensen & Lamberts, 2011).

Claridge indicated that building simulation was intended to be used for the entire life-cycle of a building, maintaining and optimizing the routine ongoing operation. He was not able to find any examples. He clarified that the accuracy of each program developed for building energy performance software was dependable upon the user’s ability to input correct parameters resulting in a precise building energy use model. When parameters were used from the design models, they resulted in output errors of 50% or more (Hensen & Lamberts, 2011).

2.3.1 Contrast of 20 Building Energy Performance Simulation Programs

In July 2005, the United States Department of Energy published an article contrasting 20 building energy performance software programs. These programs were BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Energy-10, Energy Express, Ener-Win, EnergyPlus, e-Quest, ESP-r, IDA ICE, IES<VE>, HAP, HEED, PwerDomus, SUNREL, Tas, TRACE and TRNSYS. For analysis reasons, Crawley also requested initial information on these programs' tools (Crawley, et al., 2008).

All 20 programs had the ability to provide full geometric description of walls, roofs, floors, doors, skylights, windows, and external shading except Energy-10 and HAP. The number of software programs decreased when importing building geometry from CAD programs; BLAST, DOE-2.1E, Ener-Win, Energy-10, HEED, SUNREL were incapable while DeST and HAP only had partial ability. All remaining software had full ability to perform this task. Of the 20 tools, DOE 2.1E, HEED, and SUNREL did not have weather data provided with their program neither did they have the capability to provide weather information from a separate download. For customers that wanted to generate data hourly from the monthly averages, DeST, ECOTECT, Ener-Win, IES<VE>, TRACE, and TRN SYS provided these capabilities.

Other general information about the tools: nine of twenty provided the ability to calculate component life-cycle costs. Only six software programs, Ener-Win, Energy-10, eQUEST, HAP, IES<VE>, and TRN SYS, provided standard life-cycle costs using private-sector rates and taxes. Eighteen of the 20 software programs were able to provide results for a buildings peak demand and 17 of the 20 showed the energy breakdowns by use. A drawback on reporting results was the inability of 14 of 20 software programs to show breakdowns of energy use of multiple sub-metering levels.

The author performed a limited review to verify the information. Unique jargon was an unanticipated finding by the author in gathering this information from the vendors. Each company's software had a certain jargon and the simulation industry was still distanced from having a clear language standard used for the simulated models (Crawley, et al., 2008). From the Department of Energy's 2005 research, there was a lack of common language among some of the more established systems for identifying the capability. Even the tables that provided the results of the research had ambiguity because developers had some difficulty communicating the tools. The researchers attempted to define the level of the companies' tools through specific lettering: X-Capable, P-Partial, O-Optional, E-Expert, or I-Difficult to obtain input. This report did not attempt to answer whether these tools would support analysis over a lifetime of a project (Crawley, et al., 2008).

2.3.2 Architect Friendly Comparison of 10 Building Performance System Tools

Another comparison study of ten different building performance simulation tools occurred in 2009 and was authored by Attia, Beltran, Herde, and Hensen. These authors screened the top ten Building Performance Tools from the Department of Energy Directory. They also developed and redefined a questionnaire sent out to environmental architects who assisted in the comparison of the companies. The ten simulation tools that these authors reviewed were DOE-2, Design Builder (DB), ECOTECT, Energy 10 (E10), Energyplus, Energyplus Sketchup (EPSU), eQUEST, Green Building Studio (GBS), HEED, and IES VE.

The opening section of this survey provided basic feedback about the department's use of energy simulation software and modeling. The middle two sections gathered interface usability and information management results as well as intelligent design integration. The last section asked the departments to rank, in their view, the most important criteria for building performance software tools. Two hundred forty-nine eligible individuals from departments nationwide responded to the survey. Thirty-eight and one half percent of these individuals were architects in the field while the second largest group was architectural designers at 19.2%.

AutoCAD, SketchUp, and Revit were the three most used CAD/3D modeling software. Architects considered graphical representation of output results over flexibility of use and navigation as the most important usable and graphical visualization. IES VE did not have easy learnability and short learning curve period whereas ECOTECT, DB, eQUEST, and GBS were not considered as having graphical representation of results in 3D spatial analysis.

Users considered IES VE, HEED, eQUEST, GBS, DB, and Energy 10 as having the ability to create comparative reports, flexible data storage, simple input options, and allowing assumptions and default values to facilitate data results. Other results showed that all but EPSU had online user help and training courses. HEED and DOE 2 did not provide their own weather data and extensive libraries of building components and systems. IES VE was not considered easily learnable by architects nor did the architects consider it to have a short period learning curve. Final results from the architect respondents broke the ten software programs into three groups. The first group consisted of IES VE, HEED, and eQUEST, and they were the most 'Architect Friendly'. The second group contained the tools ECOTECT, DB, GBS, and E10 and failed to be 'architect friendly' because the users felt the tools lacked integration during the architectural design process. The third group consisted of EPSU, EP, and DOE-2 having the lack of functionality of the tools.

2.3.3 Sustainability Analysis Software Case Study

Azhar and Brown surveyed 91 construction and design firms based in the United States for this case study. Out of these 91 firms surveyed, three energy/sustainability analysis software packages were commonly used: Integrated Environmental Solutions (IES) Virtual Environment (VE), Autodesk Green Building Studio (GBS), and Autodesk Ecotect. Based on Brown and Azhar's evaluation of the software, Virtual Environment (VE) was most user-friendly, powerful, and versatile with sustainability capabilities to evaluate LEED credit earning opportunities (Azhar, 2011). The reasons were given preferring VE in their case for running sustainability analysis. From Autodesk Revit, they exported a gbXML file to IES VE building performance simulation tool. They concluded that their VE results were not very accurate but were in a general energy range and therefore, a correct assessment. The energy analysis team then used this information to predict how many points could be earned toward the case study's LEED certification, which was 17 LEED credits and 2 prerequisites for a possible 38 points (Azhar, 2011).

Brown and Azhar noted that BIM-based sustainability software calculated results much quicker than the traditional methods. BIM-based sustainability software saved substantial resources and time. The use of BIM-based sustainability software provided no one-to-one relationship with LEED certification process. Brown and Azhar also noted that users should review the results manually as there are discrepancies periodically in the reporting (Azhar, 2011).

2.4 Heating and Cooling Loads

An engineer's responsibility included the design phase of a building and calculating the estimates of heating and cooling loads. Accurately calculating the heating and cooling loads was necessary because it effected everything from system selections to equipment selections to air distribution hardware selections and placement of said equipment to airway sizing and duct placement. When heating and cooling loads were accurately calculated, these loads-matched with the correct equipment capacity-delivered reliability, efficiency, and comfort throughout the span of operating conditions (Rutkowski, 2002).

Heating Loads were calculated based on the structure of the building and are impacted by the materials used to construct the building, the number of floors, and the number of exterior doors and windows. Cooling loads were calculated based on the heat gains from heat transfer throughout a building envelope and were heavily produced by lights, people, and appliances (Rutkowski, 2002). The combination of the heating and cooling loads was known as the thermal load. Thermal loads were a calculation of the two loads in order to maintain a constant temperature (Spitler, 2011).

Engineers with years of experience learned a few rules of thumb when calculating heating and cooling loads. They knew that calculations usually are 400/sf per ton, 1 cfm/sf, and 25 Btu/h-sf heating. With the development of more complex buildings, these rules of thumb were still useful, but they were not always reliable. To help engineers, advanced and extensive software was developed to account for the heating and cooling. The software handled the difficult calculations of these complex buildings (Bruning, 2012).

As great a tool as the advanced software was, it did take time to make calculations. Bruner found that in some cases, where time was essential, a simple spreadsheet was a useful tool for calculating heating and cooling loads. This was certainly true during early stages of design. But even during late design and construction phases, a simple spreadsheet illustrated the impacts of individual components relative to the total loads. This feature was non-existent with advanced software (Bruning, 2012).

3 METHODOLOGY

This chapter explains the method of research used for this study. In thus study, the author explains how the sample size was established; the method of gathering measured data; the method of hand calculations and data; and the method of choosing a building energy performance software and the gathering of simulation data.

3.1 Autodesk Revit Models

The University's BIM manager has transformed many of the drawings of buildings on campus from 2-D CAD drawings into 3-D Revit drawings. Of the 100 academic buildings, 35 have been completed in Revit and another 10 are in progress. Starting in the mid-2000s for any new construction, BYU required architects to create an accurate as-built 3-D Revit model. Buildings were diagramed with a modeled envelope that included floor types, ceiling types, and interior and exterior wall types.

The author first selected ten buildings for a sufficient sample size. Each model was exported into a gbXML file and then imported into GBS. Of the ten buildings chosen, only four were fully imported into GBS and successfully ran energy simulations. Since only four building models successfully achieved energy simulations, the author attempted to import the 25 remaining models into GBS as gbXML files. Only two of the 25 building models were successfully imported. Issues with the import functions are discussed below.

3.1.1 Issues Exporting to gbXML

Two errors occurred when 3-D models were exported from Revit to gbXML. Errors are listed in the order that they occurred and were corrected for all Revit models.

One error stated "Can't create any energy analysis surfaces. There are no Room bounding elements defined in the current phase. Please check the Project Information settings." This occurred when the model did not have the project phase defined. This error was quickly resolved when the project phase was defined as Existing.

A second error stated "Room tag is outside of its Room. Enable leader or move Room Tag within its Room." The model was modified to either relocate the room tag within the room or to eliminate the room tag in situations where there were two room tags for one space.

3.1.2 Issues Uploading gbXML into Green Building Studio

Five errors occurred as the gbXML files were uploaded into Green Building Studio and were unable to be read by the simulation software.

The first error encountered was "Issue: Your model has exceeded the limits of DOE-2.2. The limits exceeded are listed below:
 Too many exterior shades (1119), 1024 maximum allowed." This error occurred with five files, each exceeding the 1024 maximum allowed exterior shades. These files were discarded and not pursued further for energy analysis.

A second error encountered was "Issue: An unrecoverable internal error has occurred." This had no explanation beyond the note. The issue was researched on the web and an Autodesk support team's email address was provided to another user for examination of the other user's model by the support team. The first model with this error was emailed to the same address and there has been no response. This error occurred with two different building gbXML files and these files were not used in further research.

A third error encountered was "Issue: Your model has exceeded the limits of DOE-2.2. The limits exceeded are listed below:
 Too many interior type surfaces (8920), 8192 maximum allowed. Try combining small spaces with adjacent ones to reduce the number of unique interior type surfaces (wall, floors, & ceilings).
". The error only occurred with one gbXML file and was not used in further research.

A fourth error encountered said "Invalid gbXML file: Surface id= su-5608, an UndergroundCeiling, has openings in it and openings are not allowed in these surfaces." Upon further investigation in the gbXML file through Microsoft Excel, su-5608 provided only Cartesian coordinates with the model. It was near impossible to determine where these locations were based on coordinates. Unfortunately, no model with this issue was successfully used.

The fifth error encountered read "Invalid gbXML file: space id= sp-201_A-Room has a negative or zero Area. Space id= sp-201_A-Room has a negative or zero Volume. There are no surfaces next to space id=sp-201_A-Room in the gbXML file received by Green Building Studio. These room errors were located in the Autodesk Revit model and room area/volume outlines were modified to eliminate the error.

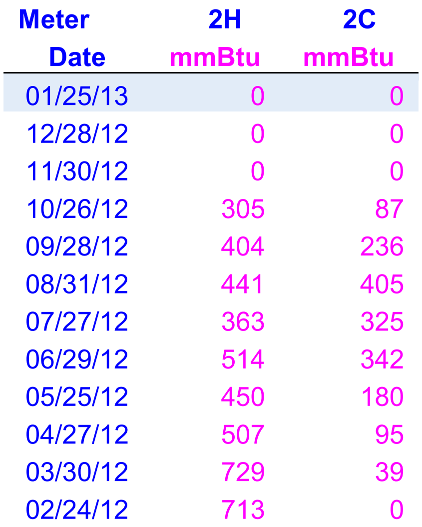
All 35 Autodesk Revit models were revisited in attempt to maintain the sampling number of ten. After modifying the models to eliminate importing and exporting errors, only six gbXML files successfully uploaded into Green Building Studio and are available for research comparisons. These six buildings are renamed as projects 1 through 6.

3.2 **Measured Data**

The Brigham Young University Physical Plant Capital Needs and Utility Analysis (CNA) Department has collected energy data for several decades. Such energy data was used to help verify utility costs and to help pay the utility bills. Indicators obtained are the mmBtu (Millions of British Thermal Units) used.

Table 1 is a collection of heating and cooling load data for one of the projects used in this research. The dates for the last twelve months are included on the left side of the diagram. This date indicates when the meters were read and recorded for billing. The middle column of the diagram is the mmBtu quantity for heating loads and the right column of the diagram is the mmBtu quantity for cooling loads. Two (2) is the meter number and H stands for heating while C stands for cooling. Examples of the university's energy data are shown below in Table 1:

Table 1: An Example of BYU Energy Data Collected



Meter	2H	2C
Date	mmBtu	mmBtu
01/25/13	0	0
12/28/12	0	0
11/30/12	0	0
10/26/12	305	87
09/28/12	404	236
08/31/12	441	405
07/27/12	363	325
06/29/12	514	342
05/25/12	450	180
04/27/12	507	95
03/30/12	729	39
02/24/12	713	0

Each building tracking the quantity of energy used has its own meters. The CNA department receives bills that calculate costs in units other than British Thermal Units (Btu). CNA uses conversion factors to convert all units to Million British Thermal Units (mmBtu). The author collected the measured data in units of mmBtu for the six buildings from the CNA department. The author then averaged the measured data from the previous ten years for each month. The author collected the measured data into a spreadsheet labeling the measured data as ‘10 Year Average.’

3.3 Hand Calculation Data

Brigham Young University’s mechanical engineers in the University planning department hand-calculate heating and cooling loads for all campus remodels. These hand-calculations are automated through an Excel spreadsheet that requires information on the size of the space, the amount of lighting and equipment, etc. (ME, discussion 2013). This same spreadsheet was used to hand-calculate the heating and cooling load estimates of the sample of Brigham Young University buildings.

There are twelve different fields of calculations that are common to all six projects. Calculations for heating and cooling loads were computed for:

1. Roof: Square Footage estimate calculated by Green Building Studio is used as the roof area multiplied by the U factor of each building’s roof, multiplied by an average monthly degree day factor for heating loads. For the cooling loads, an average monthly degree day factor is used. For all further items, an average monthly degree day factor is used as the temperature degree differences between indoor and outdoor.
2. Exterior wall square footage is calculated by subtracting total window area from total exterior wall area multiplied by U factor of .090, multiplied by an average monthly degree day factor for heating loads and for cooling loads.
3. Windows: Total square footage of all exterior windows and exterior glass doors multiplied by U factor of .490, multiplied by an average monthly factor for heating loads and for cooling loads. The total window area is calculated by adding the area of windows and glass doors on the north, south, east and west surfaces of the building.

4. Exterior door square footage is calculated as the total area of exterior doors, minus glass doors, multiplied by U factor of 1, multiplied by a monthly average degree day factor for heating and cooling loads, respectively.
5. North, South, East, and West Solar are the areas for all windows on the building's respective wall's surface multiplied by a monthly average in BTU/ft^2, multiplied by a shade coefficient of 0.7.
6. Calculations for interior lighting equal the net area of the building multiplied by an estimate from Green Building Studio in the units $Watts/ft^2$, multiplied by 3.413 BTU/Watts.
7. The cooling load for the capacity of people in the building at once is estimated by calculating the quantity of people in classrooms and office spaces, multiplied by 250 BTU/person.
8. Equipment cooling load, measured in amps, is calculated from the estimate in Green Building Studio multiplied by 120 Volts, multiplied by 3.413 BTU/Watts
9. Infiltration heat load is interior light area multiplied by a factor of 8, multiplied by Air Density Factor of 0.91, multiplied by the monthly average degree day factor.

CNA calculated the degree day data daily for the last ten years. The author calculated an average monthly degree day for the heating loads and for the cooling loads. The degree days were calculated based on an internal building temperature of 65 degrees. This factor was used in fields 1 through 4, and 9.

The author calculated the North, South, East, and West Solar Btu/ft^2 based on a ASHRAE study where thermal heat calculations were recorded as an hourly average for each month of the year at 40 degrees North Latitude. This is the closest latitude to Provo, Utah. The author averaged the hourly quantities together for one monthly quantity reported in Btu/ft^2. The 40 degree North Latitude shows that thermal energy impacts the south side of buildings during the October to March months more than thermal energy on the east side of buildings. The opposite is true where thermal energy impacts the east side of a building from April to September more than the south side of the building.

This author calculated capacity use by adding the capacities of all classrooms together for a time period in the fall and recalculated for a time period during spring. The capacity dropped significantly during the months of May through August because university use decreased with students breaking from the academic year.

The author used these fields to calculate the heating and cooling loads for each building each month. See Appendices A for the average values used that were mentioned above. These monthly totals were calculated for a one hour time period and therefore, the heating and cooling load totals were multiplied by 12 hours (for the hours in a day that the building is used) and multiplied by the number of days in the month to get the correct estimation of energy use per month per project. The number is multiplied by 12 hours instead of 24 hours to get comparable results to Green Building Studio because all projects were selected as 12/7 facilities within the building performance software. These calculation totals were gathered into a spreadsheet and called ‘hand calculations.’

3.4 Building Energy Performance Software

Several building energy performance software are available to use for energy modeling. Autodesk’s Green Building Studio (GBS) was one of the top ten building energy performance software considered by the Department of Energy. It was chosen as the software for this research for several reasons as bulleted below.

- GBS provided building energy analysis on building envelopes.
- GBS had an extensive database of weather.
- GBS had the flexibility to interchange reporting units.
- GBS has the ability to import building geometry from CAD models.
- GBS provided energy breakdown by use.
- GBS provided comparative reports and simple input options that allowed assumptions and default values to facilitate data results.

Other software programs considered for this analysis were EnergyPlus, Ecotect, and VE. EnergyPlus was not used because users needed sufficient programming skills to communicate and run processes. Ecotect was not used because the program focused more on daylighting, shadowing, and reflections than hourly, daily, and monthly energy usage. IES VE was not used because users did not consider the program to have a simple learning curve and be easily learnable.

3.4.1 Autodesk Green Building Studio

Before each of the six gbXML files were uploaded, the author modified four project default fields under the ‘space’ tab. The condition parameter was modified to the setting ‘heated and cooled’ for each building. The lighting power density parameter was modified to reflect the density for each building. The equipment power density was modified to reflect the density for each building. The lighting and equipment power densities were calculated by GBS for each project through preliminary project uploads that did not have any project default fields modified. The design temperature was modified to 65 degrees Fahrenheit for each building.

After project default fields were modified, gbXML files were uploaded into GBS. As each project was uploaded, the author defined each building's type as a School or University Project. The author also selected each building's schedule as a 12/7 facility because GBS stated that a 12/7 facility is a "building that operates everyday, but is closed at night." After the projects were successfully uploaded and finished simulating energy use, the author collected the heating and cooling load simulated data, in mmBtu, into a spreadsheet and titled the data 'GBS H' and 'GBS C' for Green Building Studio Heating and Cooling simulated data, respectively.

3.4.2 Autodesk Green Building Studio Results

The electricity and fuel results breakdown the percentages and totals of all components that receive the end-uses of electricity and fuel. Area lighting, miscellaneous equipment, exterior usage, pumps and auxiliary, ventilation fans, space cooling, and space heating are the component list of electricity end-uses (Singleton, 2012). Miscellaneous equipment is represented as the plug load of the building, and therefore, not used in our calculations of heating and cooling loads. Hot water and space heat are the components of fuel end-use. Hot water has been removed from the fuel end-use totals leaving just space heat (Schieb, 2010). Space cooling from electricity and space heating totals from electricity and fuel combined were the only totals used to show heating and cooling load comparisons to hand calculations and historical energy use.

Green Building Studio provides graphs that breakdown the energy use of a building through electricity and fuel. Energy data is shown through annual totals or monthly breakdowns that can be evaluated by cost or energy. Energy consumption can be adjusted to British Thermal Units (Btu's), kilowatt-hours (kWh), or mega joules (MJ).

4 RESULTS AND FINDINGS

4.1 Results

All six buildings have a natural heating and cooling trend. Heating loads increase during the winter months and decrease during the summer months whereas cooling loads are minimal during the winter months and increases during the summer months. Each building has hand calculations that estimate the heating and cooling load totals.

A ten-year average was provided for projects 1 thru 3, 5 and 6 and range from January 2003 until December 2012. Project 4 had inconsistent data from 2006 to 2008 due to an addition and therefore, the ten-year average ranged from January 1996 to December 2005. Each project describes the results of the ten-year average use data, Green Building Studio, and Hand Calculations for the heating load data and cooling load data.

4.1.1 Project 1

Project 1 is a two story building on the Brigham Young University campus and is approximately 37,700 gross square feet. Construction of the building concluded in 1959 and has been used since completion. During the summer of 2012, there was a significant remodel. The windows, which comprise of the second floor perimeter of the building, were all replaced and a new roof was installed.

Heating

- The 10-year average was 165 mmBtu/month
- The hand calculation average was 48 mmBtu/month
- The Green Building Studio average was 156 mmBtu/month
- The hand calculations were 29% of the 10-year average heating load per month
- Green Building Studio was 95% of the 10-year average heating load per month
- The 10-year average heating load varied from 363 mmBtu in January to 30 mmBtu in July
- Hand calculations ranged from 116 mmBtu in January to .1 mmBtu in July
- Green Building Studio ranged from 456 mmBtu in January to .4 mmBtu in July

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

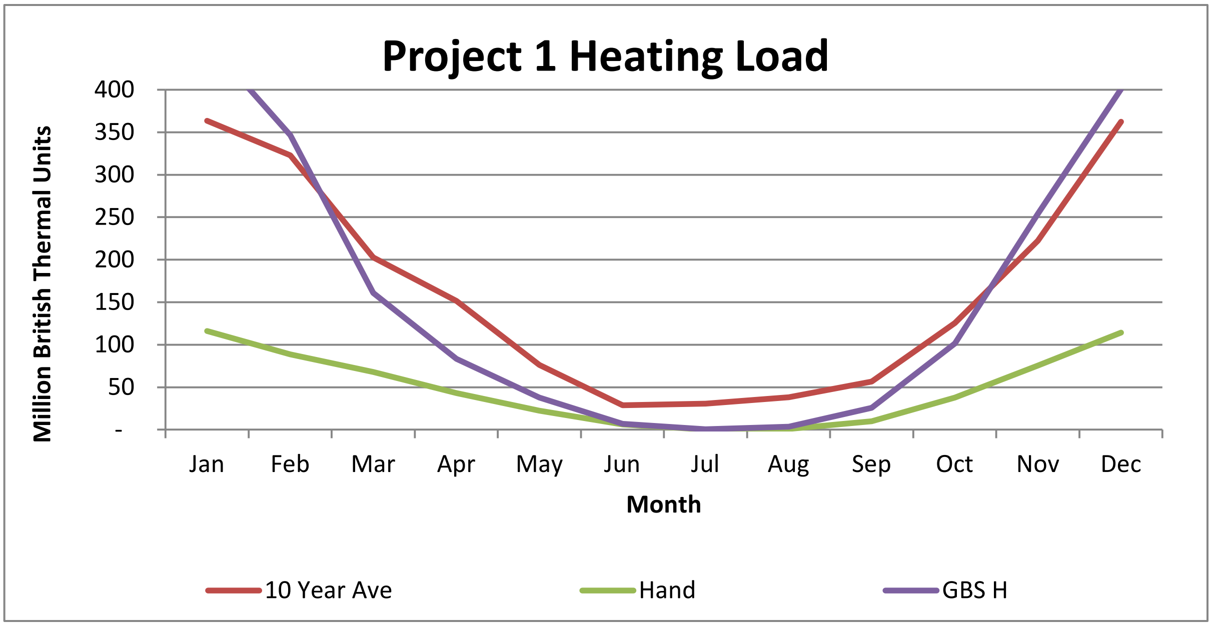


Figure 4-1: Project 1 Heating Load

Cooling

- The 10-year average was 98 mmBtu/month
- The hand calculation average was 216 mmBtu/month
- The Green Building Studio average was 19 mmBtu/month
- The hand calculations were 219% of the 10-year average cooling load per month
- Green Building Studio cooling load was 20% of the 10-year average per month
- The 10-year average cooling load varied from .6 mmBtu in January to 275 mmBtu in July
- Hand calculations ranged from 217 mmBtu in January 225 mmBtu in July
- Green Building Studio ranged from 6 mmBtu in January to 61 mmBtu in July

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

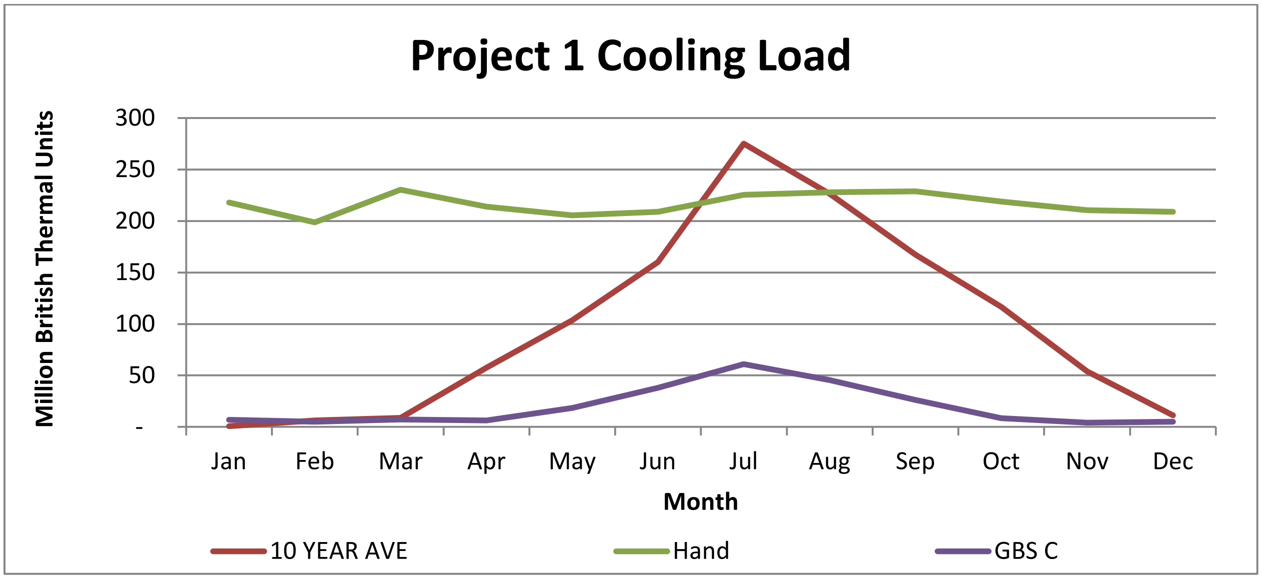


Figure 4-2: Project 1 Cooling Load

4.1.2 Project 2

Project 2 is a three story building on the Brigham Young University campus and is approximately 26,800 gross square feet. Construction of the building concluded in 1925 and has been used since completion. The building has undergone a few renovations since 1925. The building has also changed its function as it used to be a library and now serves as a testing center for students.

Heating

- The 10-year average was 72 mmBtu/month
- The hand calculation average was 43 mmBtu/month
- The Green Building Studio average was 93 mmBtu/month
- The hand calculations were 60% of the 10-year average heating load per month
- Green Building Studio was 130% of the 10-year average heating load per month
- The 10-year average heating load varied from 170 mmBtu in January to 19 mmBtu in July.
- Hand calculations ranged from 84 mmBtu in January to .1 mmBtu in July
- Green Building Studio ranged from 284 mmBtu in January to .0005 mmBtu in July.

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

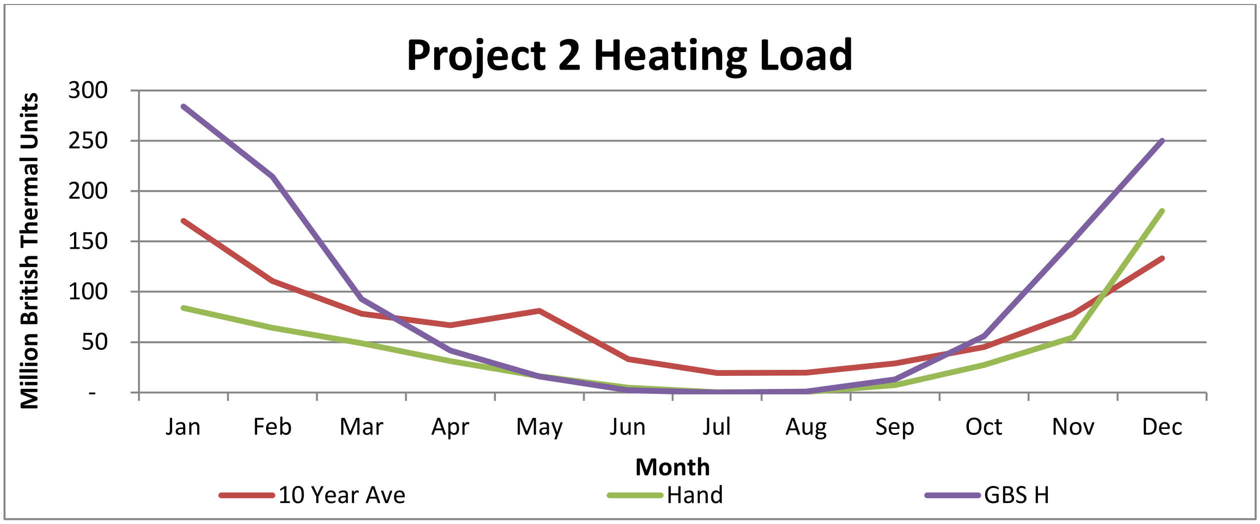


Figure 4-3: Project 2 Heating Load

Cooling

- The 10-year average was 140 mmBtu/month
- The hand calculation average was 169 mmBtu/month
- The Green Building Studio average was 18 mmBtu/month
- The hand calculations were 120% of the 10-year average cooling load per month
- Green Building Studio was 13% of the 10-year average cooling load per month
- The 10-year average cooling load varied from 31 mmBtu in January to 335 mmBtu in July
- Hand calculations ranged from 185 mmBtu in January to 161 mmBtu in July
- Green Building Studio ranged from 8 mmBtu in January to 41 mmBtu in July

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

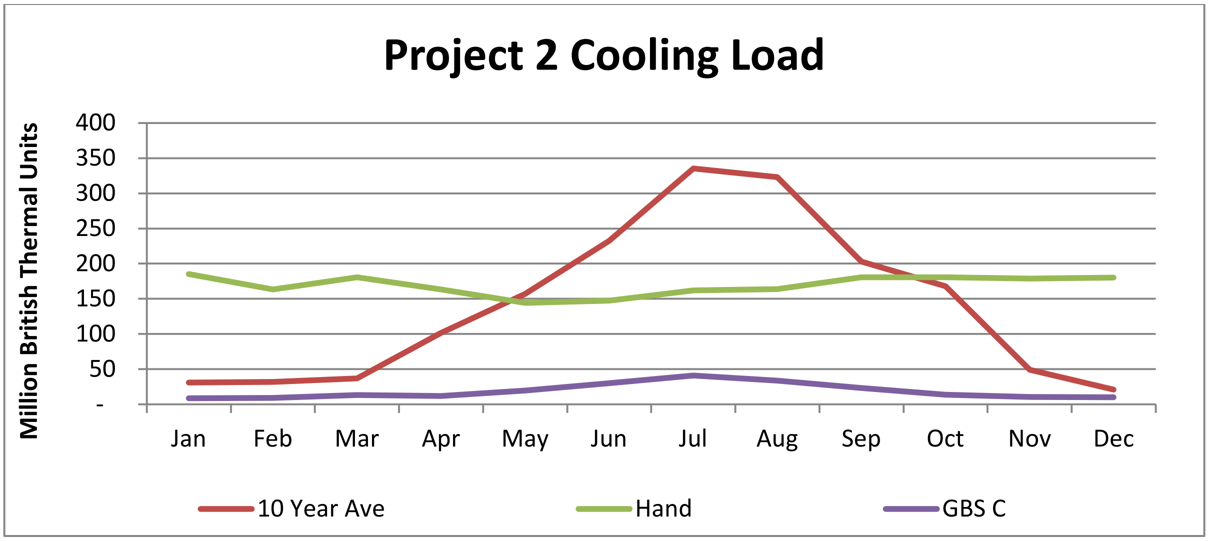


Figure 4-4 Project 2 Cooling Load

4.1.3 Project 3

Project 3 is a three story building on the Brigham Young University campus and is approximately 73,300 gross square feet. Construction of the building concluded in 1991 and has been occupied since completion. The building has not undergone any major renovations. The building houses classrooms, offices and a large, 800+ seat auditorium.

Heating

- The 10-year average was 230 mmBtu/month
- The hand calculation average was 70 mmBtu/month
- The Green Building Studio average was 343 mmBtu/month
- The hand calculations were 30% of the 10-year average heating load per month
- Green Building Studio was 149% of the 10-year average heating load per month.
- The 10-year average heating load varied from 436 mmBtu in January to 90 mmBtu in July
- Hand calculations ranged from 170 mmBtu in January to .2 mmBtu in July
- Green Building Studio ranged from 1005 mmBtu in January to .0005 mmBtu in January

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

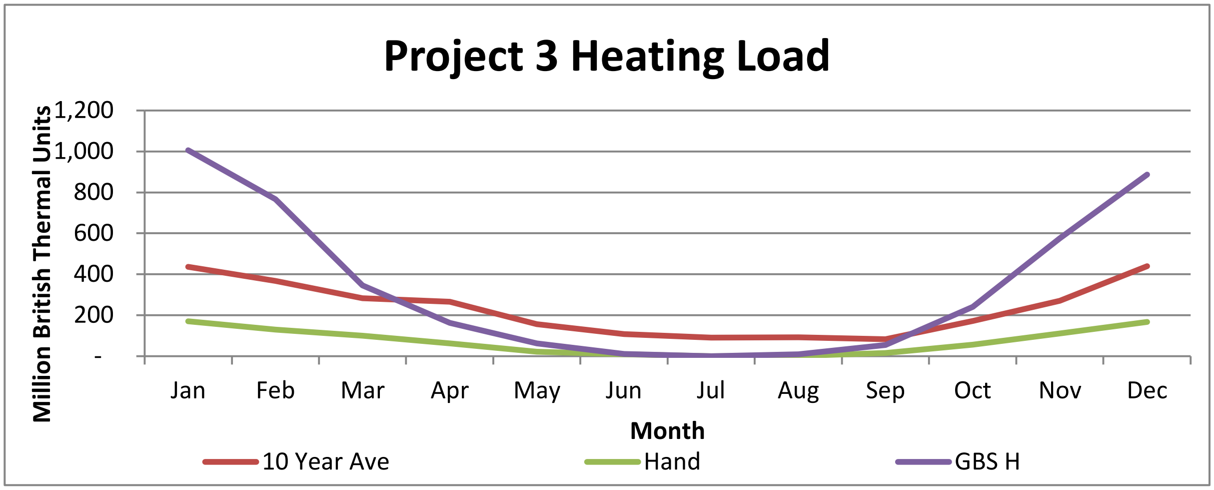


Figure 4-5: Project 3 Heating Load

Cooling

- The 10-year average was 164 mmBtu/month
- The hand calculation average was 324 mmBtu/month
- The Green Building Studio average was 48 mmBtu/month
- Hand calculations were 197% of the 10-year average cooling load per month
- Green Building Studio was 29% of the 10-year average cooling load per month
- The 10-year average cooling load varied from .1 mmBtu in January to .468 mmBtu in July
- Hand calculations ranged from 332 mmBtu in January to 319 in July
- Green Building Studio ranged from 33 mmBtu in January to 118 mmBtu in July

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

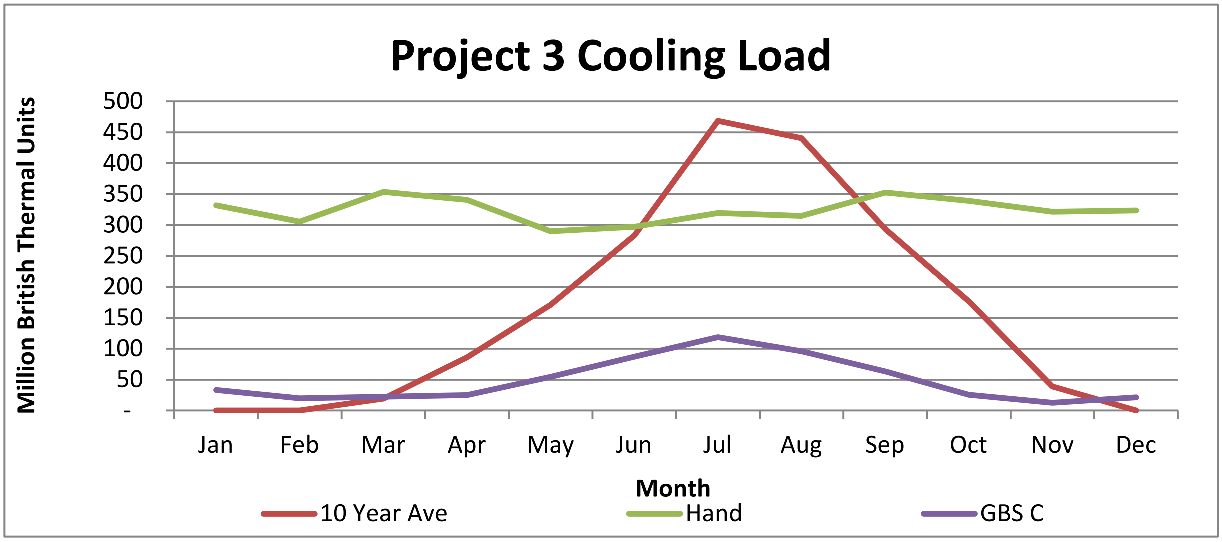


Figure 4-6: Project 3 Cooling Load

4.1.4 Project 4

Project 4 is a seven story building on the Brigham Young University campus and is approximately 145,000 gross square feet. Construction of the building concluded in 1983 and has been occupied since completion. The building has not undergone any major renovations though an addition was added seven years ago. The building houses classrooms, offices and does not include data on a newer addition.

Heating

- The 10-year average was 805 mmBtu/month
- The hand calculation average was 160 mmBtu/month
- The Green Building Studio average was 289 mmBtu/month
- The hand calculations were 20% of the 10-year average heating load per month
- Green Building Studio was 36% of the 10-year average heating load per month.
- The 10-year average heating load varied from 983 mmBtu in January to 503 mmBtu in July

- Hand calculations ranged from 385 mmBtu in January to .6 mmBtu in July
- Green Building Studio ranged from 864 mmBtu in January to 5 mmBtu in July

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

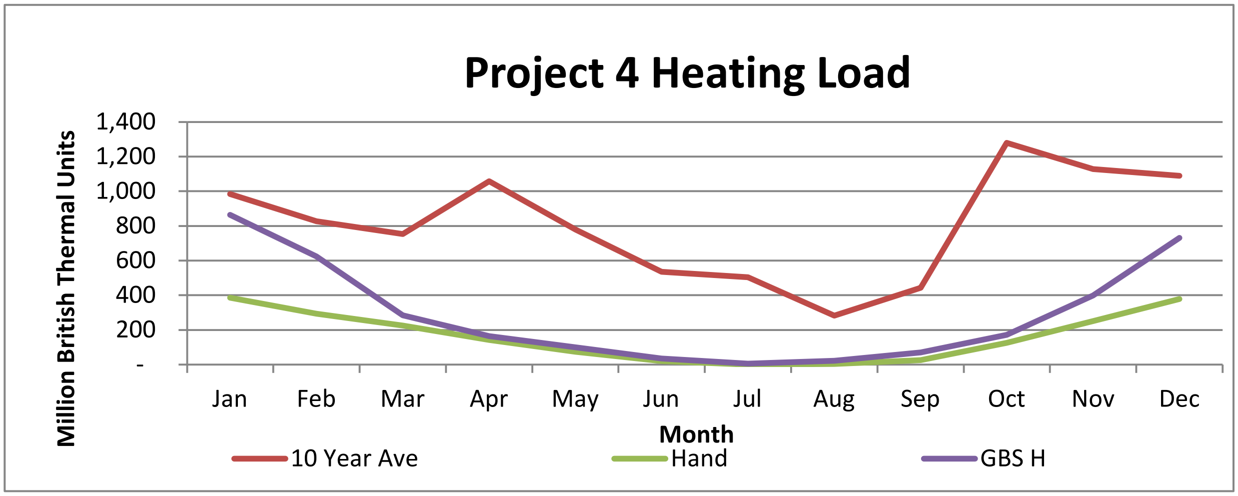


Figure 4-7: Project 4 Heating Load

Cooling

- The 10-year average was 457 mmBtu/month
- The hand calculation average was 1023 mmBtu/month
- The Green Building Studio average was 129 mmBtu/month
- The hand calculations were 223% of the 10-year average cooling load per month
- Green Building Studio was 28% of the 10-year average cooling load per month
- The 10-year average cooling load varied from 11 mmBtu in January to 1132 mmBtu in July
- Hand calculations ranged from 1115 mmBtu in January to 977 mmBtu in July
- Green Building Studio ranged from 69 mmBtu in January to 258 mmBtu in July

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

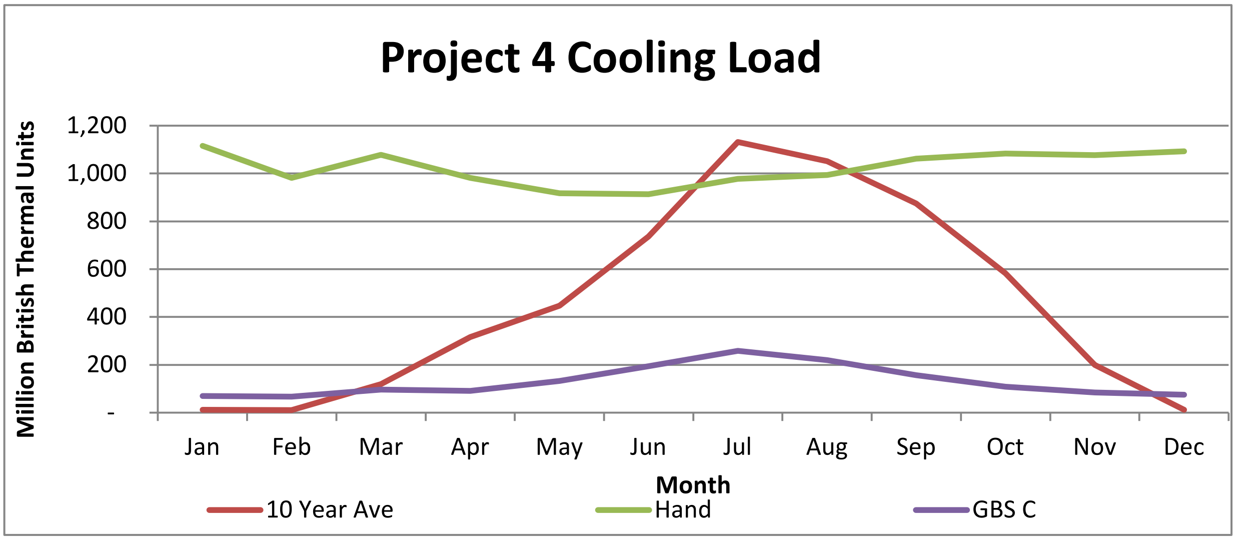


Figure 4-8: Project 4 Cooling Load

4.1.5 Project 5

Project 5 is a two story building on the Brigham Young University campus and is approximately 17,500 gross square feet. Construction of the building concluded in 1995 and has been occupied since completion. The building underwent an interior renovation in 1999. The building is comprised of offices.

Heating

- The 10-year average was 92 mmBtu/month
- The hand calculation average was 24 mmBtu/month
- The Green Building Studio average was 49 mmBtu/month
- The hand calculations were 26% of the 10-year average heating load per month
- Green Building Studio was 53% of the 10-year average heating load per month.

- The 10-year average heating load varied from 140 mmBtu in January to 44 mmBtu in July
- Hand calculations ranged from 58 mmBtu in January to .09 mmBtu in July
- Green Building Studio ranged from 153 mmBtu in January to .001 mmBtu in July

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

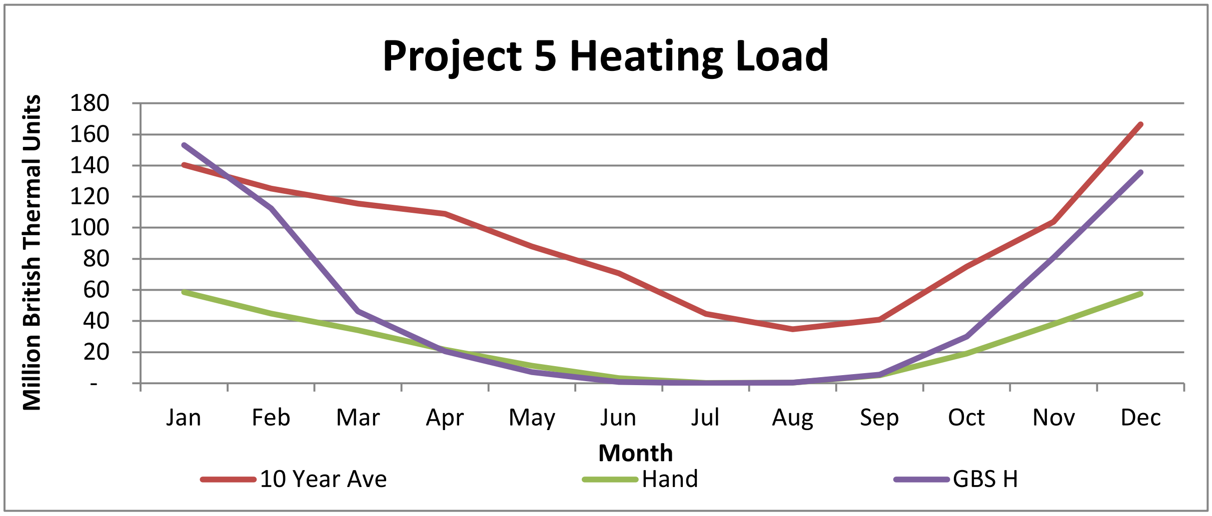


Figure 4-9: Project 5 Heating Load

Cooling

- The 10-year average was 57 mmBtu/month
- The hand calculation average was 106 mmBtu/month
- The Green Building Studio average was 7 mmBtu/month
- The hand calculations were 184% of the 10-year average cooling load per month
- Green Building Studio was 14% of the 10-year average cooling load per month
- The 10-year average cooling load varied from 1 mmBtu in January to 166 mmBtu in July

- Hand calculations ranged from 125 mmBtu in January to 94 mmBtu in July
- Green Building Studio ranged from .1 mmBtu in January to 27 mmBtu in July

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

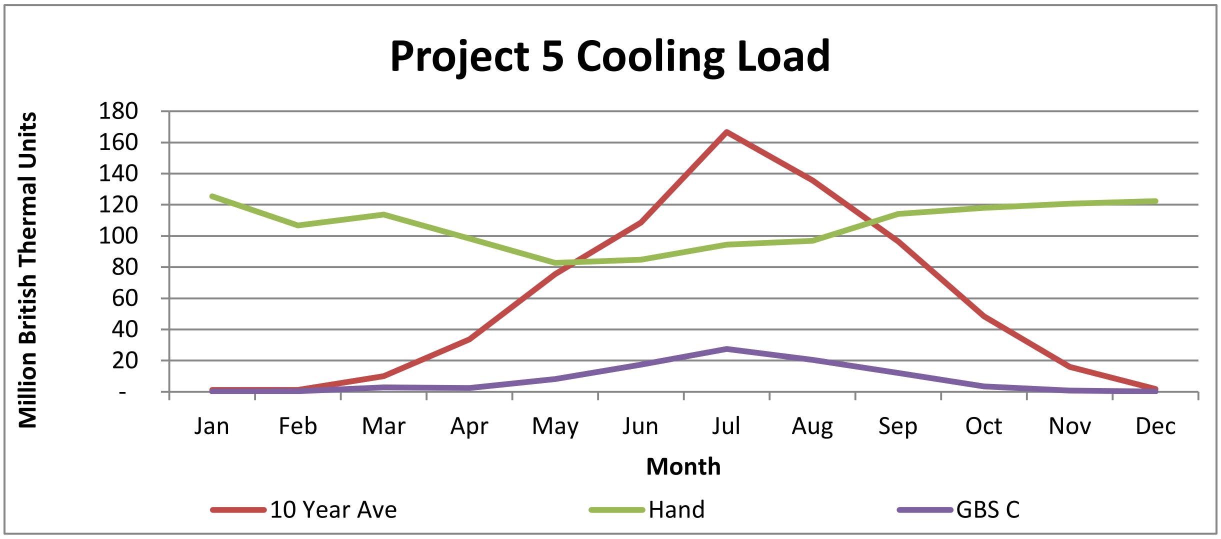


Figure 4-10: Project 5 Cooling Load

4.1.6 Project 6

Project 6 is a four story building on the Brigham Young University campus and is approximately 55,700 gross square feet. Construction on the building completed in 1978. The building is comprised of offices and exhibit spaces with a 100+ seat auditorium.

Heating

- The 10-year average was 332 mmBtu/month
- The hand calculation average was 59 mmBtu/month
- The Green Building Studio average was 123 mmBtu/month
- The hand calculations were 18% of the 10-year average heating load per month

- Green Building Studio was 37% of the 10-year average heating load per month.
- The 10-year average heating load varied from 499 mmBtu in January to 176 mmBtu in July
- Hand calculations ranged from 141 mmBtu in January to .2 mmBtu in July
- Green Building Studio ranged from 443 mmBtu in January to .0005 mmBtu in July

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

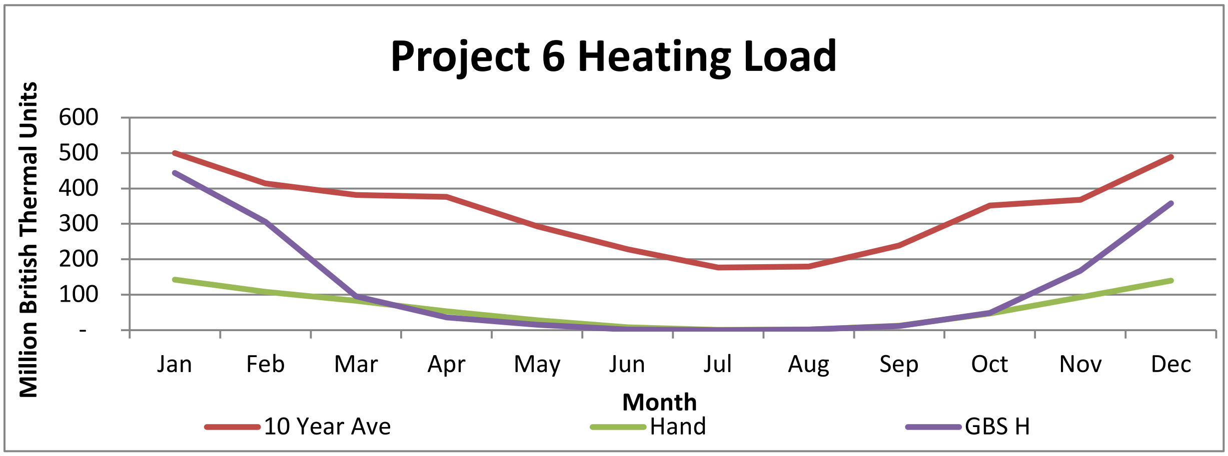


Figure 4-11: Project 6 Heating Load

Cooling

- The 10-year average was 223 mmBtu/month
- The hand calculation average was 285 mmBtu/month
- The Green Building Studio average was 35 mmBtu/month
- The hand calculations were 128% of the 10-year average cooling load per month
- Green Building Studio was 16% of the 10-year average cooling load per month
- The 10-year average cooling load varied from .00005 mmBtu in January to 470 mmBtu in July

- Hand calculations ranged from 281 mmBtu in January to 315 mmBtu in July
- Green Building Studio ranged from 1 mmBtu in January to 84 mmBtu in July

The diagram below shows the data for the measured ten-year average, the estimated hand calculations, and the simulated Green Building Studio estimates.

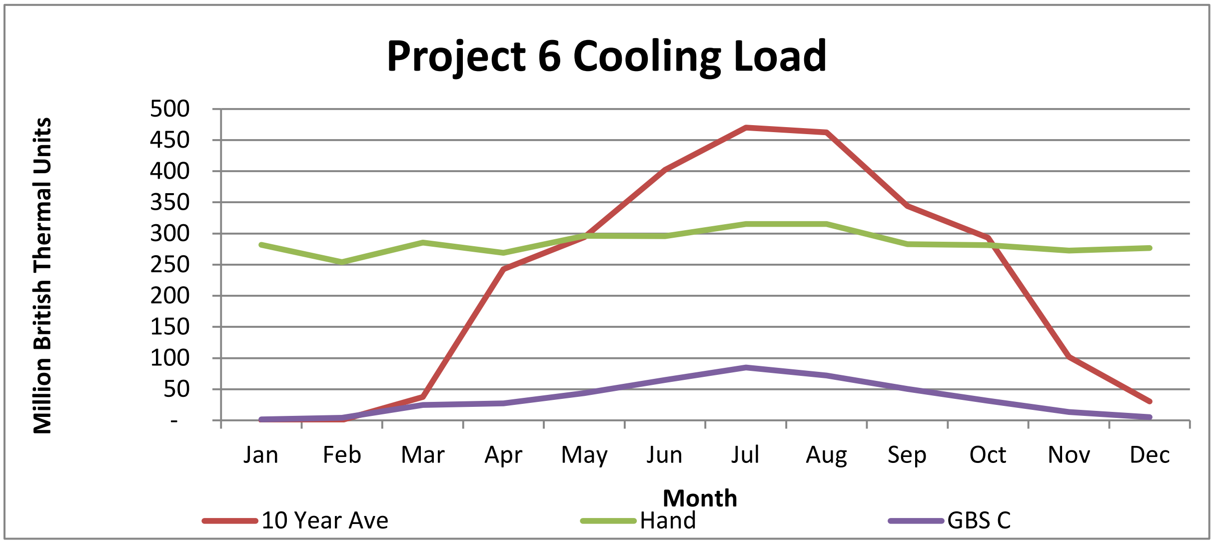


Figure 4-12: Project 6 Cooling Load

4.2 Autodesk Green Building Studio Findings

After researching GBS data and defaults, GBS did not provide flexibility for the fluctuation of people during different months of the year. As this research was conducted at a university, the student population fluctuated after April when the winter semester concluded and after August when the fall semester began. The student population on campus is greatly reduced during summer months, from May to August. GBS was limited as it kept the amount of people constant for a twelve-month period.

GBS has a second limitation wherein it does not have transparency with its heating and cooling load formulas and values. Whereas hand calculation estimates show the formula and the amount of Btu’s for each factor, GBS does not provide heating and cooling load values for any of the contributing elements.

4.3 Autodesk Revit 3-D Model Findings

Several of the 3-D models did not initially have the project phase defined. This prevented all elements in the 3-D model from becoming room binding. When Revit’s 3-D models were exported to gbXML files, Revit could not complete the process because it did not recognize any rooms that could allow for energy analysis.

Other 3-D models had either multiple room tags for the same spaces or had room tags outside the rooms. This is a modeling error. Though the 3-D model allows for such actions, exporting to gbXML files prevented the action from completing. This could be due to several reasons, some of which may include failure to read, interpret, or calculate energy analysis for those specified spaces.

4.4 Sample Size Findings

A problem encountered with GBS was that it did not import and run energy analysis for all of the 3-D Revit models successfully. Of the initial ten 3-D Revit models selected, only four imported successfully and completed energy simulations. The author experimented with the remaining 25 models and attempted to export them to gbXML files and then import them to GBS. Of those remaining 25, only two successfully imported and completed energy simulations while 23 encountered errors while being imported. The six successfully imported files comprise those used for this study’s sample size.

4.5 **Project 4 Measured Data Findings**

Project 4 measured data is an outlier as the curve reflects unnatural jumps and dips. From 2003 to 2008, the measured data appears to have estimates and bad measurements. For example, during the months of May to August when heating is typically lower or near 0, the meter readings indicate energy use like that used in March or September at 100-300 mmBtu instead of 0-50 mmBtu. During this same time period, the meters reported the months of April and October as using 2000 mmBtu to 3000 mmBtu, which was abnormal when compared to the quantity of mmBtu used for the same months from 2009 until 2012, which were 600 mmBtu to 1100 mmBtu.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Review of Findings

Measured data was the benchmark data of this study. Measured data has been used for decades and was studied carefully by mechanical engineers and technicians to understand if meters are correctly working. The lack of accuracy within this study by hand calculations and GBS further dictate that measured data is the best choice for a data benchmark.

Hand calculations and GBS simulation data curves mimicked measured data curves for the heating loads. Though all curves were similar, GBS was closer than hand calculations when compared to the average measured data. In this comparison, GBS was at 95% for Project 1; 130% for Project 2; 149% for Project 3; 36% for Project 4; 53% for Project 5; and 37% for Project 6. The range variation was no more than 64% either direction. Hand calculations, however, were at 29% for Project 1; 60% for Project 2; 30% for Project 3; 20% for Project 4; 26% for Project 5; and 18% for Project 6. The average range variation was 82% as the average hand calculations never overestimated the average measured data.

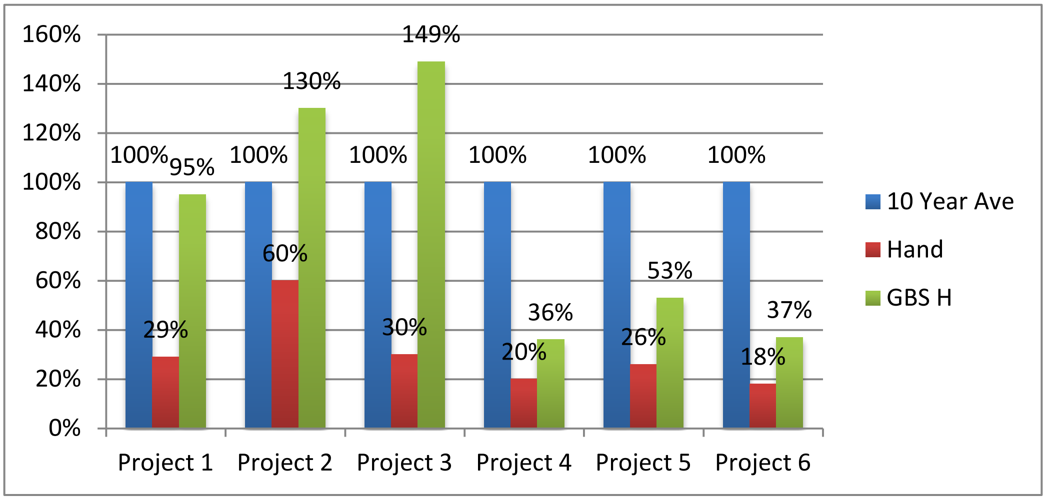


Figure 4-13: Heating Load Summary for Projects 1-6

Third finding from chapter 4 indicated that hand calculations and GBS did not come close to the average measured data for cooling loads. GBS data was 20% for Project 1; 13% for Project 2; 29% for Project 3; 28% for Project 4; 14% for Project 5; and 16% for Project 6. The range variation was no greater than 87%. Hand calculations were 219% for Project 1; 120% for Project 2; 197% for Project 3; 223% for Project 4; 184% for Project 5; and 128% for Project 6. The range variation of hand calculations to measured data was no greater than 123%.

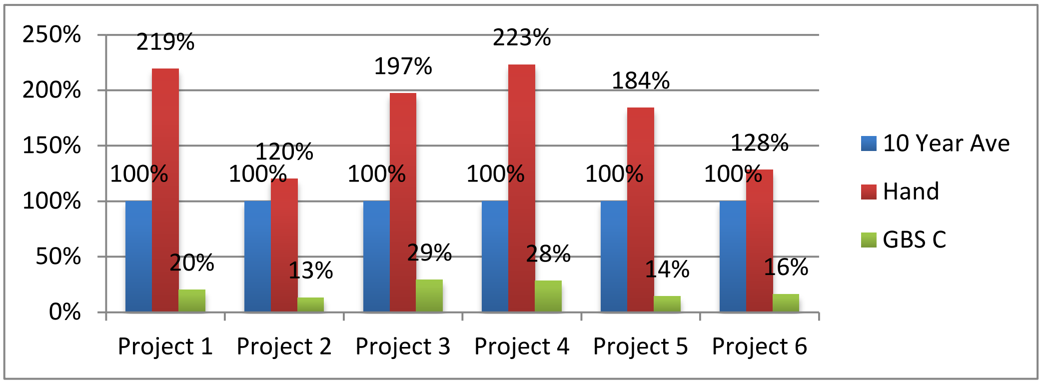


Figure 4-14: Cooling Load Summary for Project 1-6

Hand calculations used by BYU mechanical engineers were meant to calculate the worst-case scenario. These hand calculations were modified to estimate the actual energy use in a building rather than calculate the worst-case scenario. With result to the flat line hand calculation estimates for cooling loads, the weight and quantity of mmBtu for lights, people and equipment was greater than the mmBtu quantity for windows, doors, walls, and doors. Estimated actual energy use results did not match worst-case scenario estimates for heating loads and cooling loads. The spreadsheets have not been used before to calculate full-building energy analysis nor has BYU taken an active interest in knowing what results of energy analysis during the design phase of new construction.

A fifth finding from the results is found within GBS. Green Building Studio keeps the people count constant throughout the year. This does not work effectively at a university as the academic year begins in August or September and concludes in April or May. Many students take a break between academic years and do not enroll in classes. Academic class enrollment drops dramatically which results in fewer students in university buildings.

A sixth finding showed that GBS did not readily and easily make apparent that thermal energy analysis is being calculated and included in the cooling load. GBS was not transparent with formulas or values within heating and cooling loads. Thermal energy analysis did not appear to be calculated within the energy analysis.

A seventh finding was unknown factors in building envelopes. There are potential modeling factors in the building envelope that impacted the results of the energy analysis. In comparison to total window square footage, GBS always calculated a different total than the author calculated and used in the hand calculations.

5.2 **Conclusions**

From this study, there are currently no standards from hand calculations or building energy performance software. Too many engineers, architects, facility managers who use building energy performance software plug numbers in and get numbers out but do not know how precise or accurate these numbers are to actual measured data.

I have learned that there is a lack of case studies where building energy performance software simulations are compared to measured data. More case studies need to be created for simulation data to be compared to measured data. This will allow for benchmarks to be created and used other than measured energy data. I also have learned that GBS has limitations that greatly impact the amount of detail on a model. Too many exterior surfaces or shaded regions will prevent GBS from successfully running and completing an energy analysis for a building.

5.3 **Recommendation**

There is a lack of accurate energy simulation for benchmarking energy use in the facilities management industry. Energy simulation is a feature that has been developed and is continuing to be refined so that it is easier to use and provides better data. Education can enhance any company's knowledge about energy simulation and the advantages of using this technique. As building energy performance software is refined, more companies will use the software and use it to design facilities that use less energy.

It is recommended that a pilot program be set up to select a number of universities and a number of building energy performance software and document the results of simulated data against measured data of university buildings. Using a variety of software and increasing the sample pool of several buildings from different campuses will lead to more accurate results, a better understanding of how accurate is building energy performance software, and which building energy performance software is the most accurate. This will also lead to possible energy range benchmarks to be established for measured, university type building data.

It is also recommended that Autodesk Green Building Studio and Autodesk Revit communicate more to resolve technical issues. Models created in Revit and imported correctly should be able to upload successfully into GBS and have an energy analysis completed. It is also recommended that Autodesk Green Building Studio further elaborate the problems than what was simply stated inside an instruction box.

5.4 Further Research

The researcher encourages further study of the following questions:

1. Is there faulty metering on the cooling side, or is the cooling just less effective than the calculations show?
2. Are there possible compromises in the building envelope if the building simulation data for heating or cooling loads are dramatically off in comparison to measured heating and cooling load data?
3. Does BYU need to re-examine how hand calculations are performed for the cooling loads?
4. Is there anything that needs to be refined in the process for hand calculating the cooling load?
5. Can a range be established through Green Building Studio to be used as a benchmark for any projects that are of the category School/University with the 12/7 time schedule?
6. What are the financial benefits in facilities management by using energy simulation software to calculate heating and cooling loads?

7. Why is GBS off on the cooling loads?
8. Is a ten year average a good benchmark for comparing the heating and cooling loads of a project for the current year?

REFERENCES

Attia, S., L. Beltran, A. De Herde, and J. Hensen. " 'Architect Friendly': A Comparison of Ten Different Building Performance Simulation Tools." Paper presented at the Eleventh International IBPSA Conference, Glasgow, Scotland, July 27-30, 2009.

Azhar, S. "Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry." *Leadership and Management in Engineering* (July 2011): 241-252.

Azhar, S., W. A. Carlton, D. Olsen, and I. Ahmad. "Building Information Modeling for Sustainable Design and LEED® Rating Analysis." *Automation in Construction* 20 (2011): 217-224.

Bruning, S. F. "Load Calculation Spreadsheets: Quick Answers Without Relying on Rules of Thumb." *ASHRAE Journal* (January 2012): 40-46.

Claridge, D. E. "Building Simulation for Practical Operational Optimization." In *Building Performance Simulation for Design and Operation*, edited by Jan L. M. Hensen and Roberto Lamberts, 365-401. New York: Spon Press, 2011.

Crawley, D. B, J. W. Hand, M. Kummert, and B. T. Griffith. "Contrasting the Capabilities of Building Energy Performance Simulation Programs." *Building and Environment* 43 (2008): 661-673.

Douglass, C. Daniel. "Instructional Modules Demonstrating Building Energy Analysis Using a Building Information Model." MS Thesis, University of Illinois at Urbana-Champaign, 2010.

Eastman, C., P. Teicholz, R. Sacks, and K. Liston. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*. Hoboken, NJ: John Wiley and Sons, Inc., 2008.

Francois, L. *BIM in Small-Scale Sustainable Design*. Hoboken, NJ: Wiley, 2012.

Hensen, J. L.M. and R. Lamberts. "Introduction to Building Performance Simulation." In *Building Performance Simulation for Design and Operation*, edited by Jan L. M. Hensen and Roberto Lamberts, 365-401. New York: Spon Press, 2011.

Howard, R., and B. Bjork. “Building Information Modelling – Experts’ Views on Standardisation and Industry Deployment.” *Advanced Engineering Informatics* 22 (2008): 271-280.

“Intoperability with Building Information Modeling and Facility Management Processes,” RICS, last modified September 13, 2012, accessed June 29, 2013, http://www.rics.org/us/knowledge/research/conference-papers/cobra-2012-interoperability-with-building-information-modeling-and-facility-management-processes/.

Krygiel, E. and B. Nies. *Green BIM: Successful Sustainable Design with Building Information Modeling*. Indianapolis, IN: Wiley Publishing, Inc., 2008.

Kubba, S. “Building Information Modeling.” *Handbook of Green Building Design and Construction LEED, BREEAM, and Green Globes*. Waltham, MA: Butterworth-Heinemann, 2012.

Kymmell, W. *McGraw-Hill Construction Series: Building Information Modeling*. New York: McGraw-Hill Professional Publishing, 2008.

Leite, F., A. Akcamete, B. Akinci, G. Atasoy, and S. Kiziltas. “Analysis of Modeling Effort and Impact of Different Levels of Detail in Building Information Models.” *Automation in Construction* 20 (2011): 601-609.

Lu, W. W.S. and H. Li. “Building Information Modeling and Changing Construction Practices.” *Automation in Construction* 20 (2011): 99-100.

McBride, J. “Energy Metering: Costly Overhead or Cost-Effective Conservation?” *Energy User News* (June 2002): 12-14.

Reddy, K. Pramod. *BIM for Building Owners and Developers: Making a Business Case for Using BIM on Projects*. Hoboken, NJ: John Wiley & Sons, 2011.

Rutkowski, H. and Air Conditioning Contractors of America. *Residential Load Calculation: Manual J*. Arlington, VA: Air Conditioning Contractors of America, 2002

Scheib, N. B. “Technical Report: Three.” *Mechanical Option* (November 2010): 1-27.

Singleton, M. “Report on the Design Charrette for DCL Green Healthcare Centre Stouffville, Ontario.” *Sustainable Buildings Canada* (January 2012): 1-31.

Spitler, J. D. “Thermal Load and Energy Performance Prediction.” In *Building Performance Simulation for Design and Operation*, edited by Jan L. M. Hensen and Roberto Lamberts, 365-401. New York: Spon Press, 2011.

"Sub-Metering Energy Use in Colleges and Universities: Incentives and Challenges," Energy Star. Accessed October 16, 2012. http://www.energystar.gov/ia/business/higher_ed/Submeter_energy_use.pdf.

WeatherSpark. "Temperature." WeatherSpark Averages. Accessed June 4, 2013. http://weatherspark.com/averages/31337/Provo-Utah-United-States.

Weygant, R. S. *BIM Content Development: Standards, Strategies, and Best Practices*. Hoboken, NJ: Wiley, 2011.

Wroblaski, K. and J. Morton. "BIM Tools Driven by Green Building Growth." *Buildings* (November 2010): 16.

Yoders, J. "Big-time BIM." *Building Design & Construction,* March 2010.

APPENDIX A. HAND CALCULATION DOCUMENTS

The hand calculation sheets for the twelve months of the year are provided below. These resources are provided by Brigham Young University and were created as spreadsheets. Information and values that are not project specific are provided in the spreadsheets below.

January Hand Calculation Sheet

HEAT AND COOLING LOAD FOR

Project:
Bldg:
Room: January
W.O. Number:
Date:

AREA (ft^2)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF	X	0.033	X	31.19	=		
			X	0	=		
WALL	X	0.090	X	31.19	=		
			X	0	=		
WINDOW 0	X	0.490	X	31.19	=		
			X	0	=		
DOOR	X	1.000	X	31.19	=		
			X	0	=		
N SOLAR (ft^2 win)	X	(BTU / ft^2) 12	X	(Shade Coefficient) 0.7	=		
S SOLAR (ft^2 win)	X	(BTU / ft^2) 163	X	(Shade Coefficient) 0.7	=		
E SOLAR (ft^2 win)	X	(BTU / ft^2) 51	X	(Shade Coefficient) 0.7	=		
W SOLAR (ft^2 win)	X	(BTU / ft^2) 51	X	(Shade Coefficient) 0.7	=		
LIGHTS (ft^2)	X	(Watts)	X	(BTU / Watts) 3.413	=		
PEOPLE (number)	X	(BTU / person) 250	=				
EQUIP (amps)	X	(Volts) 120	X	(BTU / Watts) 3.413	=		
INFILT(ft^3 / 45 min) 0	X	(Air Density Factor) 0.91	X	(ΔT) 31.19	=		
(Heating ΔT) 45		(Cooling ΔT) 20		**BTU LOAD** (BTUH)		0	0
				CFM REQUIRED		0	0

February Hand Calculation Sheet

HEATING AND COOLING LOAD FOR

Project:
Room: February
W.O. Number:
Bldg:
Date:

AREA (ft²)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF	X	0.033	X	26.34	=		
			X	0	=		
WALL	X	0.090	X	26.34	=		
			X	0	=		
WINDOW 0	X	0.490	X	26.34	=		
			X	0	=		
DOOR	X	1.000	X	26.34	=		
			X	0	=		
N SOLAR (ft² win)	X	(BTU / ft²) 14	X	(Shade Coefficient) 0.7	=		
S SOLAR (ft² win)	X	(BTU / ft²) 137	X	(Shade Coefficient) 0.7	=		
E SOLAR (ft² win)	X	(BTU / ft²) 61	X	(Shade Coefficient) 0.7	=		
W SOLAR (ft² win)	X	(BTU / ft²) 61	X	(Shade Coefficient) 0.7	=		
LIGHTS (ft²)	X	(Watts)	X	(BTU / Watts) 3.413	=		
PEOPLE (number)	X	(BTU / person) 250	=				
EQUIP (amps)	X	(Volts) 120	X	(BTU / Watts) 3.413	=		
INFILT(ft³ / 45 min) 0	X	(Air Density Factor) 0.91	X	(ΔT) 26.34	=		
(Heating ΔT) 45		(Cooling ΔT) 20		**BTU LOAD** (BTUH)		0	0
				CFM REQUIRED		0	0

March Hand Calculation Sheet

HEAT AND COOLING LOAD FOR

Project:
Bldg:
Room: March
W.O. Number:
Date:

AREA (ft²)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF	X	0.033	X	18.19	=		
			X	0.13	=		
WALL	X	0.090	X	18.19	=		
			X	0.13	=		
WINDOW 0	X	0.490	X	18.19	=		
			X	0.13	=		
DOOR	X	1.000	X	18.19	=		
			X	0.13	=		
N SOLAR (ft² win)	X	(BTU / ft²) 19	X	(Shade Coefficient) 0.7	=		
S SOLAR (ft² win)	X	(BTU / ft²) 116	X	(Shade Coefficient) 0.7	=		
E SOLAR (ft² win)	X	(BTU / ft²) 79	X	(Shade Coefficient) 0.7	=		
W SOLAR (ft² win)	X	(BTU / ft²) 79	X	(Shade Coefficient) 0.7	=		
LIGHTS (ft²)	X	(Watts)	X	(BTU / Watts) 3.413	=		
PEOPLE (number)	X	(BTU / person) 250	=				
EQUIP (amps)	X	(Volts) 120	X	(BTU / Watts) 3.413	=		
INFILT(ft³ / 45 min) 0	X	(Air Density Factor) 0.91	X	(ΔT) 18.19	=		
(Heating ΔT) 45		(Cooling ΔT) 20		**BTU LOAD** (BTUH)		0	0
				CFM REQUIRED		0	0

April Hand Calculation Sheet

HEAT AND COOLING LOAD FOR

Project: **Room**: April **W.O. Number**:

Bldg: **Date**:

AREA (ft^2)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF	X	0.033	X	11.91	=		
			X	0.94	=		
WALL	X	0.090	X	11.91	=		
			X	0.94	=		
WINDOW	X	0.490	X	11.91	=		
			X	0.94	=		
DOOR	X	1.000	X	11.91	=		
			X	0.94	=		
N SOLAR (ft^2 win)	X	(BTU / ft^2) 22	X	(Shade Coefficient) 0.7	=		
S SOLAR (ft^2 win)	X	(BTU / ft^2) 70	X	(Shade Coefficient) 0.7	=		
E SOLAR (ft^2 win)	X	(BTU / ft^2) 79	X	(Shade Coefficient) 0.7	=		
W SOLAR (ft^2 win)	X	(BTU / ft^2) 79	X	(Shade Coefficient) 0.7	=		
LIGHTS (ft^2)	X	(Watts)	X	(BTU / Watts) 3.413	=		
PEOPLE (number)	X	(BTU / person) 250	=				
EQUIP (amps)	X	(Volts) 120	X	(BTU / Watts) 3.413	=		
INFILT(ft^3 / 45 min) 0	X	(Air Density Factor) 0.91	X	(ΔT) 11.91	=		
(Heating ΔT) 45		(Cooling ΔT) 20		**BTU LOAD** (BTUH)		0	0
				CFM REQUIRED		0	0

May Hand Calculation Sheet

HEAT AND COOLING LOAD FOR

Project:
Bldg:
Room: May
W.O. Number:
Date:

AREA (ft^2)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF	X	0.033	X	5.96	=		
			X	4.05	=		
WALL	X	0.090	X	5.96	=		
			X	4.05	=		
WINDOW	X	0.490	X	5.96	=		
			X	4.05	=		
DOOR	X	1.000	X	5.96	=		
			X	4.05	=		
N SOLAR (ft^2 win)		(BTU / ft^2)		(Shade Coefficient)			
	X	27	X	0.7	=		
S SOLAR (ft^2 win)		(BTU / ft^2)		(Shade Coefficient)			
	X	45	X	0.7	=		
E SOLAR (ft^2 win)		(BTU / ft^2)		(Shade Coefficient)			
	X	75	X	0.7	=		
W SOLAR (ft^2 win)		(BTU / ft^2)		(Shade Coefficient)			
	X	75	X	0.7	=		
LIGHTS (ft^2)		(Watts)		(BTU / Watts)			
	X		X	3.413	=		
PEOPLE (number)		(BTU / person)					
	X	250	=				
EQUIP (amps)		(Volts)		(BTU / Watts)			
	X	120	X	3.413	=		
INFILT(ft^3 / 45 min)		(Air Density Factor)		(ΔT)			
0	X	0.91	X	5.96	=		
(Heating ΔT)		(Cooling ΔT)		**BTU LOAD** (BTUH)		0	0
45		20		**CFM REQUIRED**		0	0

June Hand Calculation Sheet

HEAT AND COOLING LOAD FOR

Project: **Room**: June **W.O. Number**:
Bldg: **Date**:

AREA (ft²)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF	X	0.033	X	1.73	=		
			X	9.55	=		
WALL	X	0.090	X	1.73	=		
			X	9.55	=		
WINDOW	X	0.490	X	1.73	=		
			X	9.55	=		
DOOR	X	1.000	X	1.73	=		
			X	9.55	=		
N SOLAR (ft² win)	X	(BTU / ft²) 32	X	(Shade Coefficient) 0.7	=		
S SOLAR (ft² win)	X	(BTU / ft²) 39	X	(Shade Coefficient) 0.7	=		
E SOLAR (ft² win)	X	(BTU / ft²) 77	X	(Shade Coefficient) 0.7	=		
W SOLAR (ft² win)	X	(BTU / ft²) 77	X	(Shade Coefficient) 0.7	=		
LIGHTS (ft²)	X	(Watts)	X	(BTU / Watts) 3.413	=		
PEOPLE (number)	X	(BTU / person) 250	=				
EQUIP (amps)	X	(Volts) 120	X	(BTU / Watts) 3.413	=		
INFILT(ft³ / 45 min) 0	X	(Air Density Factor) 0.91	X	(ΔT) 1.73	=		
(Heating ΔT) 45		(Cooling ΔT) 20		**BTU LOAD** (BTUH)		0	0
				CFM REQUIRED		0	0

July Hand Calculation Sheet

HEAT AND COOLING LOAD FOR

Project:
Bldg:
Room: July
W.O. Number:
Date:

AREA (ft²)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF	X	0.033	X	0.05	=		
			X	16.52	=		
WALL	X	0.090	X	0.05	=		
			X	16.52	=		
WINDOW	X	0.490	X	0.05	=		
			X	16.52	=		
DOOR	X	1.000	X	0.05	=		
			X	16.52	=		
N SOLAR (ft² win)	X	(BTU / ft²) 28	X	(Shade Coefficient) 0.7	=		
S SOLAR (ft² win)	X	(BTU / ft²) 44	X	(Shade Coefficient) 0.7	=		
E SOLAR (ft² win)	X	(BTU / ft²) 74	X	(Shade Coefficient) 0.7	=		
W SOLAR (ft² win)	X	(BTU / ft²) 74	X	(Shade Coefficient) 0.7	=		
LIGHTS (ft²)	X	(Watts)	X	(BTU / Watts) 3.413	=		
PEOPLE (number)	X	(BTU / person) 250	=				
EQUIP (amps)	X	(Volts) 120	X	(BTU / Watts) 3.413	=		
INFILT(ft³ / 45 min) 0	X	(Air Density Factor) 0.91	X	(ΔT) 0.05	=		
(Heating ΔT) 45		(Cooling ΔT) 20		**BTU LOAD** (BTUH)		0	0
				CFM REQUIRED		0	0

August Hand Calculation Sheet

HEAT AND COOLING LOAD FOR

Project: **Room**: August **W.O. Number**:
Bldg: **Date**:

AREA (ft²)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF	X	0.033	X	0.22	=		
			X	13.17	=		
WALL	X	0.090	X	0.22	=		
			X	13.17	=		
WINDOW	X	0.490	X	0.22	=		
			X	13.17	=		
DOOR	X	1.000	X	0.22	=		
			X	13.17	=		
N SOLAR (ft² win)	X	(BTU / ft²) 23	X	(Shade Coefficient) 0.7	=		
S SOLAR (ft² win)	X	(BTU / ft²) 68	X	(Shade Coefficient) 0.7	=		
E SOLAR (ft² win)	X	(BTU / ft²) 78	X	(Shade Coefficient) 0.7	=		
W SOLAR (ft² win)	X	(BTU / ft²) 78	X	(Shade Coefficient) 0.7	=		
LIGHTS (ft²)	X	(Watts)	X	(BTU / Watts) 3.413	=		
PEOPLE (number)	X	(BTU / person) 250	=				
EQUIP (amps)	X	(Volts) 120	X	(BTU / Watts) 3.413	=		
INFILT(ft³ / 45 min) 0	X	(Air Density Factor) 0.91	X	(ΔT) 0.22	=		
(Heating ΔT)		(Cooling ΔT)		**BTU LOAD** (BTUH)		0	0
45		20		**CFM REQUIRED**		0	0

September Hand Calculation Sheet

HEAT AND COOLING LOAD FOR

Project:
Room: September
W.O. Number:
Bldg:
Date:

AREA (ft²)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF							
	X	0.033	X	2.81	=		
			X	5.68	=		
WALL							
	X	0.090	X	2.81	=		
			X	5.68	=		
WINDOW							
	X	0.490	X	2.81	=		
			X	5.68	=		
DOOR							
	X	1.000	X	2.81	=		
			X	5.68	=		
N SOLAR (ft² win)		(BTU / ft²)		(Shade Coefficient)			
	X	20	X	0.7	=		
S SOLAR (ft² win)		(BTU / ft²)		(Shade Coefficient)			
	X	112	X	0.7	=		
E SOLAR (ft² win)		(BTU / ft²)		(Shade Coefficient)			
	X	76	X	0.7	=		
W SOLAR (ft² win)		(BTU / ft²)		(Shade Coefficient)			
	X	76	X	0.7	=		
LIGHTS (ft²)		(Watts)		(BTU / Watts)			
	X		X	3.413	=		
PEOPLE (number)		(BTU / person)					
	X	250	=				
EQUIP (amps)		(Volts)		(BTU / Watts)			
	X	120	X	3.413	=		
INFILT(ft³ / 45 min)		(Air Density Factor)		(ΔT)			
0	X	0.91	X	2.81	=		
(Heating ΔT)		(Cooling ΔT)		**BTU LOAD** (BTUH)		0	0
45		20		**CFM REQUIRED**		0	0

October Hand Calculation Sheet

HEAT AND COOLING LOAD FOR

Project:
Bldg:
Room: October
W.O. Number:
Date:

AREA (ft^2)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF	X	0.033	X	10.13	=		
			X	1.06	=		
WALL	X	0.090	X	10.13	=		
			X	1.06	=		
WINDOW	X	0.490	X	10.13	=		
			X	1.06	=		
DOOR	X	1.000	X	10.13	=		
			X	1.06	=		
N SOLAR (ft^2 win)	X	(BTU / ft^2) 15	X	(Shade Coefficient) 0.7	=		
S SOLAR (ft^2 win)	X	(BTU / ft^2) 132	X	(Shade Coefficient) 0.7	=		
E SOLAR (ft^2 win)	X	(BTU / ft^2) 59	X	(Shade Coefficient) 0.7	=		
W SOLAR (ft^2 win)	X	(BTU / ft^2) 59	X	(Shade Coefficient) 0.7	=		
LIGHTS (ft^2)	X	(Watts)	X	(BTU / Watts) 3.413	=		
PEOPLE (number)	X	(BTU / person) 250	=				
EQUIP (amps)	X	(Volts) 120	X	(BTU / Watts) 3.413	=		
INFILT(ft^3 / 45 min) 0	X	(Air Density Factor) 0.91	X	(ΔT) 10.13	=		
(Heating ΔT) 45		(Cooling ΔT) 20		**BTU LOAD** (BTUH)		0	0
				CFM REQUIRED		0	0

November Hand Calculation Sheet

HEAT AND COOLING LOAD FOR

Project:

Room: November

W.O. Number:

Bldg:

Date:

AREA (ft²)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF	X	0.033	X	20.93	=		
			X	0.04	=		
WALL	X	0.090	X	20.93	=		
			X	0.04	=		
WINDOW	X	0.490	X	20.93	=		
			X	0.04	=		
DOOR	X	1.000	X	20.93	=		
			X	0.04	=		
N SOLAR (ft² win)	X	(BTU / ft²) 13	X	(Shade Coefficient) 0.7	=		
S SOLAR (ft² win)	X	(BTU / ft²) 160	X	(Shade Coefficient) 0.7	=		
E SOLAR (ft² win)	X	(BTU / ft²) 51	X	(Shade Coefficient) 0.7	=		
W SOLAR (ft² win)	X	(BTU / ft²) 51	X	(Shade Coefficient) 0.7	=		
LIGHTS (ft²)	X	(Watts)	X	(BTU / Watts) 3.413	=		
PEOPLE (number)	X	(BTU / person) 250	=				
EQUIP (amps)	X	(Volts) 120	X	(BTU / Watts) 3.413	=		
INFILT(ft³ / 45 min) 0	X	(Air Density Factor) 0.91	X	(ΔT) 20.93	=		
(Heating ΔT) 45		(Cooling ΔT) 20		**BTU LOAD** (BTUH)		0	0
				CFM REQUIRED		0	0

December Hand Calculation Sheet

HEAT AND COOLING LOAD FOR

Project: **Room**: December **W.O. Number**:
Bldg: **Date**:

AREA (ft²)		**U Factor** (1/R)		(ΔT)		**HEATING**	**COOLING**
ROOF							
	X	0.033	X	30.62	=		
			X	0	=		
WALL							
	X	0.090	X	30.62	=		
			X	0	=		
WINDOW							
	X	0.490	X	30.62	=		
			X	0	=		
DOOR							
	X	1.000	X	30.62	=		
			X	0	=		
N SOLAR (ft² win)		(BTU / ft²)		(Shade Coefficient)			
	X	10	X	0.7	=		
S SOLAR (ft² win)		(BTU / ft²)		(Shade Coefficient)			
	X	155	X	0.7	=		
E SOLAR (ft² win)		(BTU / ft²)		(Shade Coefficient)			
	X	43	X	0.7	=		
W SOLAR (ft² win)		(BTU / ft²)		(Shade Coefficient)			
	X	43	X	0.7	=		
LIGHTS (ft²)		(Watts)		(BTU / Watts)			
	X		X	3.413	=		
PEOPLE (number)		(BTU / person)					
	X	250	=				
EQUIP (amps)		(Volts)		(BTU / Watts)			
	X	120	X	3.413	=		
INFILT(ft³ / 45 min)		(Air Density Factor)		(ΔT)			
0	X	0.91	X	30.62	=		
(Heating ΔT)		(Cooling ΔT)		**BTU LOAD** (BTUH)		0	0
45		20		**CFM REQUIRED**		0	0

APPENDIX B. RAW DATA

Included below is the raw data for the six projects. Each project has two groups-Heating Load and Cooling Load. There are three categories for each group-10 Year Average data, Hand calculations estimates, and Autodesk's Green Building Studio simulation data (GBS).

Project 1	Heating Load			Cooling Load		
Month	10 Year Ave	Hand	GBS H	10 Year Ave	Hand	GBS C
Jan	363,426,265	113,008,020	456,960,000	603,229	262,733,556	6,868,000
Feb	322,950,972	86,199,792	346,707,000	6,265,963	239,140,272	5,219,000
Mar	202,609,768	65,906,496	161,084,000	8,808,885	275,384,160	7,200,000
Apr	151,625,242	41,760,360	83,348,000	57,748,384	257,242,680	6,306,000
May	76,359,946	21,594,228	37,865,000	103,571,261	262,272,648	18,347,000
Jun	28,729,975	6,066,000	6,990,000	160,031,744	263,230,560	38,114,000
Jul	30,787,664	181,164	404,000	275,207,856	280,662,840	61,124,000
Aug	38,236,542	797,196	3,596,000	226,366,184	283,587,876	45,571,000
Sep	56,619,720	9,852,840	25,784,000	167,393,443	271,688,040	26,288,000
Oct	125,457,010	36,703,380	101,430,000	116,606,283	263,759,904	8,638,000
Nov	222,491,961	73,387,800	254,038,000	53,913,974	253,812,960	4,249,000
Dec	362,286,624	110,943,048	400,796,000	11,273,008	253,819,320	5,206,000
AVE TOTALS	**165,131,807**	**47,200,027**	**156,583,500**	**98,982,518**	**263,944,568**	**19,427,500**

Project 2	Heating Load			Cooling Load		
Month	10 Year Ave	Hand	GBS H	10 Year Ave	Hand	GBS C
Jan	170,480,000	82,225,020	284,079,000	31,030,000	185,402,940	8,951,000
Feb	110,520,000	62,719,104	214,478,000	32,140,000	163,177,056	9,118,000
Mar	78,332,526	47,953,404	92,712,000	37,073,139	180,597,072	13,304,000
Apr	66,707,474	30,385,080	41,564,000	101,686,861	163,180,800	11,838,000
May	81,070,000	15,712,164	15,811,000	156,830,000	165,778,452	19,827,000
Jun	19,250,000	4,413,600	2,157,000	232,710,000	167,923,440	30,283,000
Jul	19,250,000	131,688	500	335,190,000	182,543,004	41,247,000
Aug	19,743,000	579,948	751,000	322,955,000	184,752,684	33,765,000
Sep	28,953,372	7,169,040	12,877,000	203,067,000	180,478,440	23,249,000
Oct	45,020,000	26,705,136	56,049,000	167,808,000	180,382,800	13,720,000
Nov	77,860,000	53,397,000	151,261,000	49,430,000	178,891,200	10,494,000
Dec	133,150,000	197,719,488	249,894,000	21,250,000	180,297,984	9,929,000
AVE TOTALS	**69,089,697**	**44,092,556**	**93,469,458**	**140,930,833**	**176,117,156**	**18,810,417**

Project 3	Heating Load			Cooling Load		
Month	10 Year Ave	Hand	GBS H	10 Year Ave	Hand	GBS C
Jan	436,054,047	174,222,480	1,005,615,000	128,670	332,167,356	33,302,000
Feb	367,402,256	132,892,704	766,912,000	-	305,678,688	20,086,000
Mar	282,093,538	101,606,592	345,540,000	19,466,891	353,705,040	22,399,000
Apr	265,623,013	64,381,320	162,526,000	85,998,269	340,881,120	25,135,000
May	156,354,603	33,291,768	62,252,000	170,804,204	356,787,804	54,475,000
Jun	107,725,614	9,351,720	10,114,000	283,292,652	362,211,840	87,137,000
Jul	90,878,119	279,372	500	468,606,390	387,643,344	118,851,000
Aug	91,790,855	1,228,716	8,193,000	440,795,528	382,386,240	96,193,000
Sep	82,255,886	15,189,840	55,016,000	293,555,863	353,504,520	63,556,000
Oct	172,364,265	56,584,548	239,938,000	176,672,512	339,467,484	25,670,000
Nov	270,802,154	113,140,440	574,910,000	39,112,243	321,763,320	12,367,000
Dec	438,847,656	171,038,532	887,236,000	3,072	323,701,752	21,225,000
AVE TOTALS	**230,182,667**	**72,767,336**	**343,187,708**	**164,869,691**	**346,658,209**	**48,366,333**

Project 4	Heating Load			Cooling Load		
Month	10 Year Ave	Hand	GBS H	10 Year Ave	Hand	GBS C
Jan	983,406,952	383,581,104	864,458,000	11,322,944	1,250,083,308	69,709,000
Feb	826,980,397	292,586,112	624,362,000	10,666,196	1,102,880,352	66,507,000
Mar	753,935,521	223,704,432	284,817,000	119,210,341	1,211,903,460	96,106,000
Apr	1,057,565,636	141,746,760	164,520,000	316,371,592	1,111,574,880	91,239,000
May	778,978,806	73,297,392	98,877,000	446,980,917	1,128,996,192	132,478,000
Jun	535,244,800	20,589,480	34,993,000	736,018,438	1,118,375,640	194,235,000
Jul	503,199,315	614,916	5,969,000	1,132,163,367	1,188,298,572	258,897,000
Aug	282,283,203	2,705,556	21,654,000	1,051,578,439	1,205,209,692	219,146,000
Sep	442,870,141	33,443,280	70,318,000	875,299,948	1,191,724,200	156,115,000
Oct	1,279,443,564	124,580,940	171,401,000	582,507,183	1,218,217,416	107,632,000
Nov	1,127,335,360	249,098,040	398,007,000	199,301,599	1,206,920,880	84,256,000
Dec	1,088,945,143	376,571,136	730,620,000	12,399,221	1,227,691,140	74,653,000
AVE TOTALS	**805,015,736**	**160,209,929**	**289,166,333**	**457,818,349**	**1,180,156,311**	**129,247,750**

Project 5	Heating Load			Cooling Load		
Month	10 Year Ave	Hand	GBS H	10 Year Ave	Hand	GBS C
Jan	140,316,066	56,186,880	153,131,000	1,191,487	125,333,124	119,000
Feb	125,121,773	42,858,144	112,520,000	1,216,934	106,767,024	319,000
Mar	115,534,128	32,768,364	46,170,000	9,929,008	113,631,864	2,918,000
Apr	108,832,122	20,763,000	20,510,000	33,699,021	98,274,600	2,476,000
May	87,987,712	10,736,664	7,068,000	75,539,401	98,347,128	8,226,000
Jun	70,740,271	3,016,080	710,000	108,503,028	99,552,600	17,346,000
Jul	44,601,887	90,024	1,000	166,600,572	109,097,556	27,457,000
Aug	34,602,396	396,180	296,000	135,778,001	111,795,672	20,479,000
Sep	40,953,123	4,898,880	5,477,000	96,572,898	113,739,840	12,063,000
Oct	74,974,690	18,248,460	29,936,000	48,484,202	117,942,600	3,387,000
Nov	103,699,300	36,487,800	80,791,000	15,895,660	120,762,720	806,000
Dec	166,489,510	55,160,160	135,559,000	1,813,337	122,313,228	189,000
AVE TOTALS	**92,821,081**	**23,467,553**	**49,347,416**	**57,935,295**	**111,463,163**	**7,982,083**

Project 6	Heating Load			Cooling Load		
Month	10 Year Ave	Hand	GBS H	10 Year Ave	Hand	GBS C
Jan	499,386,129	139,719,108	443,862,000	54	346,619,184	1,380,000
Feb	413,820,066	106,574,160	306,104,000	617,061	312,381,888	4,252,000
Mar	381,400,628	81,483,996	95,047,000	37,419,403	349,881,996	24,645,000
Apr	376,528,099	51,631,200	35,428,000	242,870,575	331,768,080	27,329,000
May	292,835,664	26,698,440	14,457,000	294,126,577	342,050,280	43,771,000
Jun	228,019,880	7,499,880	1,656,000	402,180,396	339,441,480	64,691,000
Jul	176,139,267	223,944	500	470,040,394	360,099,348	84,923,000
Aug	179,384,963	985,428	1,571,000	462,073,978	360,329,244	71,932,000
Sep	239,116,743	12,181,680	11,114,000	344,064,776	344,863,080	50,327,000
Oct	351,918,335	45,378,420	48,422,000	293,019,394	345,882,996	31,579,000
Nov	367,937,448	90,733,680	167,861,000	101,788,695	335,123,640	13,543,000
Dec	488,565,778	137,165,700	358,121,000	30,132,768	341,629,176	5,301,000
AVE TOTALS	**332,921,083**	**58,356,303**	**123,636,958**	**223,194,505**	**342,505,866**	**35,306,083**