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Worcester City Hall: Energy Analysis and Building Information Modeling

A Major Qualifying Project Proposal
Submitted to the faculty of
WORCESTER POLYTECHNIC INSTITUTE

Submitted to:
Professor Guillermo Salazar

Professor Frederick Hart

By:

Josh Brodin

Samantha Varnerin

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Abstract

This project conducted an energy analysis of Worcester City Hall, a historical building constructed in the 19th century. Using Building Information Modeling (BIM) software this project simulated the current energy consumption of Worcester City Hall and identified ways to potentially improve the energy efficiency of the building.

Capstone Design Experience

This project conducted a study on the energy consumption of Worcester City Hall, a historical building constructed in the 19th century, and proposed methods to potentially improve the energy efficiency of the building. Using Building Information Modeling (BIM) software, this project simulated the current energy consumption of Worcester City Hall and conducted energy use analysis to identify specific areas for improvement.

In accordance with the Accreditation Board of Engineering and Technology (ABET) General Criterion for capstone design, this Major Qualifying Project has incorporated the following five realistic constraints:

Economic

This project reviewed the actual energy consumption costs and the projected future operating costs that Worcester City Hall should expect as a result of the energy savings associated with remodeling City Hall. Using energy analysis software, the project group determined that the energy used to heat the building after certain renovations was less than the expected energy use before the renovations in certain cases, resulting in a similar decrease in costs. Each of the renovations in question was analyzed for long-term savings.

Environmental

The well-being of the environment is fundamentally addressed in this project. This project addresses the current energy usage of Worcester City Hall along with the resulting emissions. It attempts to decrease the energy usage of the building and consequently the emissions into the environment.

Sustainability

The retrofitting of Worcester City Hall is related to the concept of "green building" in the sense that it will reduce the impact of the building on the environment. This project analyzes the social, economic, and environmental factors involved in remodeling a building, all of which must be accounted for when developing a sustainable idea.

Social

In generating solutions for the historical Worcester City Hall the potential modifications had to be socially acceptable in order to be viable. This project had to take into account the fact that Worcester City Hall is a historical site and had to have renovations that resulted in minimal impact to the building in order to preserve its cultural significance. Worcester City Hall is listed under the National Registry of Historic Places and therefore cannot be altered extensively. This project had to work under certain conditions imposed by the registry, namely the avoidance of extensive modifications to the building.

Manufacturability (Constructability)

The Worcester City Hall project recognizes that improvements that may be good for a building with respect to the aforementioned categories still cannot be necessarily implemented. For example, increasing the thermal resistance of the walls may be very difficult for Worcester City Hall as it requires extensive renovation. Consequently, this project avoided such matters. Instead, it focused on renovations that could be implemented.

Acknowledgements

We would like to thank the many experts that were more than willing to provide information regarding our topic. Without their assistance, we could not have conducted our study. First and foremost, we would like to thank our sponsors stationed in Worcester City Hall for giving us the opportunity to work with them and for their eagerness to give us any tools or information we needed regarding Worcester City Hall: Mr. Brad Cappucci, Mr. Matt Urban, Mr. Rick Trifero, Mr. Paul Marrone, and Mr. John Odell. Mr. David Legg, the Deep Energy Pilot Program Director from National Grid also provided us with many useful resources that led to possible solutions for Worcester City Hall.

We would also like to thank our consultants and advisers, Frederick Hart, PhD, and Guillermo Salazar, PhD, for giving us their insight and continuous guidance for our project. We also appreciate and are thankful for the help of two PhD students at Worcester Polytechnic Institute, Nakisa Alborzfard and Sergio Alvarez-Romero, both of whom were also more than willing to provide advice for contacting city hall and for their troubleshooting assistance with both the BIM software, Autodesk Revit, and the energy analysis software, Ecotect.

Authorship

The Worcester City Hall: Long-Term Sustainability project is potentially the first of many projects associated with Worcester City Hall and was started by Josh Brodin and Samantha Varnerin, both seniors at Worcester Polytechnic Institute at the time of this publication. Josh and Samantha bring together a strong skillset that made this project possible including their previous undergraduate work experience together and their group project experiences in Interactive Qualifying Projects. While this project could not have been completed without either one of them, they both deserve to be acknowledged for their individual contributions to the project.

Josh was the primary Revit designer and modeled the terrain, exterior, and the majority of the interior of the Worcester City Hall model. He ran several Ecotect analyses using the parameters given by Samantha. Josh did a lot of the initial proposal writing (most of which became the background for the final paper). After the main section of the report was complete, he wrote up the design capstone, abstract, the first half of the methodology (3.1-3.4), one section of the results (4.1), sections of the recommendations (5.1, 5.2, 5.2.2, and 5.2.3) and the conclusion. Josh also visited City Hall for data gathering several times over the course of this project.

Samantha was the primary Ecotect user and went through the process of contacting Information Technology at Worcester Polytechnic Institute to secure an Ecotect license for the duration of this project. She made adjustments to the interior of the first floor and part of the second floor in Revit. She was responsible for all of the cost analysis. The following sections were her writing primarily: Acknowledgements, Executive Summary, Methodology (3.5-3.5.2), and Results (4.2 - 4.3.1).

Josh and Samantha worked as a team to provide viable solutions for the City of Worcester. While they worked very hard on the aforementioned individual tasks, they also worked together equally to stay in contact with Worcester City Hall. Both had contributed to preparing presentations for City Hall and for other related groups at Worcester Polytechnic Institute. Both conducted research on the topics associated with this project and wrote the Introduction (1.1-1.5) and Background (2.1-2.8). Lastly, they shared responsibility for the editing and formatting of this report.

Executive Summary

Societies worldwide are applying the concepts of sustainability to their constructed facilities in order to reduce the amount of harmful emissions they produce. However, older buildings are still in use and many lack sustainable features. While they may not be energy efficient at first, older buildings can be updated to become more sustainable and, in some cases, they are considered for a Leadership in Energy and Environmental Design (LEED) certificate. According to the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), buildings consume energy based on the building envelope's efficiency, the HVAC system's energy output, the water heating systems, the lighting systems, and the various electrical operations taking place within the building. Improvements with regards to efficiency to any of these systems lead to overall energy efficiency improvements in the building.

The City of Worcester is retrofitting over 90 buildings in the city at the time of this publication, one of the most important of which is Worcester City Hall, a historical building constructed in 1896. Representatives for both Worcester City Hall and Worcester Polytechnic Institute identified this project to determine potential renovations to make the building more sustainable. After reviewing the specific objectives of the project, the project group determined that analyzing the building envelope would be the most beneficial at this point in time.

To facilitate and better visualize the analysis process and to incorporate recent advances in the use of architecture and engineering software, Building Information Modeling tools were selected. More specifically, Autodesk Revit 2013 and Ecotect Energy Analysis 2011 were chosen for this study. With the use of blueprints facilitated by the Worcester City Hall administration, a virtual 3D model was constructed with the Building Information Modeling software. The Building Information Modeling software defined the thermal properties of the building while the Energy Analysis software analyzed the effects of weather, location, and people upon the building. The Energy Analysis software utilized long-term weather data from the Department of Energy for the Worcester area. Based on the building's oil usage, the initial model to represent current conditions had a variance of 34.01% compared to the actual conditions for Worcester City Hall. After the model was created to reflect existing conditions, several options for energy improvement were simulated and analyzed.

While the derived results are still preliminary, insulation solutions that show potential solutions include insulating the first floor, second floor, third floor, and the attic. Based on values from RSMeans, a trusted construction industry resource for estimating costs, the cost of installation on these floors is

lower than the cost savings in less than a five-year period. It is suggested that additional data and further studies be conducted to confirm or expand these results as well as to decrease the variance of energy usage between the virtual model and the actual conditions of Worcester City Hall.

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Chapter 1: Introduction

Countries such as the United States are striving to make renovations to buildings and also to make new construction more sustainable to better protect the environment, the economy, and society. The energy used to build, operate, and demolish buildings is one of the leading causes of greenhouse gas (GHG) emissions. Approximately 30-40% of all energy use and around 40-50% of all GHGs can be attributed to buildings (Muneer, 2007). A building generates GHG through the usage of electricity and heating, two items of which can be regulated and/or reduced. Designing buildings to be more energy efficient is an effective action to reduce these GHGs. In 2008, Americans saved an estimated $19 billion due to the implementation of green measures (EPA, 2010). Examples of these green measures in new home construction include but are not limited to effective insulation, high performance windows (low rate of thermal transfer across the panes and sufficient natural lighting), tight construction and ducts (minimal leaks between the exterior and interior surfaces of the house), proper home ventilation, and third party verification that the home was built correctly (EPA, 2010).

The City of Worcester wants to implement sustainable changes to municipal buildings, specifically Worcester City Hall, and has already taken the steps to create a Climate Action Plan for the city. Under the Energy Savings Contract program the city is currently retrofitting over 90 buildings in the city at the time of this publication. One of the most important buildings in this retrofitting movement is Worcester City Hall, a historical building constructed in 1896. The City of Worcester's ESCO Energy management team, the entity in charge of the retrofitting movement and renovating Worcester City Hall, is interested in determining the effectiveness of any potential changes they make to the building before making them.

The analysis of a building can be completed with the use of digital modeling programs such as Building Information Modeling (BIM). BIM is a technology-based approach that uses 3D object-oriented parametric and interoperable software to support planning design, construction and operation of buildings. Among other applications, a BIM approach can be used to model a building and to conduct an energy efficiency analysis. This is done by first creating a model in BIM, typically just a shell of the walls for the simplest of analyses. Once the BIM is created, it can then be exported to interoperable software to conduct quantitative analysis based on the geometric and functional characteristics of the digital model. BIM software allows for the virtual examination of several efficiency factors such as heat loss, lighting, energy spent on heating, ventilation, and cooling systems (HVAC), general energy usage, and cost. BIM and its associated programs make defining a design or renovation plan that is both “green” and affordable easier. When the designer takes the needs of the occupants into account, BIM software can be highly useful for the construction of sustainable structures. A BIM-based energy analysis of Worcester City Hall can show any major areas of concern in the building that need improvement (Eastman, 2009).

This project consisted of developing a 3D digital model of Worcester City hall and then analyzing it for its current energy efficiency. Based on the results of this study, areas of the building were identified in such a way so that they could be reasonably modified to increase the energy efficiency of the structure. At the end of this project, the Worcester City Hall building information model and a series of energy analyses intended to show the potential use of the model were given to Worcester City Hall representatives for their future use.

Chapter 2: Background

This section discusses the concept of sustainability and its importance in society. It describes how sustainability relates to the construction of buildings and how the environmentally related features of sustainable building can be analyzed using computer software such as Building Information Modeling and Energy Analysis software.

2.1 Sustainable Buildings and Sustainability

Many entities varying in size from the individual to entire countries are trying to decrease the negative impact of their activities on the natural environment. Internationally the relative importance placed on the welfare of the environment is debatable; some countries such as Costa Rica enforce very stringent emissions laws and therefore have a very clean atmosphere and well-kept environment. Meanwhile, other and more industrial nations such as China have heavily polluted the atmosphere and environment. As each country continues to go about their ways, scientists observe a multitude of planetary changes that may or may not be the result of human action. Many of these changes are undesirable in the sense that they destroy animal habitats and affect the weather, something that can ruin the livelihood of certain regions. Designing and constructing sustainable buildings is just one of many ways that may be used to reduce humanity's impact on the environment. The Environmental Protection Agency (EPA) defines sustainable building as "the practice of creating and using healthier and more resource-efficient models of construction, renovation, operation, maintenance and demolition" (EPA, 2012). Sustainable buildings are also known as "green buildings".

The basis of a sustainable building can be broken down into three distinct requirements:

- social needs
- environmental needs
- economical needs

With regards to the social state of people, a sustainable society is one that is able to establish a good quality of life for its citizens. A society with a good social quality of life includes accessible healthcare, education, and a general well-being for its citizens. A successful environment is defined by an availability of resources, acceptable air quality, acceptable water quality, and accessible energy. A positive state of the third category, economics, is defined by the income of a society's citizens, the availability of business opportunities, and a low level of unemployment. The combination and acknowledgement of all these factors is referred to as "the triple bottom line" (Plummer, 2012).

All three of these categories in the triple bottom line must be accounted for in order to achieve a sustainable society. If only two of the three categories are met, then a society is not considered sustainable. As shown in Figure 1, if a society is "bearable," only its social and environmental needs are fulfilled. In an extreme bearable society, the well-being of the citizens is accounted for and renewable resources are readily accessible. However, this society would not be considered sustainable because no one would be generating income and the economy would come to a standstill.

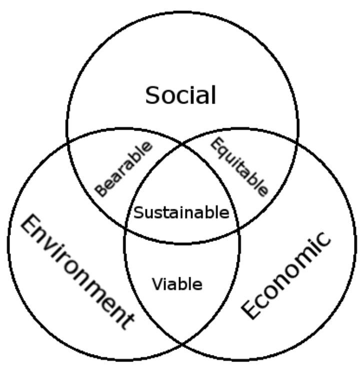

Figure 1: Diagram of the triple bottom line

Other non-sustainable societies that Figure 1 demonstrates include the "viable" society and the "equitable" society. In a "viable" society the environment and economy are sound, but the well-being of the citizens is in danger. In an "equitable" society, people have basic needs such as education and healthcare accounted for. They also have economic opportunities and the economy benefits from those opportunities. Unfortunately, in this type of society the environment is ultimately destroyed.

In sustainable building, a concept that includes both the design and construction of new structures and the renovation of existing ones, there are three main objectives that are based on the idea of a sustainable society. First, the building must meet the social needs of whoever needs to use it. Second, the building must have a minimal impact on the environment. Third, the construction and operation of the building must be economically feasible. When all these objectives are achieved, a building can be considered "sustainable."

2.2 Sustainable Efforts in Massachusetts

While there are laws governing sustainable measures both internationally and nationally, the biggest pushes for sustainable solutions have been on the state level. Massachusetts is currently one of the most successful U.S. states in its endeavors to be energy efficient. In 2006, Massachusetts was ranked 4 out of 50 by the American Council for an Energy-Efficient Economy (ACEEE), which based their rankings on a state-by-state energy efficiency scorecard ("Massachusetts Ranked First in the Nation for Energy Efficiency", 2011) . In 2009 and 2010, Massachusetts was ranked second out of 50 states, with first being California. In 2011, Massachusetts was ranked as the most energy efficient state in the United States by ACEEE.

Massachusetts' sustainable efforts that contribute to this success include, but are not limited to:

- Legislation requiring oil and gas companies to reduce their cost of operation
- Early investigation of environmental problems through the Massachusetts Environmental Police and the Hazardous Waste Bureau
- Incentive programs for businesses and individuals to switch to alternative energy or more efficient appliances
- State grants and loans to support funding for clean and renewable energy projects

Governor Deval Patrick claims that the state's phenomenal ACEEE ranking was partly thanks to the Massachusetts' Green Communities Act of 2008 ("Massachusetts Ranked First in the Nation for Energy Efficiency", 2011). This act consisted of creating regulations that required major utility companies to reduce their costs of operation. These major utility companies included oil and gas companies. The savings that came with the reduced operating costs would then be passed onto consumers. Ultimately, the Act would require 15 percent of electricity to be supplied by new renewable power facilities by 2020 (Green Communities Act: MA). While this was a very effective measure, other efforts in Massachusetts were also responsible for the above average sustainable efforts.

In addition to legislative sustainable efforts, Massachusetts has also formed a group called the Massachusetts Environmental Police. This group aims to "protect the environment and natural resources of the Commonwealth of Massachusetts through enforcement, education, and public outreach" (The Official Website of the Executive Office of Energy and Environmental Affairs). Within this group exists the Hazardous Waste Bureau, possibly one of the most important organizations with regards to Massachusetts' sustainable efforts. This group investigates and prosecutes environmental crimes that are public health hazard concerns such as water and air pollution (Hazardous Waste Bureau). Monitoring for environmental "crimes" is not setting a standard for sustainability, but rather it is a proactive (as opposed to reactive) approach for avoiding problems.

Massachusetts also has several incentive programs that allow businesses and citizens to make energy efficient changes. Statewide, one of the highest rebate incentive programs is the Micro Wind Initiative through the Massachusetts Clean Energy Center (MassCEC). Under the Micro Wind Initiative, developers of public wind projects can receive up to $130,000 in rebates from the state. Through the same program, non-public projects can get rebates of up to $100,000 (Massachusetts: Commonwealth Wind Incentive Program - Micro Wind Initiative). In addition, Massachusetts will give a property tax exemption for 20 years if the property has solar and wind powered devices that provide enough energy for the property's needs (EPA).

Not only are there incentive programs, but the state also offers grants, loans and mortgages to help pay for sustainable projects. These payments can range from a couple thousand dollars to as large as three million dollars, and they can be claimed by both residencies and businesses. Two such business loans include the Business Expansion Initiative, a loan that supports renewable energy companies, and the Clean Energy Pre-development Financing Initiative, an act that provides unsecured loans for wind, biomass, and other renewable energy projects (EPA).

Massachusetts offers many opportunities to save on sustainable solutions and additions, especially within the realm of sustainable building. Because of this and the fact that the state has incentives for all zoning types, it has emerged as one of the most sustainable states in the United States.

2.3 Sustainable Efforts in Worcester

Cities around the globe have been taking measures of varying degrees in order to prevent further damage to the environment. Massachusetts' city of Worcester is one such city. In 2003, Worcester became the nineteenth city in Massachusetts to join a program titled Cities for Climate Protection (CCP), an international movement run by the ICLEI (the title given to the association of cities that seek to promote sustainable development) that focused on the reduction of greenhouse gases (City of Worcester, 2006). In doing so, Worcester agreed to follow the five-steps associated with becoming greener:

1. Develop a baseline inventory of greenhouse gas emissions
2. Establish a target to lower emissions
3. Develop a local climate action plan to implement actions that reduce GHG emissions
4. Implement the climate action plan
5. Measure, verify, and report greenhouse gases

According to the manual written by the ICLEI, the first step the CCP program requires cities to undergo in their attempts to become greener is to develop a baseline inventory of greenhouse gas emissions (Natural Capital Solutions). This step allows the cities to analyze their current emission rate and based on what they can find, make an appropriate goal. Ideally, during this stage the city will identify areas that produce the most greenhouse gasses and later on will know where to focus their efforts. Figure 2 shows that in Worcester's case, the majority of municipal emissions are generated by waste and buildings.

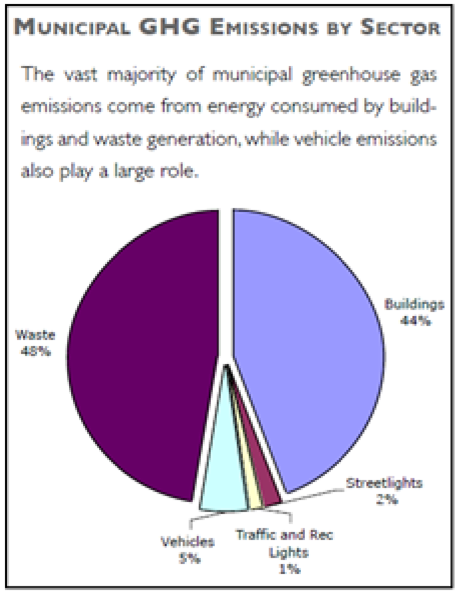

Figure 2: Worcester's Municipal GHG Emissions (Source: City of Worcester)

Once the sources of greenhouse gasses are identified, the second step of the CCP program is to create a target goal to reduce emissions. In the case above, one goal may be to reduce GHG emissions a specific amount by lowering the total emissions generated by waste. This goal fulfills the second step of the process: "establish a target to lower emissions". After establishing a goal, a city should then move on to the execution of the third and last planning step in the process: "develop a local climate action plan to implement actions that reduce GHG emissions" (Natural Capital Solutions). Developing a climate action plan requires research, and it can encompass a wide range of strategies. In the situation shown in Figure 2, a quick analysis may result in a plan that reduces the total waste generated by municipal buildings. Alternatively, buildings can also be modified to be more energy efficient.

Once a decision is reached, the city may move onto to the fourth step of the CCP program: implementation. The success of this stage will then be measured by the last step in which greenhouse gases are measured, verified, and reported (Natural Capitalism Solutions). As mentioned earlier, Worcester took part in the CCP program and ran through some of the steps in becoming a greener city. The baseline inventory was executed by an energy consultant, Carissa Williams, in April of 2004 as part of her master's degree work at Clark University (City of Worcester). The second step, the identification of a goal, was decided by the City of Worcester shortly after. Specifically, their goal was to reduce greenhouse gas emissions by 11%

between the years of 2002 to 2010 (City of Worcester). As outlined by step 3, the City of Worcester decided that it would then follow through with this goal by reducing the emissions produced from waste generated by municipal sites. Some of the ideas that the City of Worcester developed to achieve their 11% greenhouse gas reduction goal included decreasing school waste, the promotion of recycling, and the recapturing of methane from landfills (City of Worcester).

Aside from following the basic guidelines set forth by the CCP, the City of Worcester also created a list of thirty-seven unique ideas to further promote the ideals of a sustainable society. These ideas range from the social remodeling of society through the participation in an Earth Day Fair to more physical and immediate solutions such as the upgrade of exit signs from incandescent lights to LEDs. In their action plan, the City of Worcester outlines these goals along with a series of steps intended to guide the implementation process once the city is able to execute the solutions.

2.4 The Renovation of Buildings with Sustainability in Mind

While it's relatively easy to reduce some major contributors to greenhouse gas emissions such as waste, buildings are also a major source of greenhouse gasses. However, unlike waste, buildings are not as simple to regulate. For one, buildings are relatively permanent. They require a considerable amount of resources to demolish and replace; it is not plausible to tear down every building and replace it with a sustainable structure. This means the only other alternative is to keep the buildings, even if they produce greenhouse gases, and retrofit them to be more energy efficient.

There are a wide variety of methods that can be used to retrofit a building to be more energy-efficient. However, at what point can a building be considered sustainable? The U.S. Green Building Council (USGBC) is one such group that believes that they may have created a standard for building green structures. Their creation is LEED, a rating system that takes into account the number of sustainable characteristics of a building and utilizes a point system to rate the overall sustainability of a structure.

There are five main credit categories that are used to rate the energy efficiency of a structure when using the LEED system (USGBC, 2012). These categories are based on the sustainability of:

- The site
- Water efficiency
- Energy usage and the impact on the atmosphere
- Materials and resource usage
- Indoor environment quality

Each of these category groups aim to minimize the usage of resources, the impact on the environment, or both. Based on the type of building in question, there may be additional categories as well.

Within each of the LEED categories are a series of suggested items that should be considered when designing a building to be energy efficient. Whenever one of the items is completed, the authorities in charge of evaluating a building will make note and assign a certain number of points to the building. If a building has earned enough points, it may receive a level of LEED accreditation. Table 1 shows the point range to achieve any of the LEED certifications. The lowest level of accreditation a building may receive is "Certified", a level that is reached by scoring between 40-49 points out of a possible 110 (USGBC, 2008). The next level is Silver at 50-59 points, then Gold at 60-79 points, and lastly Platinum, a level which is achieved if a building scores 80 points or higher on the LEED certification exam.

Table 1: LEED Certification range

Accreditation	Point Range to Achieve
Certified	40-49
Silver	50-59
Gold	60-79
Platinum	80-110

Not all buildings can be easily outfitted to be LEED accredited. Existing buildings, especially historical ones, cannot feasibly be rebuilt to be as sustainable as a newly constructed building. Knowing this, the USGBC created a separate system designed specifically to evaluate existing buildings. This system was appropriately titled “LEED 2009 for existing buildings”. Within this system the five main credit categories are used along with the consideration of innovation in operations and the regional priority of the building to establish a final score (USGBC, 2008). By having guidelines like these, it is possible not only to construct buildings that are considered sustainable, but also to renovate existing buildings to have more sustainable standards.

2.5 History of Worcester City Hall

Worcester City Hall, the building of focus for this project, was built to accommodate the expanding city in the late 1800s. This four-story structure was built by the Norcross Brothers of Worcester in 1896 to replace the old 1825 City Hall which had become too small for the growing city (Council, 1899). The City Hall, shown in Figure 3, cost $598,000 to build. The building is still in use today, outliving its predecessor by forty five years from the date of this report. Today, many of the people that work in Worcester City Hall still keep historical photos in their office, such as the one in Figure 3. Many more photos are displayed in Appendix A.

Figure 3: City Hall in 1899

Although the building is “well-formed, true and trusty” as the building’s designer Robert Peabody had said when the building first opened (Sumner, 1896), several renovations had to be made to fit with modern use of the building. A very early renovation was to add lights to the City Hall clock so people could see the time at night (City Hall Clock: A.W Jefts is at Work on a Plan for Lighting it at Night, 1898). A more recent renovation was the updating of meeting spaces within the building to be both larger and able to include modern technology (Katsoploulous, 2005). Various other renovations include windows being renewed, the city clerk’s office being renovated, and the HVAC systems being updated (Trifero, 2012).

However, the City of Worcester retains its historical feel despite the number of renovations over the years. To ensure this continues, the United States Department of the Interior placed Worcester City Hall on the National Register of Historic Places, the plaque of which is displayed inside City Hall and shown in Figure 4. The historical feel to the building can be attributed to the many historical objects inside the building, such as the half-suits of armor that were donated from Worcester, England as a sign of friendship between the two cities (Sacks, 2008) or the portraits of previous mayors and city managers on the third and fourth floors (Dempsey, 1996). In order to preserve the historical essence, any renovations must keep within the architectural integrity of that time period.

Figure 4: Plaque hung in Worcester City Hall certifying its historical status

2.6 Energy Services Company Program (ESCO)

The goal of this project is to renovate Worcester City Hall to conform to more sustainable standards, reducing the energy consumed by the building and consequently reducing the GHGs emitted into the environment. In order to make this possible, a company titled “ESCO” (Energy Services Company Program) has been working with Worcester City Hall to reduce their energy output through renovations of the building. ESCO functions by identifying and arranging the funding for any renovations to buildings such as Worcester City Hall. Their mission is to ensure the renovations will generate enough energy cost savings to pay for the cost of the project within the span of 25 years (U.S. Department of Energy, 2012). So, for instance, ESCO may be involved in a project in which double-pane windows are installed to replace old single-pane windows on a building. The cost of the project may be $10,000. Over a period of ten years, the energy saved by the replacement of the windows may equal $10,000 and ESCO receives that part of the savings. After ten years have passed, the client receives the remaining savings.

2.7 Energy Analysis

In order to design or update buildings to be energy efficient, a process called an “energy analysis” may be first conducted. The energy analysis of a building is a process that analyzes the total energy utilization of a structure. There are three broad categories in which energy usage can be attributed to: construction, operation, and demolition. The construction and demolition phases both require general labor and the transportation of materials. They differ because while construction takes into account the manufacture and installation of building materials at the beginning of the building’s life cycle, demolition consists of the deconstruction of materials at the end of the cycle. Meanwhile, operation involves the use and inhabitance of the structure.

The level of energy utilized varies wildly based on the needs of the occupants. Operating energy can be defined using the equation:

Operating Energy = E*OA * *Lb …………………………. (1)

where

*E*OA = annual operating energy (BTU/year) and

Lb= life span of the building (year) (Ramish, 2010).

There are four essential stages in order to complete an energy analysis:

1. The identification of the scope and goals of the energy analysis
2. The conduction of an inventory analysis by quantifying building parts that are within the scope of the energy analysis
3. The generation of an impact assessment detailing the energy consumption of the building. Energy can be divided up by function such as heat usage (the focus of this project) or lighting.
4. The compilation of an improvement analysis to identify changes that will decrease the buildings' total energy utilization (Muneer, 2007)

Once the amount of energy that a building uses can be quantified through an analysis of a building's construction, operation, and demolition phases, an engineer can then rate the energy efficiency of a structure. The most important step during the energy analysis process with regards to the operation of the building is the analysis of the building envelope (Alvarez, 2012). The building envelope separates the interior of the building from the constantly-fluctuating temperatures of the outdoors and therefore will allow or prevent a great deal of atmospheric change within the interior of the building. The rate at which heat travels through the building envelope can be calculated using formulas associated with conduction, convection, radiation, and infiltration. After calculating the level of heat transfer within the building it is then possible to estimate the cost of the environmental controls within the building.

Aside from the building envelope, there are many other systems within a structure that can be examined when conducting an energy analysis of the building's operation. Some of the more notable systems include heating, ventilation, air conditioning, lighting, and power distribution. The performance standards for each of these categories can be based on a variety of guidelines. For energy efficient designs, standards such as ASHRAE 90.1 may be used.

2.7.1 Thermal Analysis

This project focuses on conducting a thermal analysis of Worcester City Hall. To do this, it's important to know how to measure the level of heat that flows through the building envelope. To determine this, the heat flow equation is needed:

$Q = A * U * (T_i – T_o)$ ………………………………. (2)

Where

Q= Heat flow through the walls in Btu / hour

A= Area of the Wall in square feet

U= Thermal Heat Losses and Gains in Btu / (hour * square foot * degrees Fahrenheit)

T_i= Temperature inside the building (degrees Fahrenheit)

T_o= Temperature outside the building (degrees Fahrenheit)

The thermal heat loss and gains of the building, U, can also be described as the inverse of the resistance factor R (Bhatia), as shown below.

$U= 1/R$ …………………………………………… (3)

Where

R = Resistance factor in (hour * square foot * degrees Fahrenheit)/Btu

Resistance factors are coefficients that prevent heat transfer. The higher the "R-value," the less heat loss that occurs (Bhatia). Formula 2 is essential to calculate the level of energy lost. The energy lost can be expressed as British Thermal Units (BTUs), a universally recognized measuring unit that can be converted from any kind of other thermal measurement to calculate cost per BTU (Bhatia).

The process of calculating the R-value for any given room within a building may not necessarily be a simple task. Rooms are frequently made up of more than one material; floors may be plywood and carpeting, the walls may be cinder blocks, windows may be made of glass, and doors may be made of wood. As a result, it can be very time-consuming to find the exact R-value of a particular room. Instead, a hand-calculated analysis may make some assumptions to get a "rough idea" of the overall R value of the room. The room may also be divided into subcomponents. Each wall can be analyzed individually for an R-value or they can be further subdivided so that an analysis looks at windows and doors separately from walls. Performing a thermal analysis on Worcester City Hall by hand would be time consuming since these calculations would need to be done for all of the rooms in Worcester City Hall.

The calculation of the rate of heat flow through the walls may also be complex. Over the course of a day for example, T_o can be expected to change significantly. The amount of sunlight projecting onto a given area of a building and heating it up can also be expected to change. If the sun's rays strike the surface of a building perpendicularly for example, that surface will experience far more energy gain than it would if the sun's rays struck at an angle (Solar Insolation, 1999). To account for the solar radiation warming of a building at any given time, the following equation is used:

$$I = S * \cos(\varnothing) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where

I = The amount of energy received by the surface in Wh/m^2

S = Surface's insolation perpendicular to sun at noon (Wh/m^2)

$\varnothing$ = Angle from sun at noon in degrees

To streamline these calculations, an energy analysis software can take a model of a building with specified R-values and not only calculate the R-value for an entire wall, but it can also calculate the heat flow for every room. The energy analysis software is also able to take the weather data for a specific area and apply it to the models it analyzes. The electronically-based energy analysis is a relatively quick way to analyze both existing structures and structures that have yet to be built.

2.8 Building Information Modeling

Building information modeling (BIM) is electronic information "generated and maintained through the lifecycle of a building" (Burr, 2011). Specifically, it is an object-oriented computer aided design system "in which all of the intelligent building objects that combine to make up a building design can coexist in a single 'project database' or 'virtual building' that captures everything known about the building. A building information model (in theory) provides a single, logical, consistent source for all information associated with the building" (Howell, 2011). When used appropriately, BIM can severely cut down on the time required to plan the layout of a building or structure because computerizing a building plan make it easier for a designer to quantify materials more accurately or see any space errors in individual rooms (Eastman, 2009). The models that result from this process can be observed and modified with relative ease and the overall impacts of just one change on the design may be immediately known.

BIM is a concept that evolved from the more general concept of computer aided design (CAD) (Howell, 2011). In the early stages of its existence, models created with CAD were limited to two-dimensional representation and the relationships between the various components of the drawing could not be represented. Essentially, CAD limited the user to create little more than a basic sketch. Later, CAD evolved to include layers, relationships between components, and eventually the modeling of three-dimensional objects. However, BIM did not arise until a few more improvements to CAD were made. Most notably, objects with "intelligence" were added. These objects had specific traits that identified not only what they were but what they could do; a designer could look at the model of a wall and know not only its basic physical characteristics like width, but also more in depth items like its color and fire resistance. (Howell, 2011).

Interacting with models constructed in a BIM environment is simple and immediate. It is easy for a designer to make one change within a building's structural plans and view the immediate impact on any systems within the building. The final building is also much easier to visualize than a two-dimensional plan as all of the components of a structure can be depicted at once. Additionally, the speed at which all of the building's resources can be combined to generate plans are quicker than what two-dimensional plans can allow, in some cases up to as much as 30% (Autodesk, 2012).

The quality of a structure is another reason why designers may decide to use BIM software. A building model generated on a screen enables contractors from any trade to understand the layout of a building or structure, even complex ones. As such, each trade can look over the plans and decide where their systems fit into the grand scheme with relative ease because the designs are both defined and accurate. Since the building is already defined, surplus space or erroneous measurements should never be an issue so long as the designer does not make a major oversight. If the designer does make an error, it is much easier to identify within a BIM model than it is on two-dimensional representation (Autodesk, 2012).

A third useful feature of BIM software is profit. The software automates many small tasks that would otherwise be utilized while drawing up building plans which means the need for employees to work on small, specialized jobs is no longer required. This saves time and reduces expenditures in the long run. At the client's end of the spectrum, a defined model makes it easier for the clients to make confident decisions with regard to their new building. Clients can look over the plans, understand them, and make timely decisions. If a client prefers a different design, a BIM designer can easily create alternatives and cater to the client's needs in a manner that is more efficient and cost-effective than if a typical two-dimensional design method is used. The use of a BIM model also reduces risk. As was stated earlier, the layout of a building or a structure in a model generated by BIM is well defined and costly errors that may arise due to errors in the design phase can for the most part be avoided. Lastly, since all of the contractors involved in a building's construction can easily look at a model created in BIM and understand the layout of everything, they can potentially identify inexpensive alternatives to what the BIM designer had planned for the structure (Autodesk, 2012).

Aside from the efficient, cost-effective, and quality based aspects of designing a building using BIM software, a BIM model may also be used for other endeavors. A finished model may be stored and kept for future reference for maintenance purposes. A building that has already been constructed may be recreated in a BIM environment for renovation, or a model of an already existing building or structure may be created and revised to make it more energy efficient. The methods in which pre-constructed buildings are modeled in BIM software are less "creative" and more "empirical". Models of existing buildings may be built based on simple techniques such as the analysis and replication of the drawn plans, or through the complex use of laser scanning, a process that identifies the XYZ coordinates of all the solid points within a building and uploads them to BIM software (Autodesk, 2012).

Lastly, the files that the BIM software generates are capable of being read and used by other types of software. Some programs that identify the energy efficiency, power requirements, heat flow, and other environment-based factors in a building can use and analyze the files generated by BIM software. Since BIM models are created with an "intelligent" design, these other programs can conduct an energy analysis and effectively report a series of expected values. For instance, because BIM can identify the components of walls and their corresponding resistance values, a house modeled with glass walls will be have energy usage results that are significantly different from a house modeled with brick walls upon being analyzed in an environmental analysis software. The resulting values from an analysis may be used to inform the client of expected costs of a building before it has been constructed, or it may allow a building to be analyzed and adjusted to be more energy efficient.

Chapter 3: Methodology

This section outlines the steps this group took to execute the project. It reviews how potential solutions to the problem of energy efficiency were generated and also discusses the specific objectives of this project.

3.1 Objectives

The objectives of this study are to:

- Better understand the history and features within Worcester City Hall
- Verify building measurements given to the group in the form of AutoCAD and .pdf files of Worcester City Hall
- Create a 3D BIM model that represents the Worcester City Hall using Autodesk Revit Architecture
- Run an Ecotect energy analysis program to simulate the energy usage of Worcester City Hall
- Research and propose sustainable solutions to energy-related concerns for Worcester City Hall
- Report the results to the City of Worcester
- Identify future uses for the 3D BIM model

These goals and task lists are outlined in Appendix B.

3.2 General Overview of Process

This project began with the group members conducting background research on Worcester City Hall. Information about the Worcester City Hall such as blueprints, specifications, and historical records is readily available and has been facilitated by the City Hall. Access to the building and guidance about its whereabouts has also been made possible through City Hall staff. Historical information about Worcester City Hall was used by the group members and is available at the Worcester Historical Society.

The two most useful documents that the group members received from Worcester City Hall were the CAD drawings of the building and a spreadsheet depicting the oil use for heating and cooling the building from fiscal year 2010 to fiscal year 2013 (Appendix G). The CAD drawings were used as a basis for the construction of the BIM model. The BIM model was then used to as the basis to conduct an energy analysis within Ecotect. The oil use results from Ecotect were then compared to the actual oil results from Worcester City Hall and from there the group was able to gauge the accuracy of the model. After constructing the model and analyzing it, the group members made a series of adjustments to the model in an attempt to make it more energy efficient.

3.3 Utilized software

Regarding the BIM program, Autodesk Revit Architecture had been selected given its availability at WPI and the group members' skills and exposure. In addition, the Autodesk Student Engineering Community, an online resource, offers the software free for engineering students. Computer modeling was chosen over pencil-and-paper methods due to both accuracy of computer calculations and because the process of making adjustments and measurements was much faster.

The group decided to use Autodesk Ecotect 2011 (also known as Ecotect) for their thermal analysis on the envelope that was created in Revit. This program was selected for use because it is designed to work specifically with models created in Autodesk Revit and because the software was easy to obtain.

3.4 The BIM model

This section describes the steps involved in generating the need for and developing a BIM model of Worcester City Hall.

3.4.1 Objectives

The purpose of modeling Worcester City Hall using BIM software was based on the need for the following:

1. A model that could be used in conjunction with an energy analysis program.
2. A model that was detailed enough to accurately represent the layout of Worcester City Hall but simple enough to model and analyze in an appropriate amount of time.
3. A model that could be easily modified if errors arose and
4. A model that allowed for the execution of energy analysis simulations that would determine energy efficient alternatives.

3.4.2 BIM Methodology

Before modeling the Worcester City Hall, the group members modeled a basic 2-bedroom building on which they executed various tests within Ecotect. The reasoning behind this was that it made much more sense for the group members to learn what could be done in Ecotect (since neither had much experience) through the analysis of a simple model that, in the event that any basic errors arose, could be both analyzed and adjusted relatively quickly.

After learning about the functionality of Ecotect, the group members gathered information about Worcester City Hall, namely AutoCAD drawings, and defined the layout of Worcester City Hall for an energy analysis using Revit Architecture.

There were a few obstacles in constructing the model. First, there was no information available on the composition of the walls and on their thermal characteristics. To compensate for this the group made assumptions on the interiors of the walls. These interiors were later adjusted after comparing the costs due to heat loss in the virtual model to the actual costs of heating Worcester City Hall. Additionally, there were a few technical problems that our group experienced and these are listed in Appendix C. Once the BIM was built, the group members conducted an impact assessment through the energy analysis.

3.5 The Energy Analysis

This section describes the goals of the energy analysis and the steps involved in the running of each analysis. This section also explains the how data pertaining to costs was extrapolated from the energy analyses.

3.5.1 Objectives

In analyzing the BIM model with Ecotect, the group members attempted to accomplish the following:

1. Calculate the energy required to sustain the thermal environment of the building.
2. Have the energy requirements of the virtual building as close to the actual conditions of the building as possible.
3. Propose and simulate solutions that change the building envelope and reduce the amount of energy required to heat and cool the building to comfortable temperatures.

3.5.2 Energy Analysis Methodology

Once the BIM was imported into Ecotect as outlined in Appendix D, our group prepared the model so that it reflected the existing conditions. Our group encountered some errors and troubleshooting involved in getting Ecotect to run, and these are listed in Appendix E. Preparing the model included

- loading the correct weather data
- calculating the zone volumes and internal adjacencies
- performing a solar access analysis to calculate the solar insolation
- Adjusting the thermostat range

The weather data used for the Ecotect analyses in this project was from the United States Department of Energy for the Worcester Regional Airport location. Worcester Regional Airport is less than three miles from Worcester City Hall, and the Department of Energy recommends using weather data relatively close to the actual site is acceptable as long as the elevation difference between the two sites is no greater than 200m (EERE). The DOE weather data assumes “typical conditions,” so minor irregularities in the future should not affect the precision of the weather data. However, it does not take into account extreme weather conditions, and the DOE does not recommend modeling for extreme conditions (EERE).

Our group ran analyses in Ecotect using the lowest settings for each type of analysis (calculation of the zone volumes and internal adjacencies and solar access analysis) and found it made a negligible difference to the output data. However, the calculation of shading marks was included because it affects how much heat goes through the simulated building. Based on our group’s observations of Worcester City Hall, the Ecotect analysis was run assuming a few parameters. The maximum amount of people per square meter was in general assumed to be 2 people per 20 square meters; the supplemental file listed in Appendix I “Room labels and people content” lists the exact number of people per room. Our group also assumed a thermostat range of 68 degrees Fahrenheit up to 75 degrees Fahrenheit, a range that was regulated by full air conditioning that was on between the hours of 7am and 6pm.

After running the analyses, our group compared the energy usage of the virtual model to that of the actual Worcester City Hall and calculated the percent error. These results are presented in Chapter 4.2. Our group then attempted to identify any discrepancies with the BIM model, adjusted the model, and reran it in Ecotect. Changing rooms, such as vaults, so that they did not have air conditioning made a minimal impact on the simulation results. However, the angle and elevation of the building had a considerable impact on the results. In the final analysis of the virtual model of Worcester City Hall, the building was set at an angle of -107.5 degrees off north and 545 feet above sea level.

Once a BIM model of Worcester City Hall had been constructed and adjusted to more accurately affect the actual building, our group made several modifications to the BIM that would potentially improve its energy usage. The three categories of modifications our group examined included the addition of insulation, the replacement of the single pane windows with double pane windows, and the adjustments of the thermostat temperature ranges. Within each of the categories were a series of similar modifications that were intended to compare small variations. For example, eight models of Worcester City Hall were created that varied only by the thickness of insulation that was added to each floor. A further exploration of these modifications and the results are in Chapter 4.2.

3.5.3 Cost Analysis

After analyzing the various models for City Hall and determining what models have an energy savings, a cost analysis based on the savings and the estimated installation costs were conducted. This cost savings analysis assumed a 4% inflation rate for oil. Although ESCO is ultimately interested in the cost savings over a 20-year period, the period for cost savings in this report ended in August 2017 due to the repeating nature of the month-by-month analysis; cost saving modifications could be identified by August 2017.

The installation costs were estimated using RSMeans, a trusted construction estimating standard publication available through Worcester Polytechnic Institute Gordon Library (Balboni, 2010). The national average prices were then adjusted based on the state of Massachusetts' index as it compares to the national average in construction (Pray, 2011). Based on both the cost for installation and the cost savings, the most cost effective modifications according to the simulations were identified.

Chapter 4: Results

4.1 The BIM model

The BIM model of Worcester City Hall was constructed based on the AutoCAD drawings obtained from ESCO. Figure 5 below shows that the interior plans are mirrored very closely in the AutoCAD drawings. However, it is evident that there are some differences. For example, Figure 5 shows some exterior wall columns while the walls in the Revit model are smooth. This is because exterior details such as this will not significantly affect the outputs of the simulation (Autodesk Ecotect Analysis 2010 Questions and Answers, 2009).

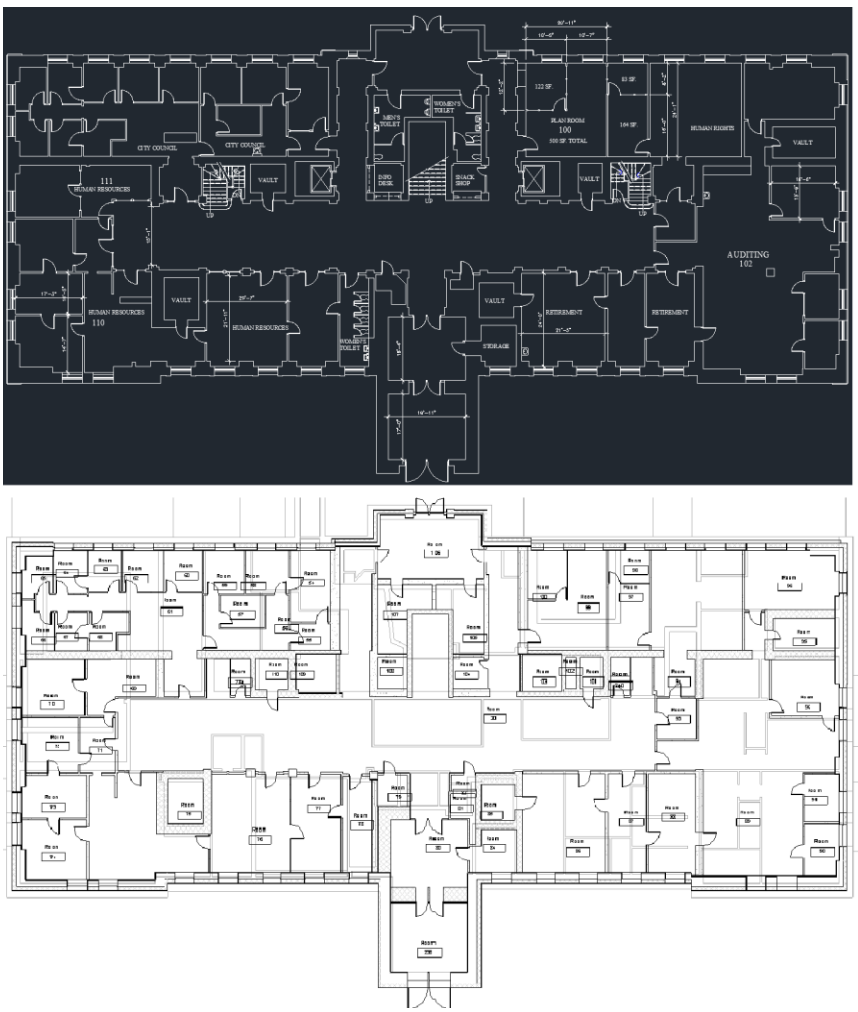

Figure 5: AutoCAD drawing (top) and Revit plan view (bottom)

The exterior walls' simplicity is also convenient for thermal analysis purposes. The group members found that by simplifying these walls, the number of errors that arose while converting the .rvt file generated by Revit to the .gbXML used by Ecotect decreased. Additionally, the simpler exterior walls made it easier to identify any problems that arose.

Some of the walls in the Revit model may not necessarily be accurate with respect to the components making up the wall. For example, some walls on the basement floor were very thick (as shown in Figure 6) and as a result were difficult to identify.

Figure 6: A 3-foot cross section of a basement wall on the eastern side of the building

The walls of Worcester City Hall were divided into three different types. The first type was the exterior walls. These were assumed to be comprised of at least a foot of concrete, an air gap, and wood paneling. The amount of concrete in the wall varied based on the thickness of the wall, a value that was easily verifiable in the blueprints our group was given by Worcester City Hall.

The second type of wall was the interior wall. With some exceptions, every wall in the building was assumed to be made of gypsum board (or drywall). The thickness of each interior wall was again based on the blueprints of Worcester City Hall. Figure 7 illustrates the general appearance of the walls within Worcester City Hall.

Figure 7: A typical hallway in Worcester City Hall

The last type of wall that was used to construct the BIM of Worcester City Hall was solid concrete. This wall type was reserved for the elevator shafts, the main atrium of the building, the clock tower, and the vaults. A picture of a concrete wall cut out for the door of a vault is shown in Figure 8.

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Figure 8: A cross-section of the wall surrounding a vault

The group members modeled a total of 200 rooms in the Worcester City Hall BIM. These rooms were verified to have no gaps in them upon export, which allowed for quick analysis within Ecotect.

4.2 Energy Analysis Results

Once the BIM file was complete, it was exported to Ecotect Analysis. Before the energy usage could be verified, the group members conducted a Solar Access Analysis simulation to verify insolation on building surfaces. Figure 9 shows the preliminary visual calculation of the insolation facing the east view of the building. Figure 9 will remain the same for any updates or internal reinforcement to the building as long as the overall shape of the building does not change. High levels of insolation are concentrated on the southeast side of the building, which is logical because the sun rises in the east and radiation is strongest in the late morning and early afternoon (Sun Safety Alliance).

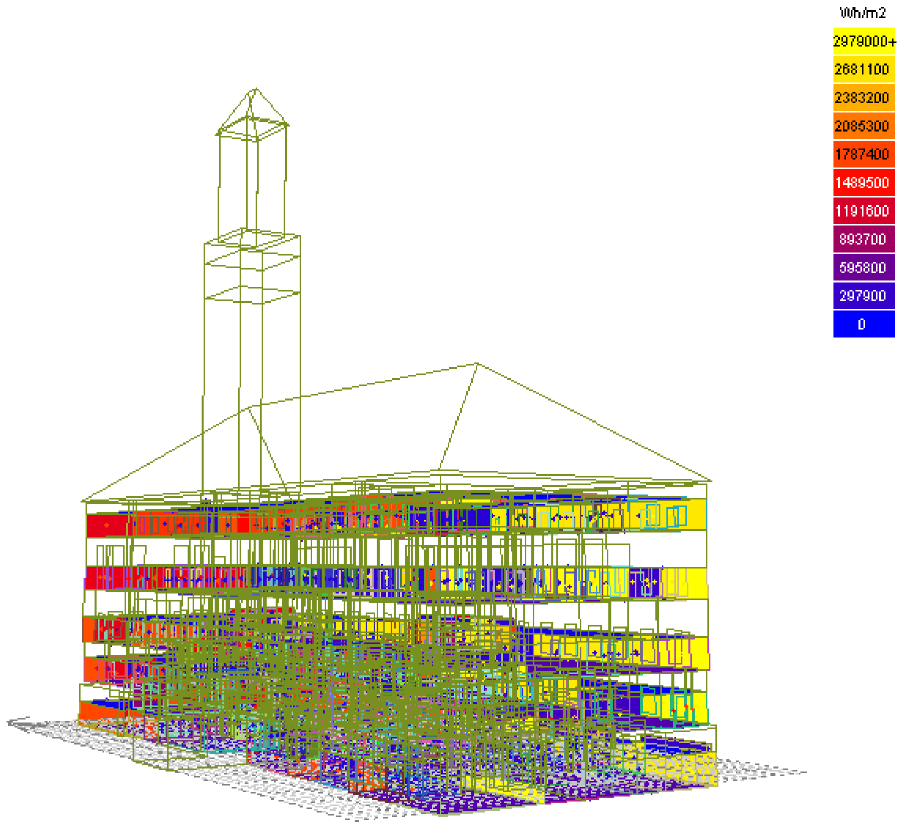

Figure 9: Display of solar radiation intensity on the model walls in Ecotect

The model was verified for precision compared to the values given by Worcester City Hall using a Monthly Loads/Discomfort calculation. The graph in Figure 10 shows the energy used every month to keep the building between 68.0 degrees Fahrenheit and 75.0 degrees Fahrenheit. A table containing the numerical values associated with this graph is located in Appendix F. The red bar in the graph indicates the amount of energy used for heating (in BTUs), and the blue bar indicates the energy used for cooling (in BTUs). Each of the bars across the x-axis represents a different month of the year with January being the bar of the far left. The blue bars below the red values is to separate itself from heating loads, but all of the values on the graph are positive excluding zero.

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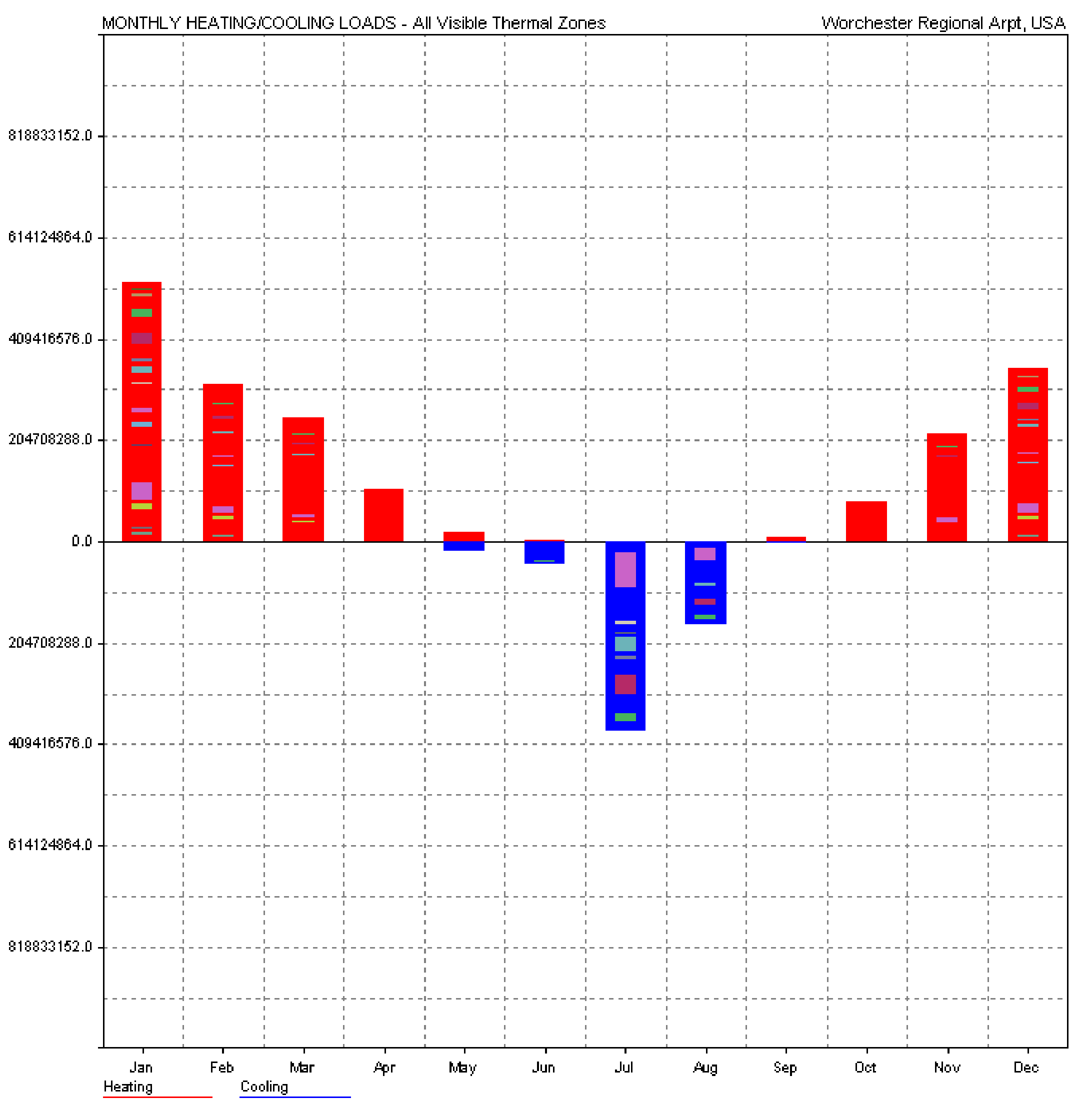

Figure 10: Monthly heating and cooling loads for existing conditions model

According to the preliminary Ecotect model simulation displayed in Figure 10 and the numerical results listed in Appendix F, the most heat is needed in January (524,537,888 BTUs or 524.5379 MBTUs) and the most cooling is needed in July (381,576,736 BTUs or 381.5767 MBTUs). The building uses an average of 2499.4615 MBTUs per year. In comparison to Worcester City Hall's average oil usage over a 33-month period in Appendix G, the preliminary Ecotect model has a 34.01% variance.

After speaking with Worcester ESCO representatives, the variance may be a result of ideal conditions not being met. Ideal conditions not being met could include, but not be limited to:

- Open windows
- HVAC systems running outside of business hours and on weekends
- Conferences in the Worcester City Hall resulting in an increase in the amount of people in the building
- Atypical weather conditions in Massachusetts from November 2011 to March 2012
- The absence of a weather strip along the windows
- The exclusion of ventilation fans, specifically Worcester City Hall's main fan that circulates air at a rate of 20,000 cfm

When testing out what the savings would be when replacing small single-pane windows with double-pane windows, the BIM was edited and re-imported into Ecotect. As stated earlier in the report, the insolation or solar radiation on the building did not change at all because the overall shape of the building remained the same. The temperature range and number of people per room also remained the same. Figure 11 shows that although the monthly heating increased overall due to the window replacements, the cooling loads decreased dramatically. The annual energy usage was 2,600,784,640 BTUs, or 2600.784 MBTUs (see Appendix F for more detailed results). Energy loads do not decrease compared to the original model in the calendar year until May, and these reduced energy use loads stay relatively low until October.

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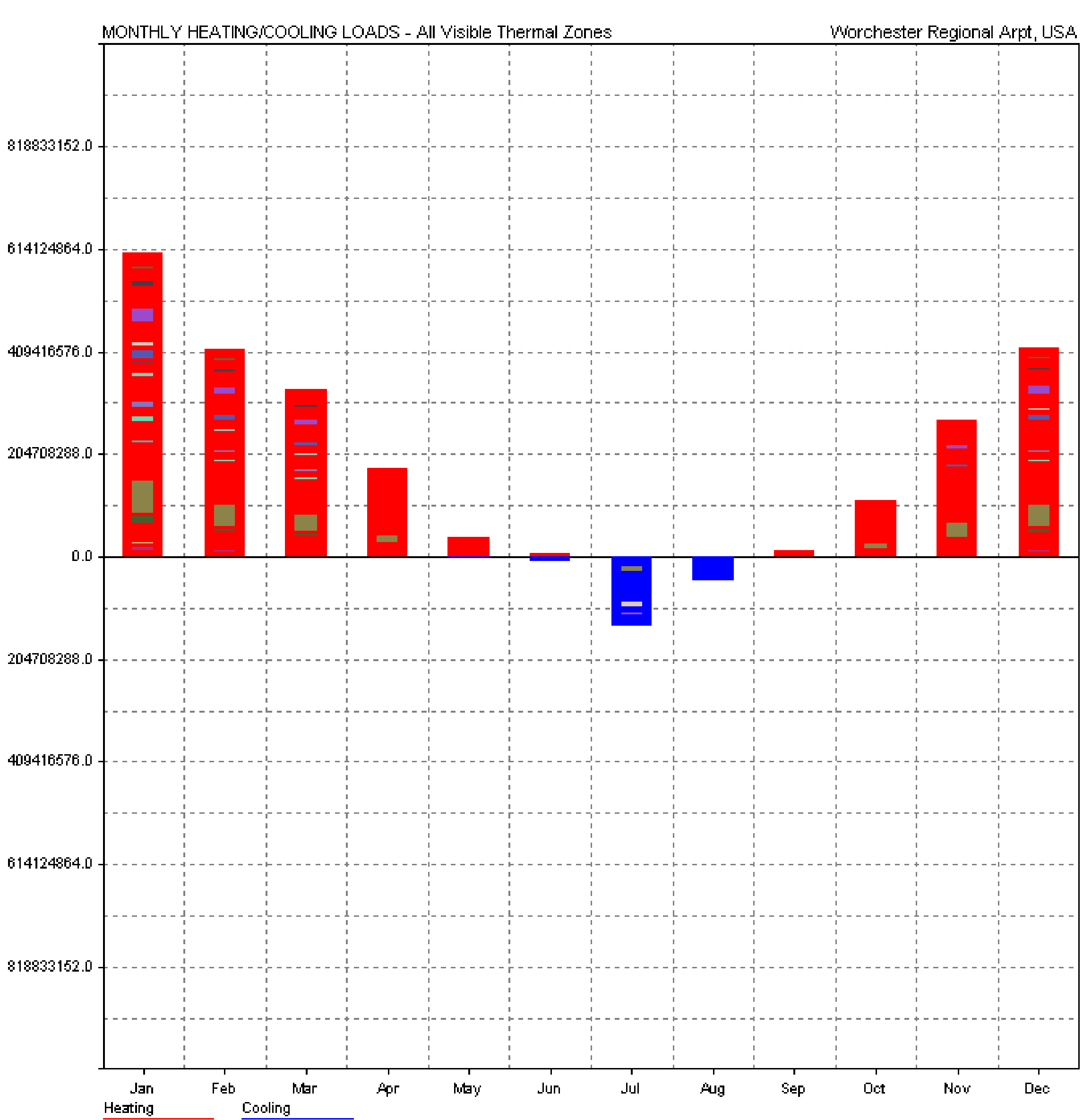

Figure 11: Heating and cooling loads for replacing all of the small windows with double pane

Ecotect did not respond to double pane windows being placed in different locations. The output for replacing windows on the warmer East side of the building had the same exact value on the West side.

The other modifications to Worcester City Hall, specifically the addition of insulation and the modification of the comfort bands within the building, varied in effectiveness but the results followed the same cooling trend as shown in Figure 11. Detailed results by month are in Appendix F. Results by year are in Table 2. A positive percent variance in the table indicates the associated modification caused an increase in energy usage when compared to the energy usage by the simulation of the unaltered Worcester City Hall. A negative percent variance in the table indicates a decrease in energy usage.

Table 2: Chart comparing the energy usage of potential modifications to Worcester City Hall

Modification	Mbtu/yr	% variance compared to initial
Average Actual Conditions	3788.1533	N/A
Initial model	2499.4615	N/A
Comfort band down one degree(67F-74F)	2570.0279	2.82%
Comfort band up one degree (69-76F)	2464.692	-1.39%
Double pane windows	2600.7949	4.05%
1 inch insulation 1st floor	2476.7585	-0.91%
2 inch insulation 1st floor	2476.7806	-0.91%
3 inch 1st floor	2476.7584	-0.91%
3 inch 2nd floor	2476.4695	-0.92%
3 inch insulation 3rd floor	2476.7586	-0.91%
3 inch insulation 4th floor	2766.6984	10.69%
1 inch insulation Attic	2476.7814	-0.91%
2 inch insulation Attic	2476.7805	-0.91%
3 inch insulation Attic	2604.3679	4.20%

4.3 Cost Analysis

A cost analysis using a 4% Annual Minimum Rate of Return was assumed over a 53-month period compounded monthly starting in March 2013. Some modifications that we thought would be effective showed a negative effect instead, but overall there were some trends among the entrance floor and the attic. The full Cost Analysis for all of the modifications showing the results after each month can be found in Appendix H.

4.3.1 Comparison of expected costs to actual and effectiveness

The summary of the cost analysis between the initial model and the modifications in Table 2 shows that the average Actual Conditions over the period is much higher than the initial model. Decreases in the cost compared to the initial model are highlighted in green and increases in the cost compared to the initial model are highlighted in red.

Table 2 depicts a positive trend with insulating the first floor, second floor, third floor, and the attic. The results of the attic showed a positive trend as the insulation increased. However, the cost to operate the building decreased once 3 inches were added (the equivalent of an R-value increase of 4). The entrance floor showed a consistently positive trend as the building was insulated more. This may be due to greater occupancy on that floor.

Table 2 does not show a positive result on the fourth floor. This may be due to a smaller use on the fourth floor. Additionally, increasing the comfort band for all of the rooms one degree showed a positive trend in the energy use. This suggests that it takes more energy to cool a building than it does to heat a building since the cooling costs had the highest savings.

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Table 3: Summary of Cost Analysis between Initial model and Simulated Modifications to Worcester City Hall

Suggestion	Mbtu/yr	Cost Mar 2013-Aug 2017	Lower than initial model?	Decrease
Average Actual Conditions	3788.1533	$569,336.54	N/A	N/A
Initial model	2499.4615	$368,538.09	N/A	N/A
Comfort band down one degree(67F-74F)	2570.0279	$382,897.56	No	N/A
Comfort band up one degree (69-76F)	2464.692	$361,011.65	Yes	$7,526.44
Double pane windows	2600.7949	$373,484.87	No	N/A
1 inch insulation 1st floor	2476.7585	$365,648.92	Yes	$2,889.17
2 inch insulation 1st floor	2476.7806	$365,652.05	Yes	$2,886.04
3 inch 1st floor		$365,582.83	Yes	$2,955.26
3 inch 2nd floor	2476.4695	$365,582.83	Yes	$2,955.26
3 inch insulation 3rd floor	2476.7586	$365,648.92	Yes	$2,889.17
3 inch insulation 4th floor	2766.69835	$398,496.22	No	N/A
1 inch insulation Attic	2476.7814	$365,648.92	Yes	$2,889.17
2 inch insulation Attic	2476.7805	$365,648.92	Yes	$2,889.17
3 inch insulation Attic	2604.3679	$375,669.34	No	N/A

4.3.2 Effectiveness of cost saving measures

The cost savings up to August 2017 shows up to a cost savings of $2,955.26 with implemented modifications in Table 3. To analyze what the cost difference was after installation in Table 4, RS Means 2011 was used to obtain a square foot price for installing blown cellulose, the preferred material for insulating Worcester City Hall (Balboni, 2010). It was also updated with a 4% assumed inflation increase and a 14% increase for the state of Massachusetts (Pray, 2011). The square footage of each floor changes the overall cost to install the floor, and the R value is comparable to simulating the 3 inch insulation in Ecotect. The actual square foot value on each floor was rounded up to the nearest hundred to account for possible errors with the material upon installation. As shown in Table 4, the largest cost difference was on the second floor with a cost benefit of $1,839.26 at the end of August 2017.

Table 4: Cost to Install 3.5 inch Blown Cellulose per floor (according to RS Means)

Floor	Cost to install per ft (07 21 26.10 Blown Cellulose Insulation in RS Means 2011 with 14% inflation for MA)	Square feet	Cost to install on floor	Cost benefit through August 2017
First	$0.62	1900	$1,178.00	$1,777.26
Second	$0.62	1800	$1,116.00	$1,839.26
Third	$0.62	1800	$1,116.00	$1,773.17

Chapter 5: Conclusion and Recommendations for Future Work

5.1: Review of Project

This project involved digitally recreating the Worcester City Hall within a building information modeling program and adjusting the model to be more energy efficient. Our group found that there are many ways in which a virtual model of Worcester City Hall may be recreated to become energy efficient and we recorded the impact that each modification had on the energy output. The resulting recommendations are listed below.

5.2: Recommendations

The following recommendations are based on the results of the initial Ecotect model and the modified Ecotect models. Overall, the group recommends that, based on the trends seen in the results, insulation be added to Worcester City Hall.

5.2.1 Best Value Renovations to Worcester City Hall

Due to the trend based on the cost analysis in Table 2, insulating the first, second, and third floor is highly recommended. While some insulation is possible, the MQP group recommends installing blown cellulose with an R value of at least 12 on these floors. Additionally, the cost to install these is relatively inexpensive and results in a cost benefit in less than a five-year period. However, it is recommended that the City of Worcester considers that there may be a preparation cost separate from the installation cost. Regardless, ESCO would like a 20-year payback period for their solutions, so it is possible to make a profit within a fraction of that time.

The group also advises to use caution when installing blown cellulose in the attic. According to the Ecotect model, an R value increase greater than 8 could result in an increase in the costs. Therefore, it may not be beneficial to put as much insulation in the attic as possible.

Rather, it would be ideal to focus on increasing the insulation on the first, second, and third floors.

The model has been simulated according to the best of the project group's ability. However, we also recommend future improvements on the building, such as observing the contents of individual walls and floors to obtain a more accurate R value. We also recommend monitoring the actual operating conditions more closely to observe the variance between operation and the simulation.

5.2.2 Future research

This project only took into account the thermal efficiency of the building. Future projects may look at other items that factor into energy usage such as the HVAC system, electrical usage, or lighting. Additionally, future projects can also look into the usage of green technologies such as solar panels.

The model of Worcester City Hall used in this project may or may not be accurate. At the time of this project, our group was unable to identify the interior components of the walls and as such had to make assumptions when creating the BIM. Future project groups may want to find the actual composition of the walls and update the model as needed. Future groups may also add systems to the model, such as duct systems. Rooms above the fifth floor are not accounted for in this model either; future groups may want to add the rooms above the main floors of Worcester City Hall for a more complete design.

5.2.3 Other uses for Building Information Model

The Building Information Model created in this project does not necessarily need to be used just for energy analyses. This model may also be used for renovations to the building. If a certain aspect of the building needs to be modified, especially on the exterior, the Revit model can quickly and efficiently display the impacts of the change. If applicable, these renovations can also be examined for their impact on the energy usage of the building.

Project groups specializing in architecture have many opportunities to improve the model to better reflect the current conditions at Worcester City Hall. The current model is optimized for energy analyses and as a result is very simple. It can be visually improved upon through the modification of the exterior of the building, specifically on the envelope through additions such as arched windows and decorative molding. The landscape surrounding the model is currently barren and can be improved with the addition of foliage, road, stairs, and possibly the nearby parking garage. The interior of the model can be made more visually appealing with the addition of components such as stairwells and furniture. If the model is architecturally accurate, it may be useful in deciding potential architectural renovations or furniture layout.

The BIM model may also be adjusted to provide a structural profile of the building. Autodesk Revit has the ability of adding components such as supports, and if an accurate structure is created the BIM model will then be able to report the stability of the building. Such an endeavor may be useful to determine whether or not certain major renovations to the building are safe.

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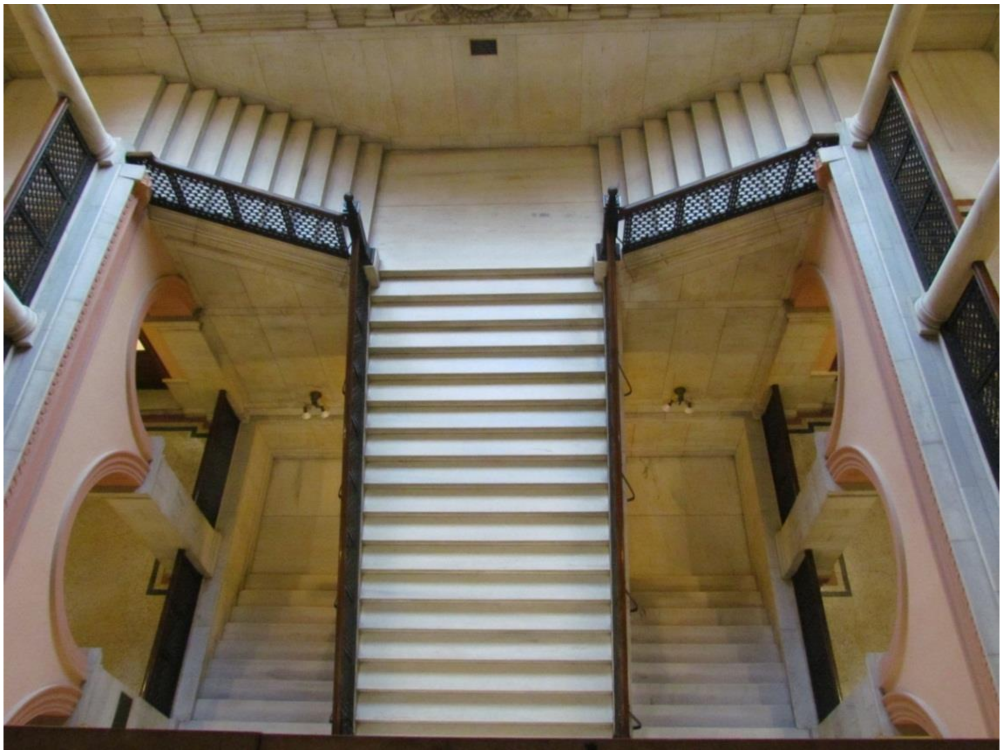
Appendix A: Photos of Worcester City Hall

North Wall of Worcester City Hall

Part of the East Wall of Worcester City Hall



Overhead View of the Atrium

Photo of a Typical Hallway within Worcester City Hall

Fifth floor of Worcester City Hall (the top of the Atrium is on the Left)

A Typical Room in the Basement

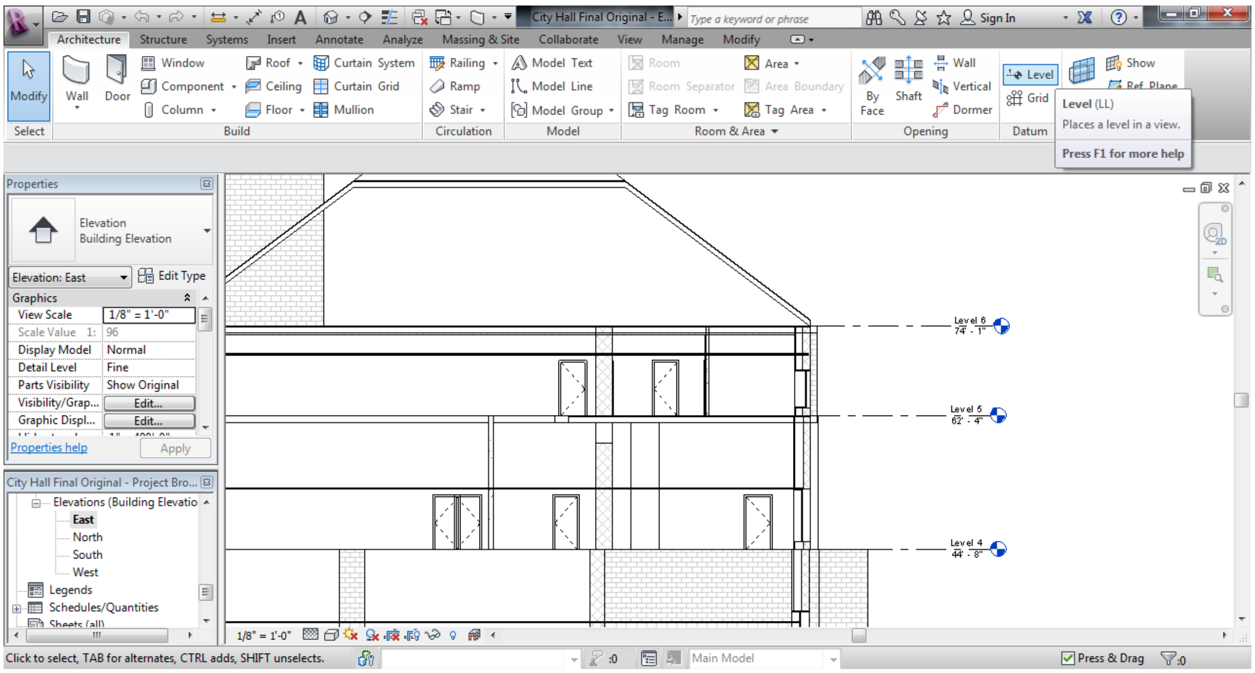
Appendix B: Schedule of Tasks

Task	Projected Start Date	Projected Finish Date
Define project task and scope	8/31/2012	9/14/2012
Gather information on conducting energy analyses	8/31/2012	9/21/2012
Choose an energy analysis software package	9/07/2012	9/21/2012
Analyze plans and specifications of building	9/27/2012	10/12/2012
Create BIM envelope using Revit Architecture	10/23/2012	11/21/2012
Preliminary energy analysis outputs	11/21/2012	12/10/2012
Progress meeting preparation and information gathering	12/10/2012	12/14/2012
Edit BIM	12/14/2012	1/10/2013
Energy analysis and comparison to actual costs	1/14/2012	1/21/2013
Modify model for precision	1/22/2013	1/29/2013
Modify model for efficiency	1/30/2013	2/22/2013
Cost analysis for efficient model	2/08/2013	2/22/2013
Identify future uses of BIM Model	2/10/2013	2/19/2013
Prepare report and presentation for Worcester City Hall	02/19/2013	2/28/2013

Appendix C: FAQ for Revit Troubleshooting

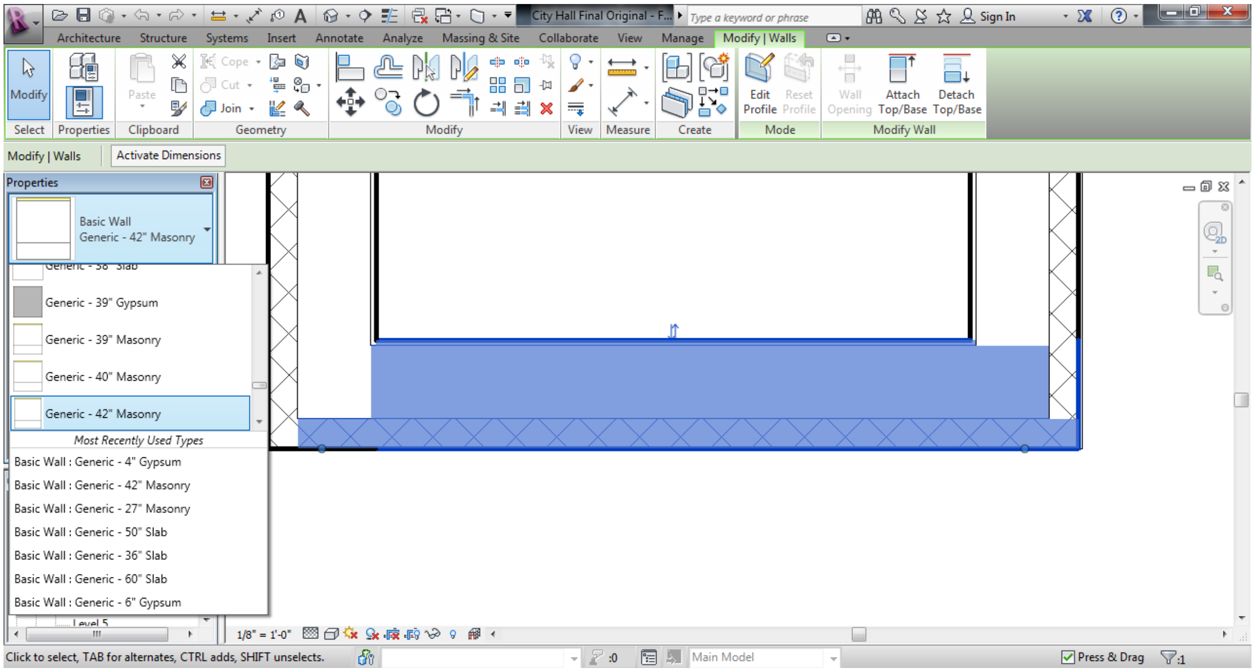
How can I make different floors?

Select one of the elevations in the view panel and select “Level” in the toolbar along the top of the screen.

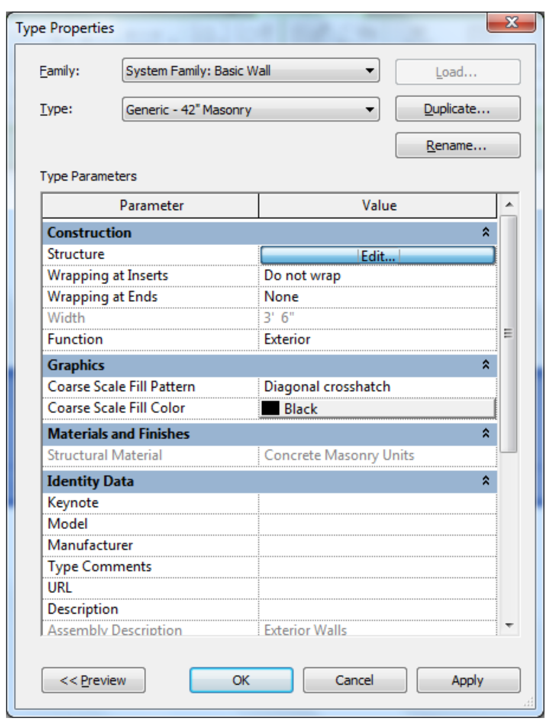


How can I change the makeup of a wall that is already created?

There are two ways to modify a wall. The first and more simple method is to select the wall by clicking it. After, you can change the wall type in the properties panel.

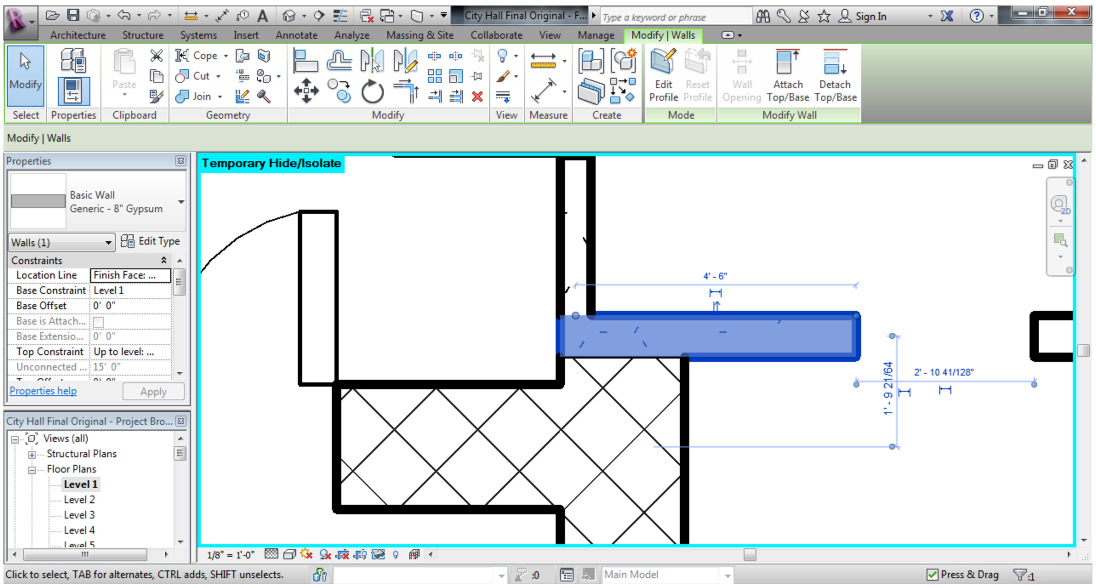


If the desired wall type isn't present, you can also select "edit type" on the properties panel. Doing so will open the screen below. By selecting "Edit…" under the construction section you can directly modify the composition of the wall.

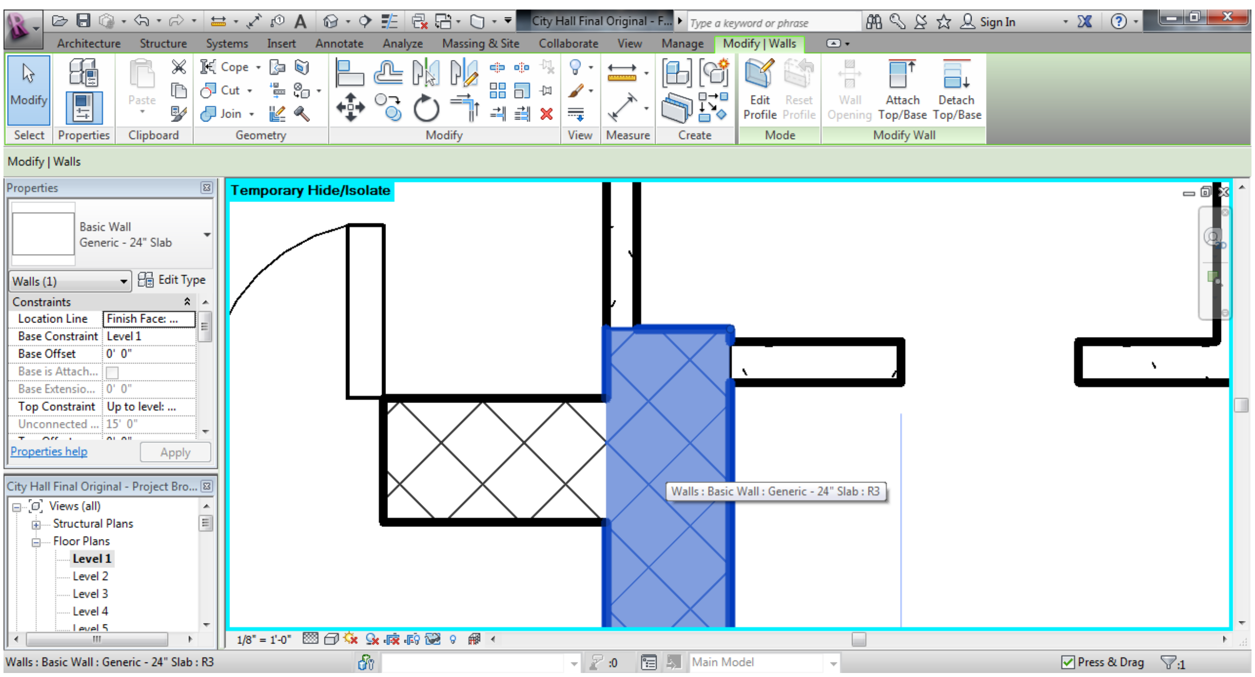


How should I attach interior walls?

Revit does most of the work in attaching walls together. However, in some cases it has difficulty attaching multiple-way intersections together. When making a section that has more than two walls joining in an area, avoid connecting walls end-to-end, only connect walls end-to-side. Connecting walls end-to-end results in air gaps along the exposed ends of the walls.



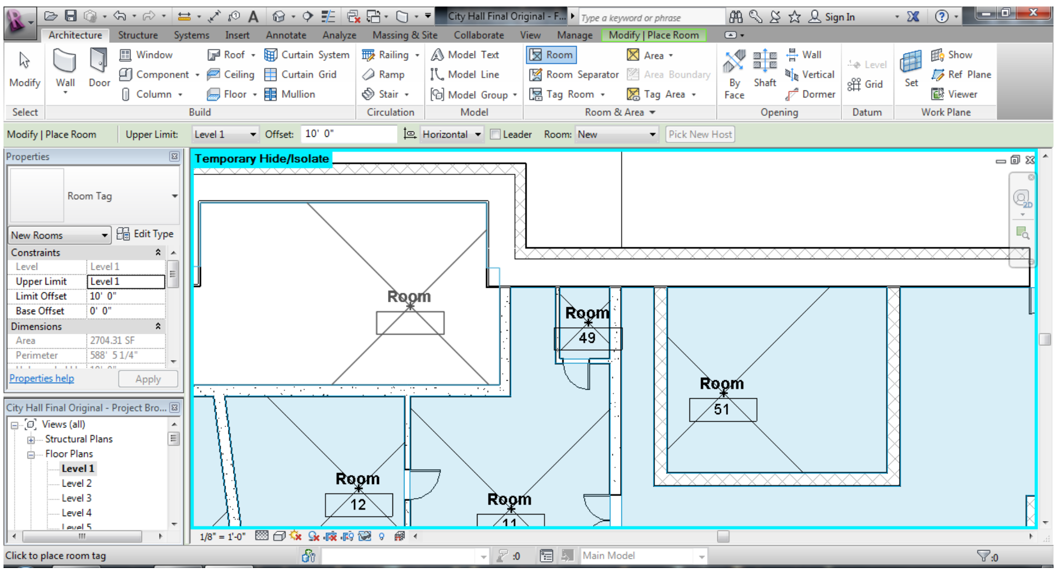
Example of a good connection



Example of an undesirable end-to-end connection

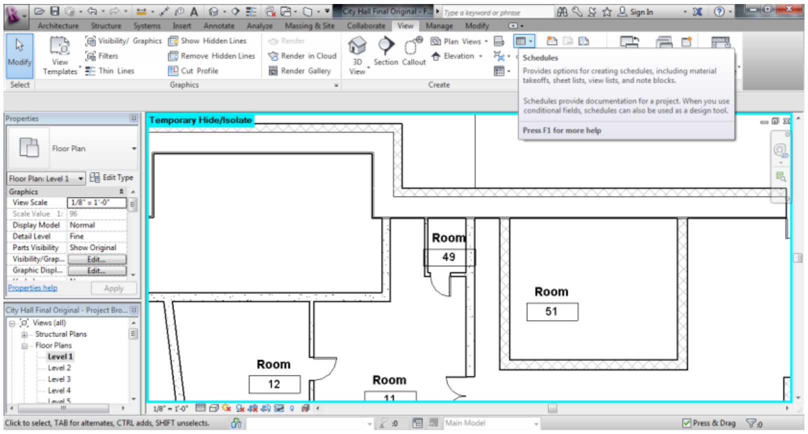
How do I establish rooms in Revit?

Rooms, which are used to analyze certain areas of the model in programs such as Ecotect, can be placed using the “Rooms” button on the Architecture tab. Rooms are placed by clicking the “Rooms” button and clicking the desired area. Revit will automatically find the walls surrounding the desired area and define them as the borders of the room.

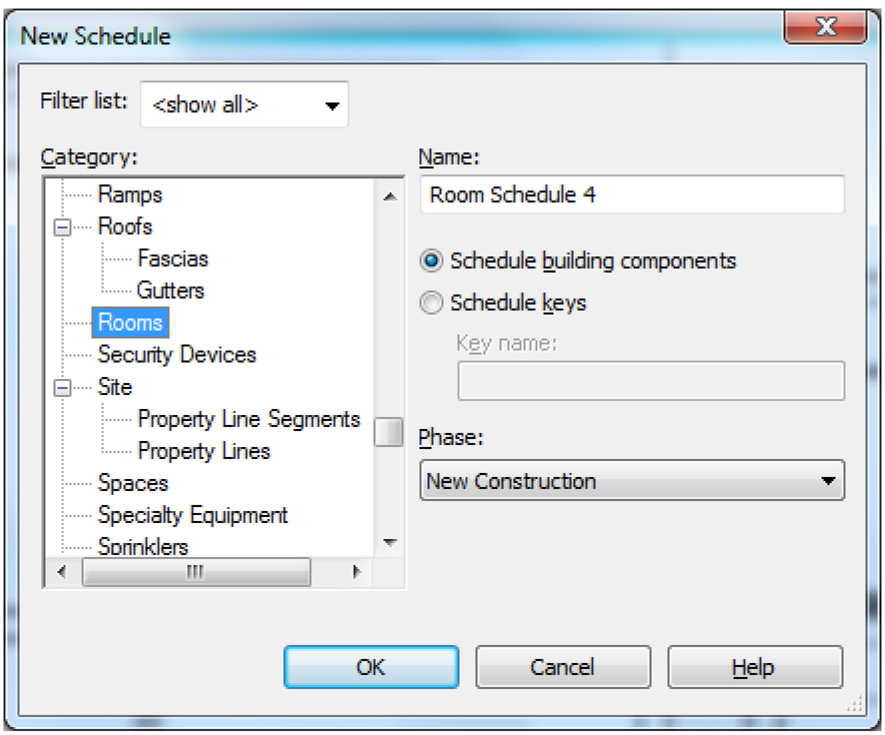


How do I delete rooms in Revit?

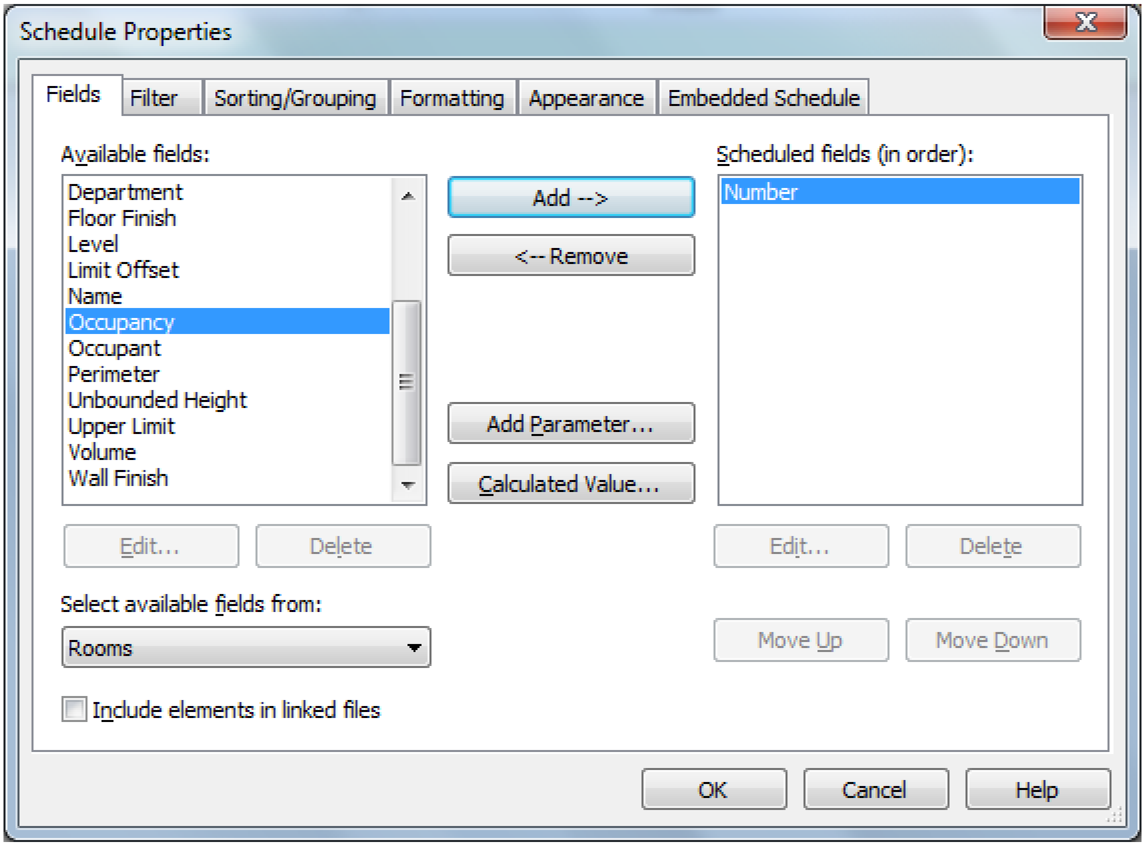
Rooms can be deleted by going to the “Schedules” and then “Schedules / quantities” button on the “view” tab.



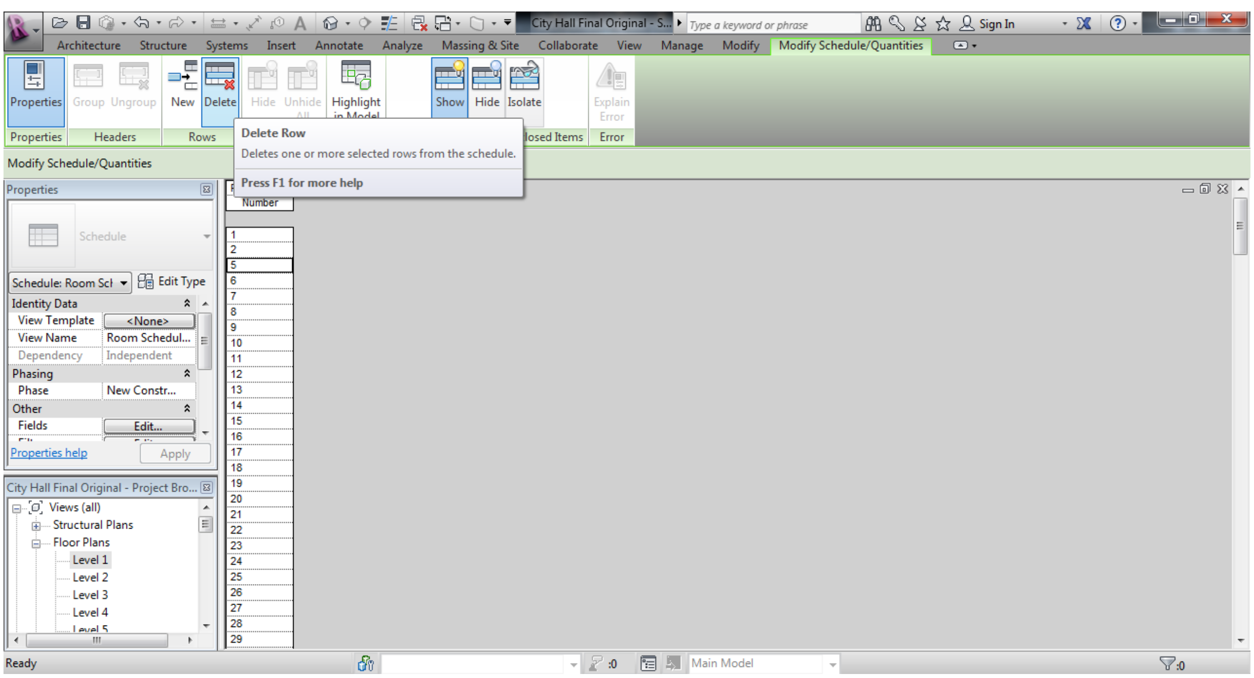
Select “Rooms” on the list that appears and click “OK”.



Add “Number” from the list of the left to the list on the right on the following screen.

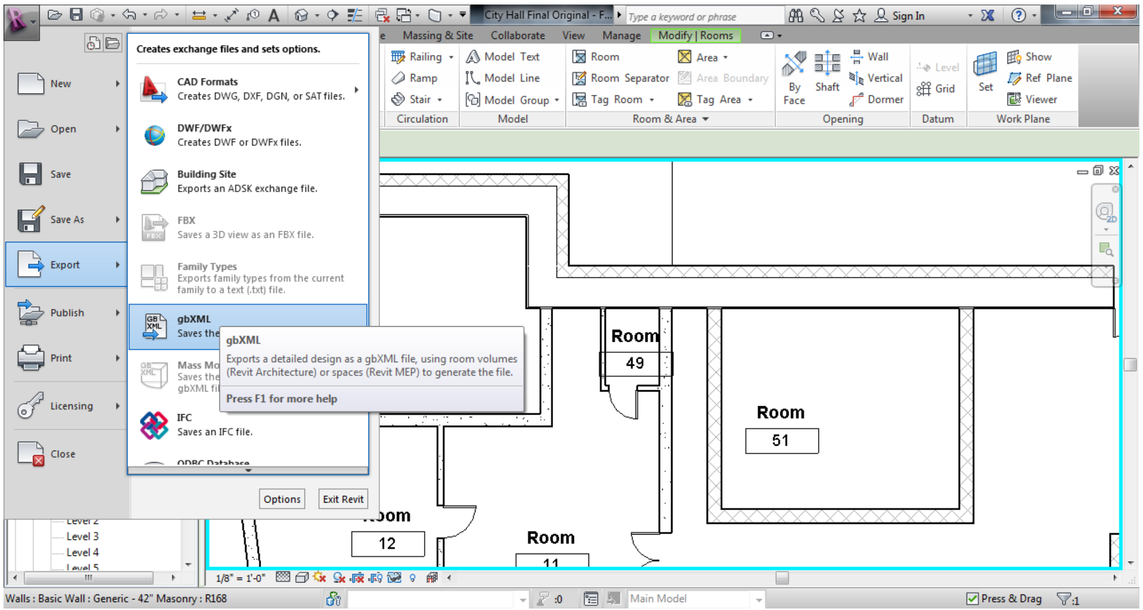


The resulting chart will display the room numbers. Select the room you want to delete and click "Delete".

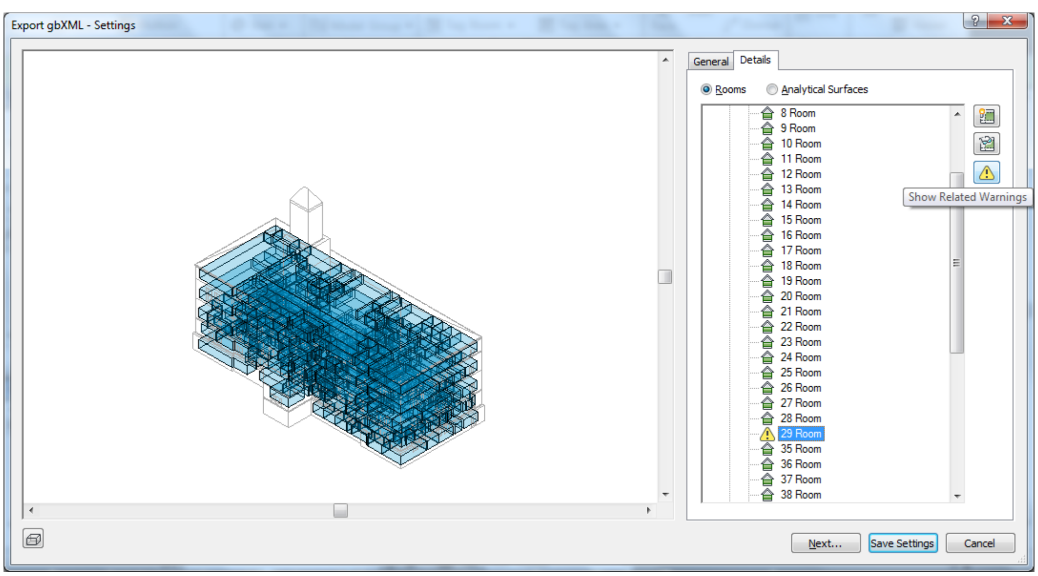


How do I export an error-free .gbXML model from Revit?

To export a model, click on the “R” in the top left of the screen and select “Export” => “gbXML” in the dropdown menu.

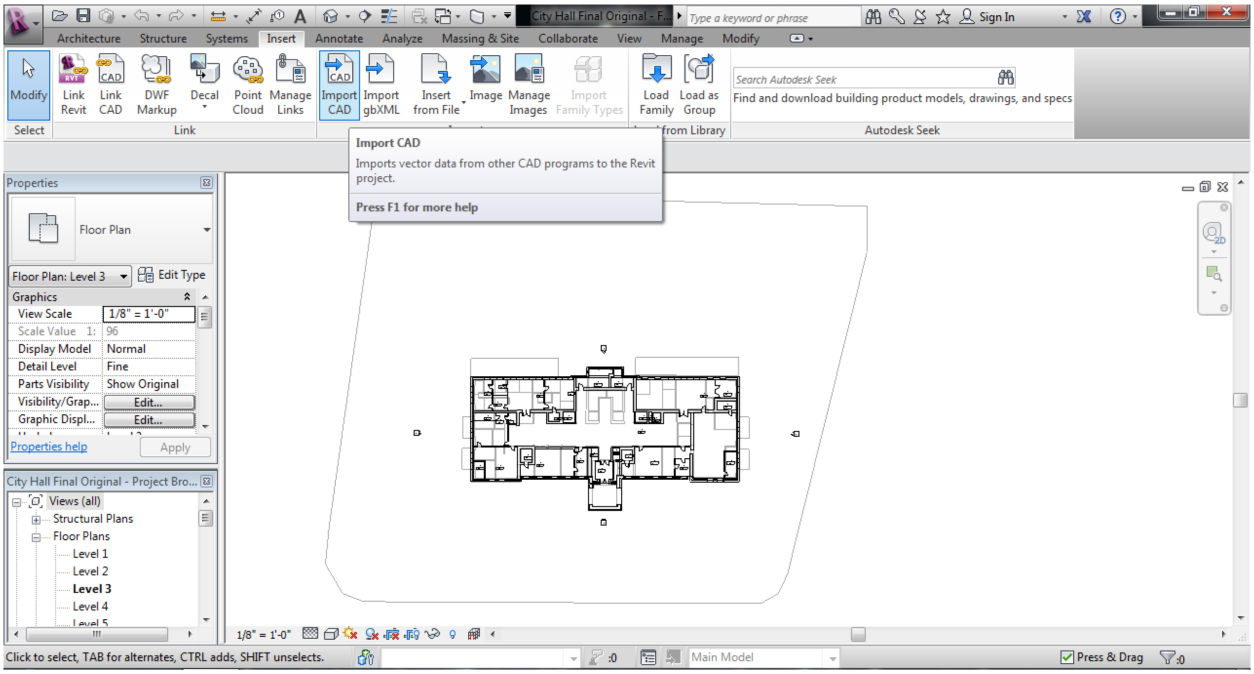


Select the “Details” tab on the resulting screen. There will be a list of rooms within the building and and rooms with errors will be marked with a “!”. These rooms can be examined in the model or the errors can also be reported using the “show related warnings” button on the right side of the screen. Once these errors are fixed, continue the export process by clicking “next” at the bottom of the screen. You will be prompted to choose a file location and after Revit will export the model for you. Note that examining the analytical surfaces of the model reveals any gaps in the structure. These can be sealed by increasing the sliver space tolerance on the “General” tab.



How do I import a CAD drawing into Revit?

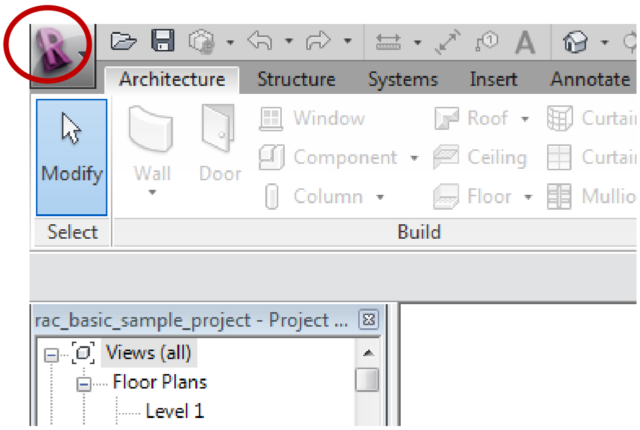
CAD drawings can be imported very easily using the “Import CAD” button under the “Insert” tab. Select the CAD file you wish to open on the resulting file directory screen and it will be loaded into Revit. The location of the CAD drawing can be moved using the mouse and options, such as the floor it is located on, can be adjusted using the properties panel.



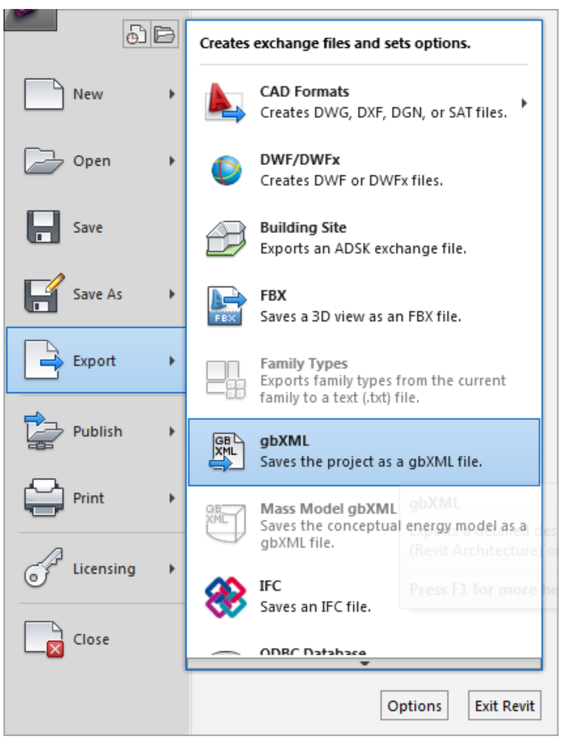
Appendix D: Importing Revit files in Ecotect

Transferring a model made in Revit to Green Building Studio or Ecotect:

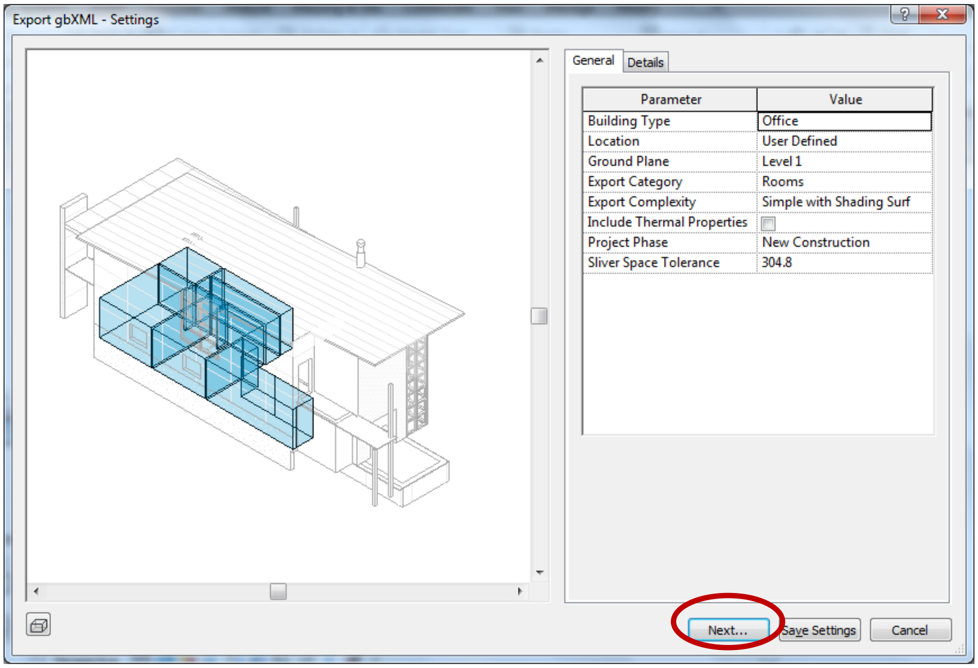
1. After constructing a model, click on the purple "R" on the top left of the screen.



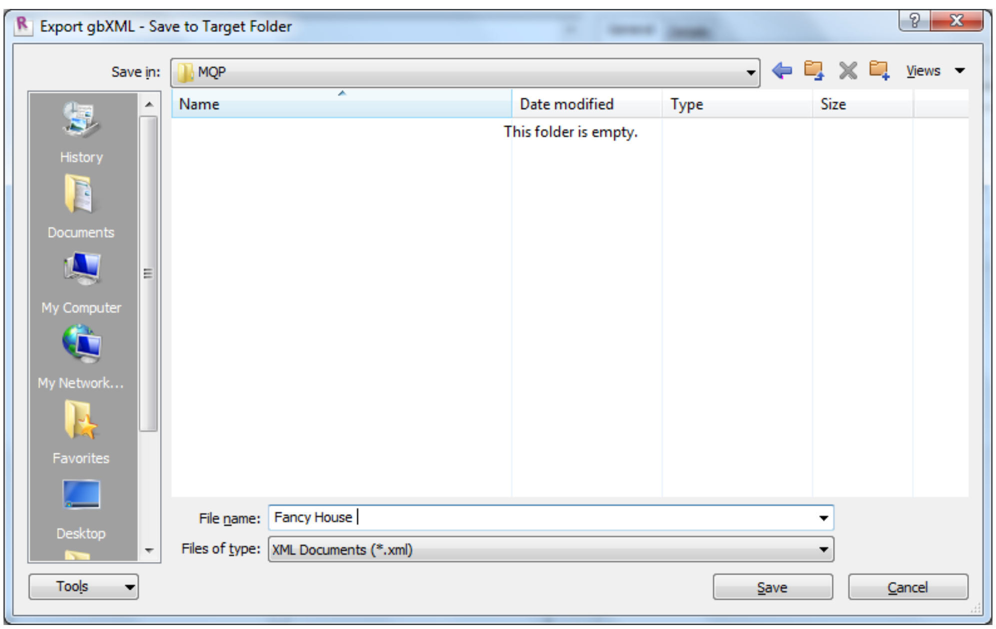
2. Follow the dropdown menu and go to "Export" -> "gbXML"



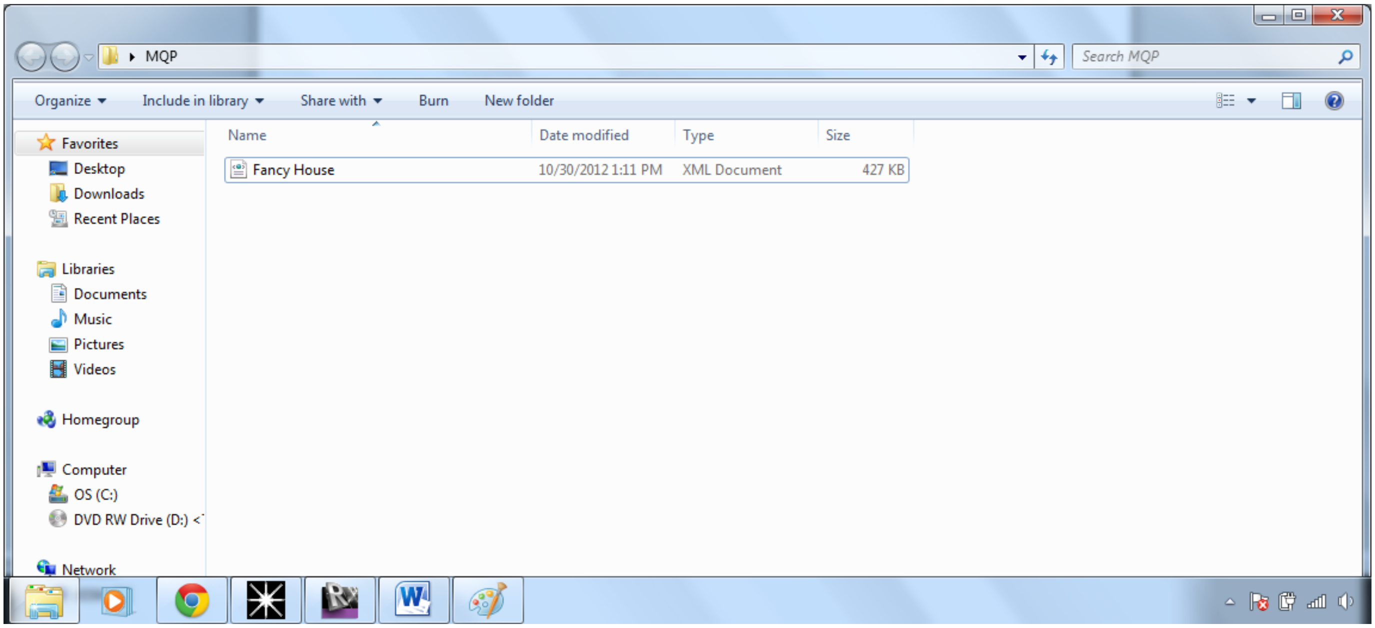
3. A screen will appear displaying the export settings. Click “next”.



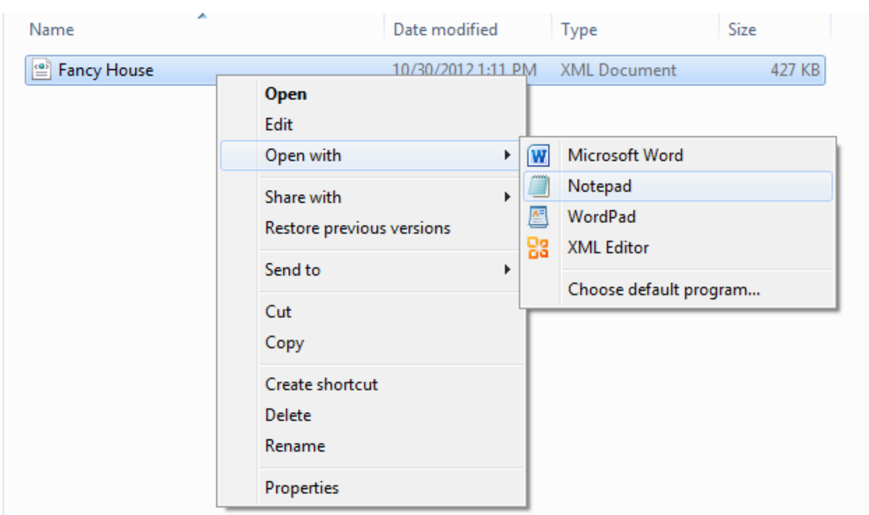
4. Save the file to a location that is easy to find, such the desktop. The file type should be .xml



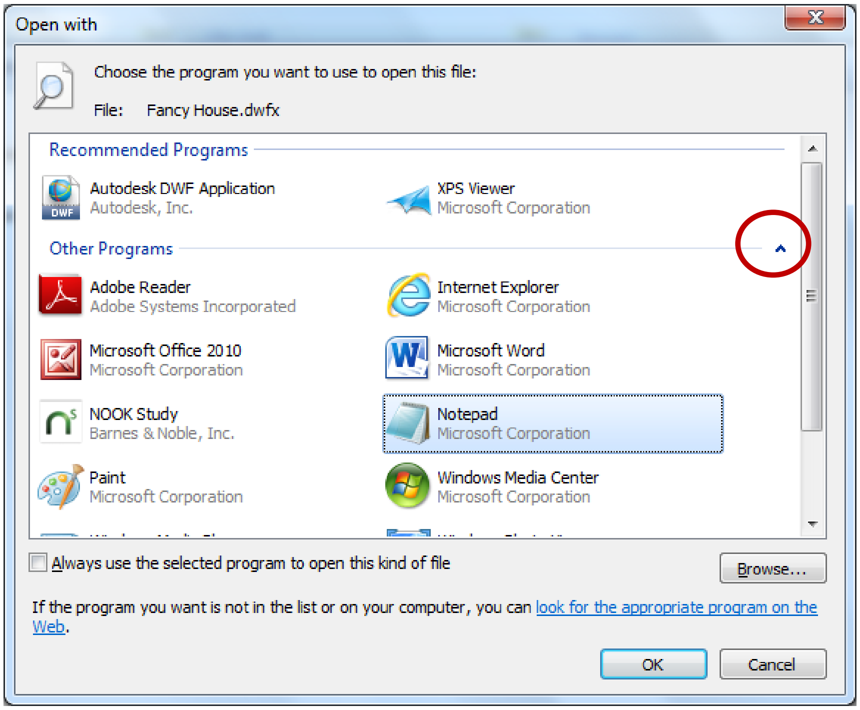
5. Leave Autodesk Revit and locate the file within the computer's memory.



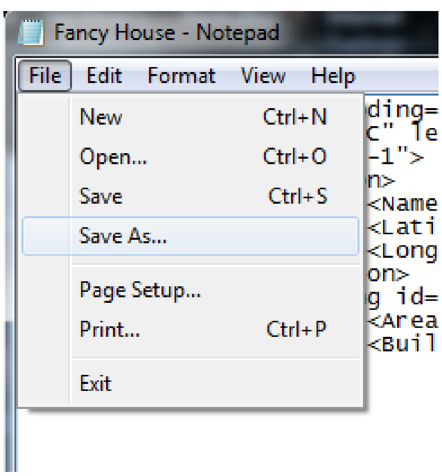
6a. Right click the file and select "open with" -> "notepad". If notepad is not available, either choose another available text editor or select "choose default program" instead.



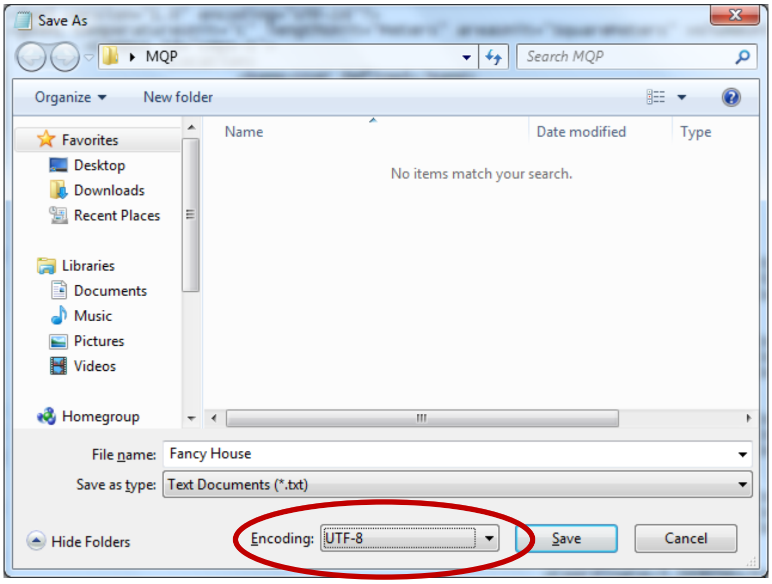
6b. Open with a text editor such as notepad (select the program and then click "ok"). If only a couple of programs are visible, there may be an arrow on the right side of the screen. Clicking on the arrow will reveal additional programs.



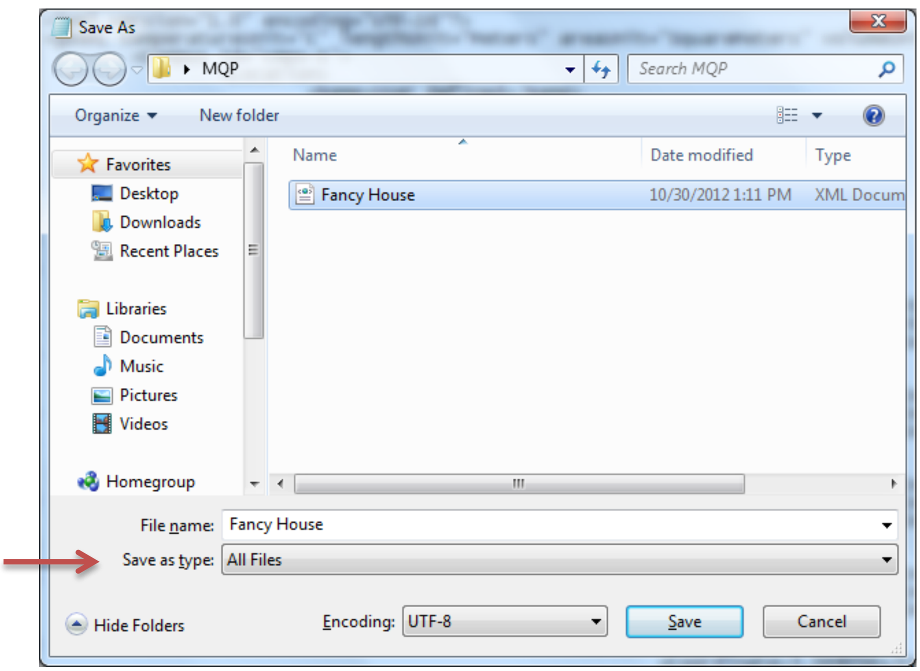
7. Go to "File" -> "Save As" in the text editor



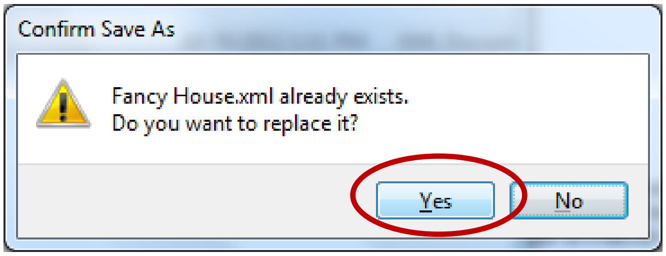
8. Change the encoding to UTF-8.



9. Change the "Save as type" to "all files".



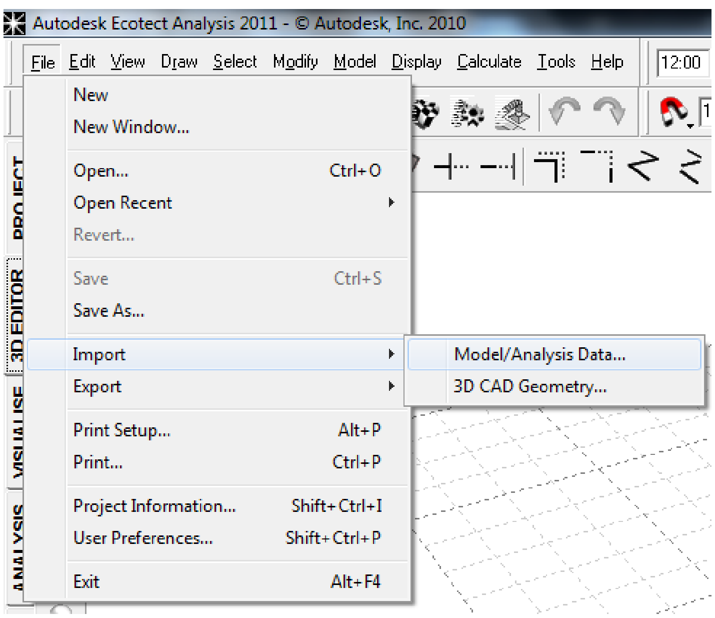
10. Double click the .gbXML file and replace it.



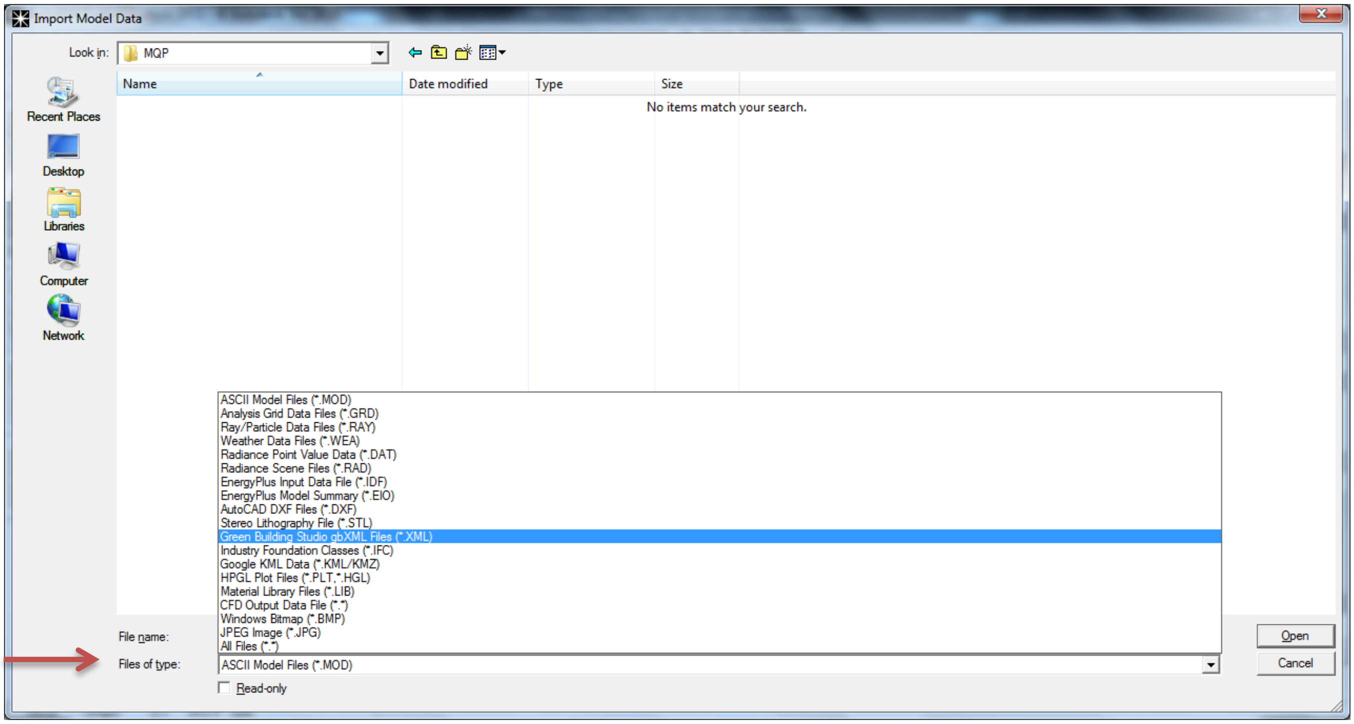
The file is now formatted so that it can be opened in both Green Building Studio and Ecotect.

Opening in Ecotect:

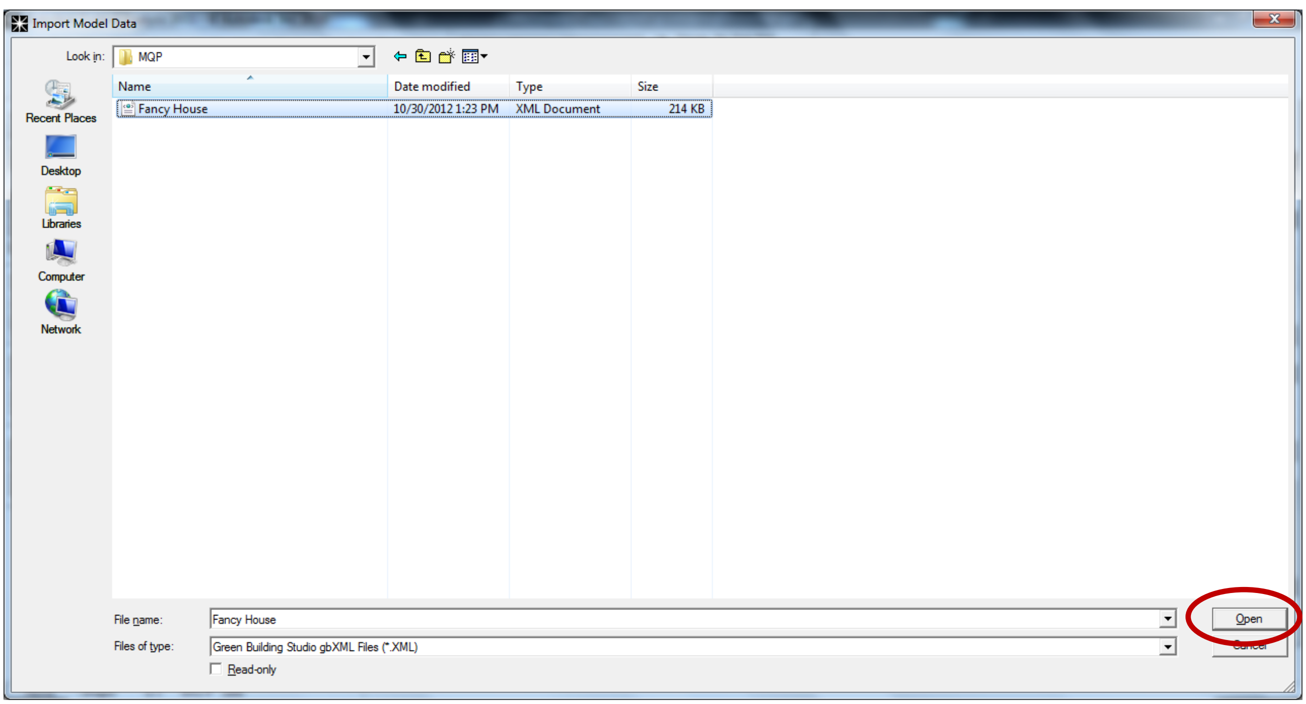
1. Go to “File” -> “Import” -> “Model / Analysis Data”



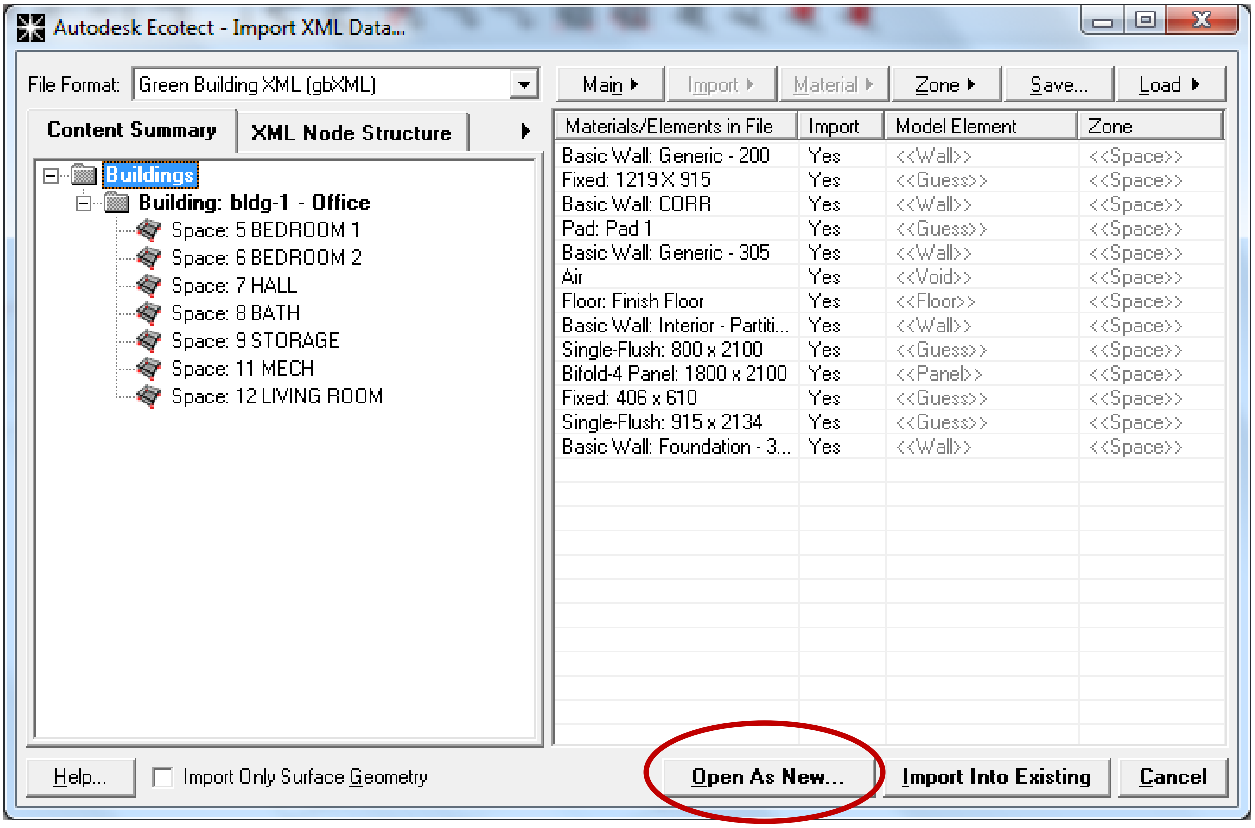
2. Change the “Files of type:” textbox to .XML



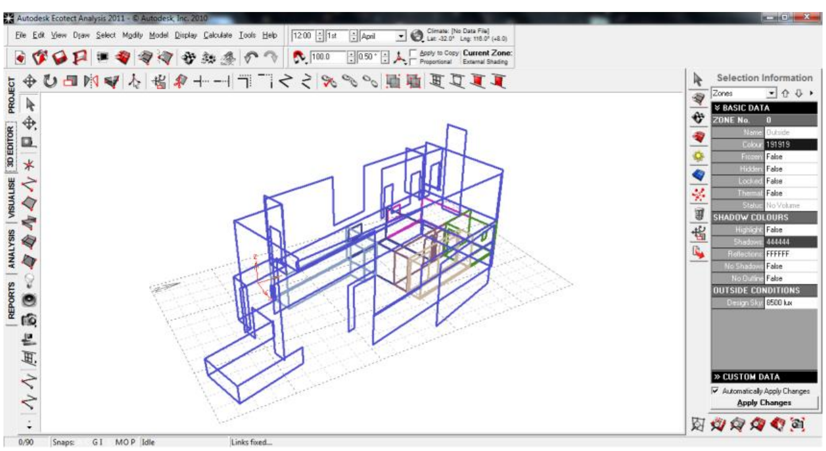
3. Select and open the desired file



4. Select “Open As New”



5. The geometry of the building should now be visible.

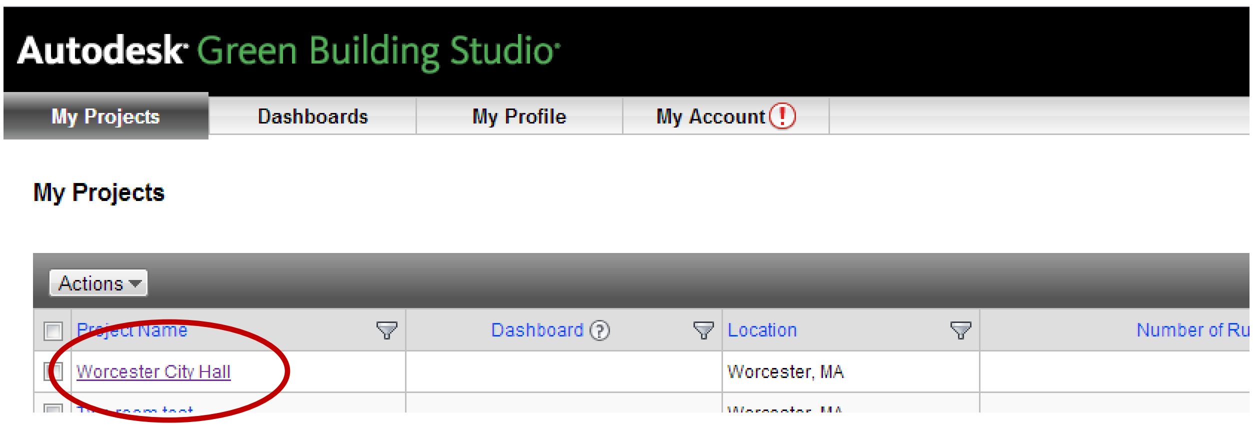


Opening in Green Building Studio:

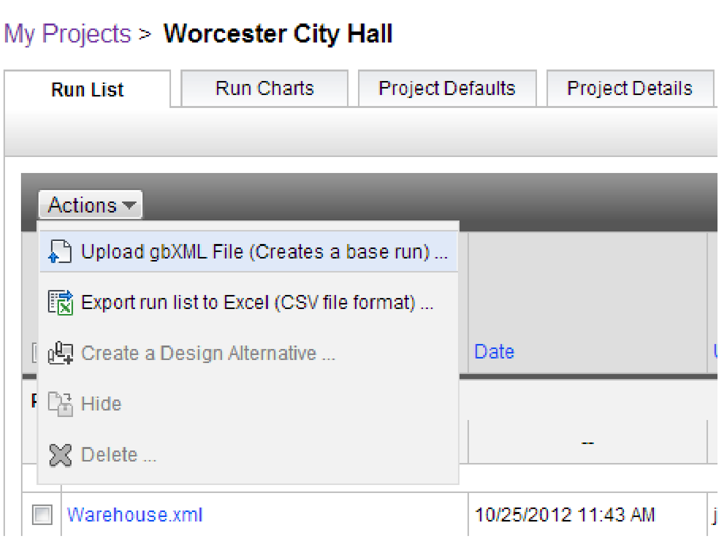
1. Log into Green Building Studio at this web address: https://gbs.autodesk.com/GBS/Account/InternalLogIn?dnoa.userSuppliedIdentifier=http%3A%2F%2Faccounts.autodesk.com&openid.mode=setup_needed&openid.ns=http%3A%2F%2Fspecs.openid.net%2Fauth%2F2.0

You will need a personal username and password. Either register an account or sign in if you have an existing account.

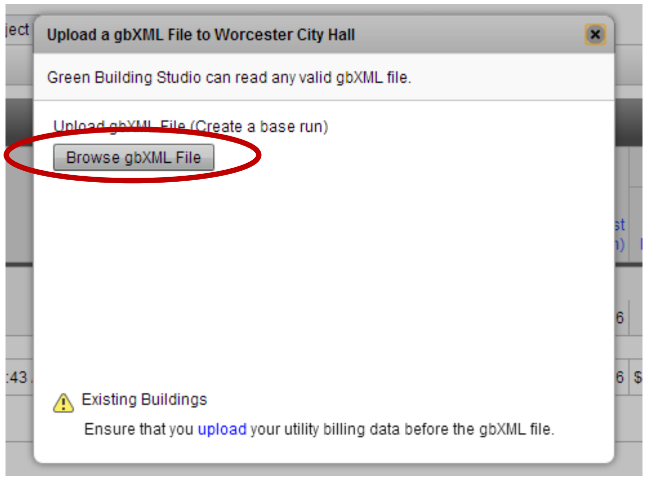
2. Either create a new project or open an existing one.

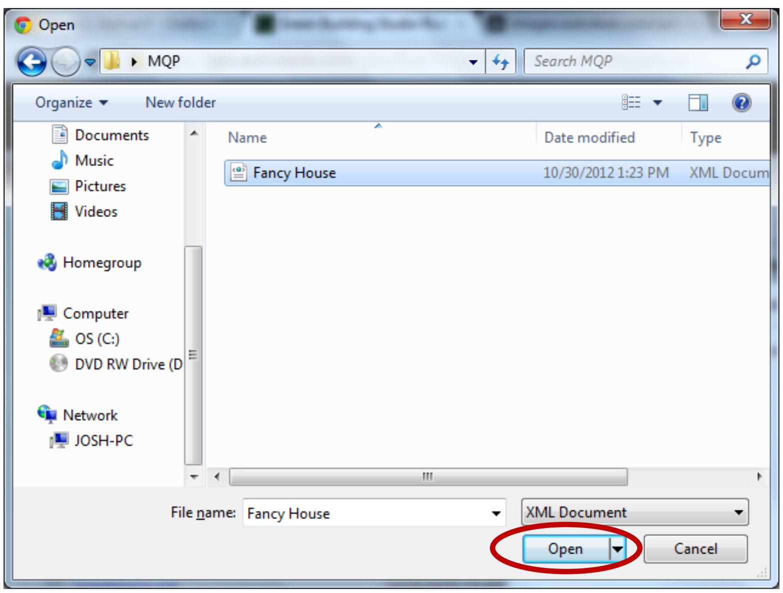


3. Select "upload gbXML File" on the "actions" dropdown menu

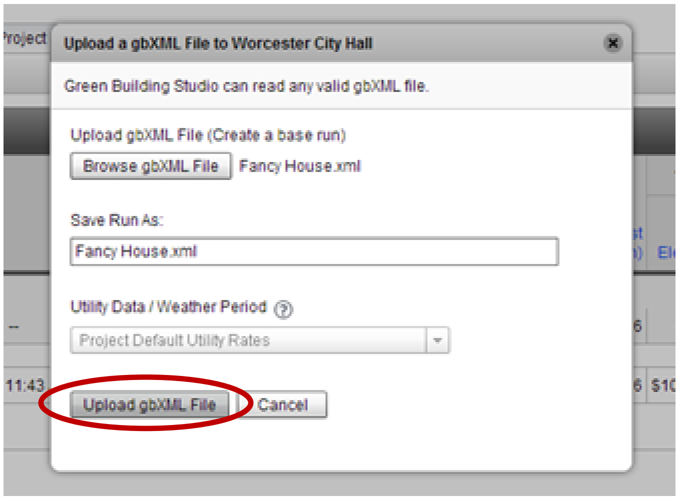


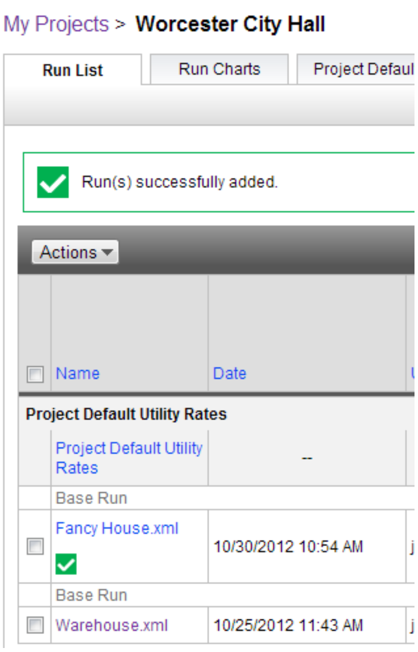
4. Locate a .gbXML file and open it





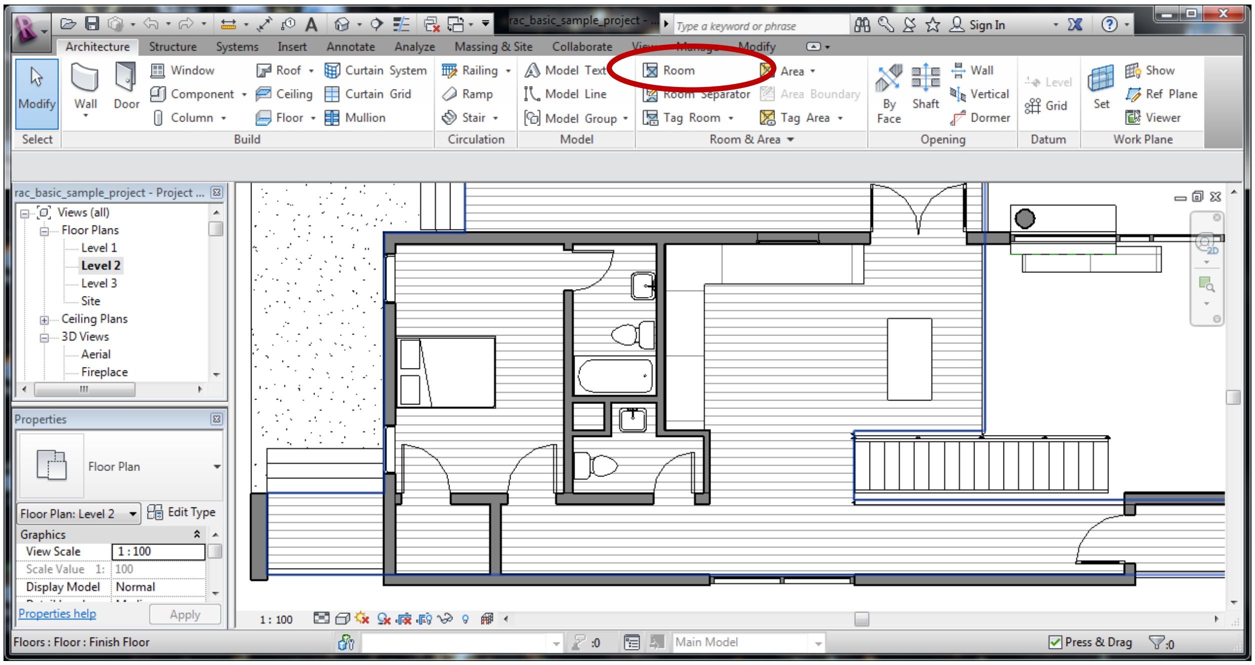
5. Lastly, select “Upload gbXML File”. The file will then appear on the dashboard.

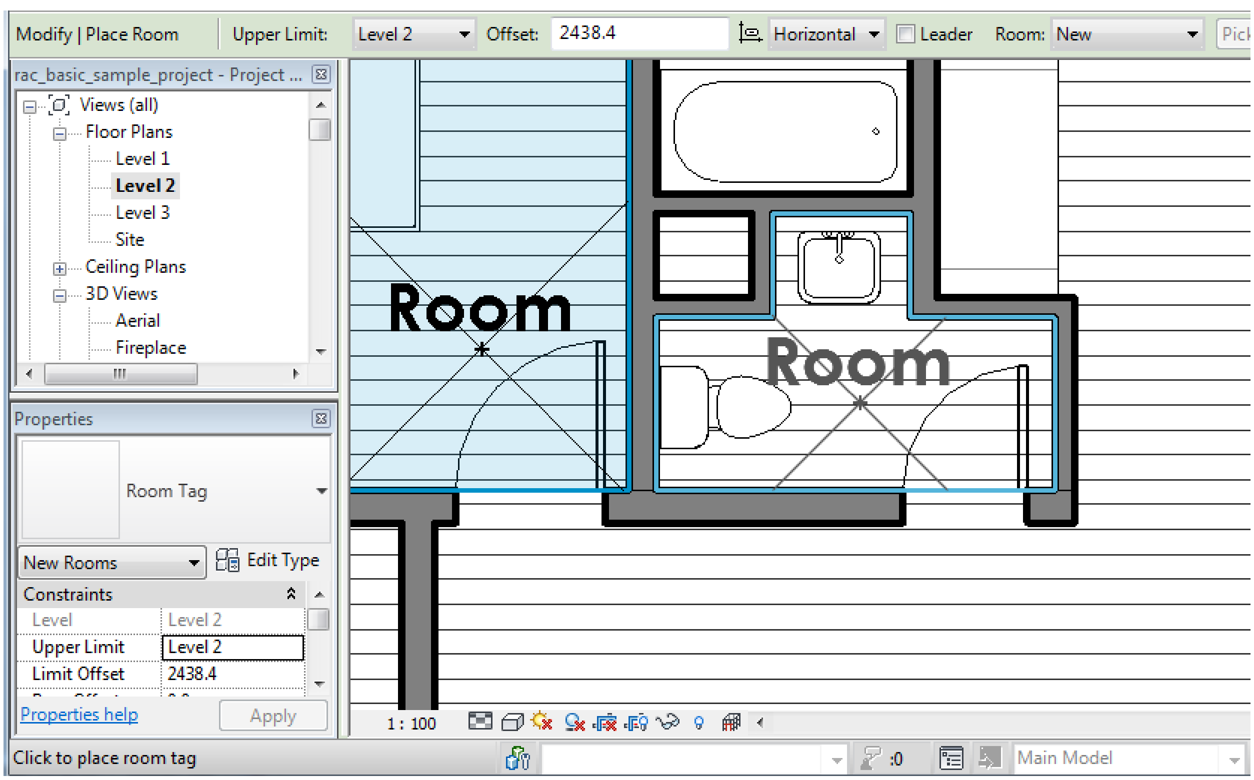




Common errors:

Ensure that the rooms of the Revit building model are defined. Do this by selecting “Room” and clicking each individual room with the cursor.

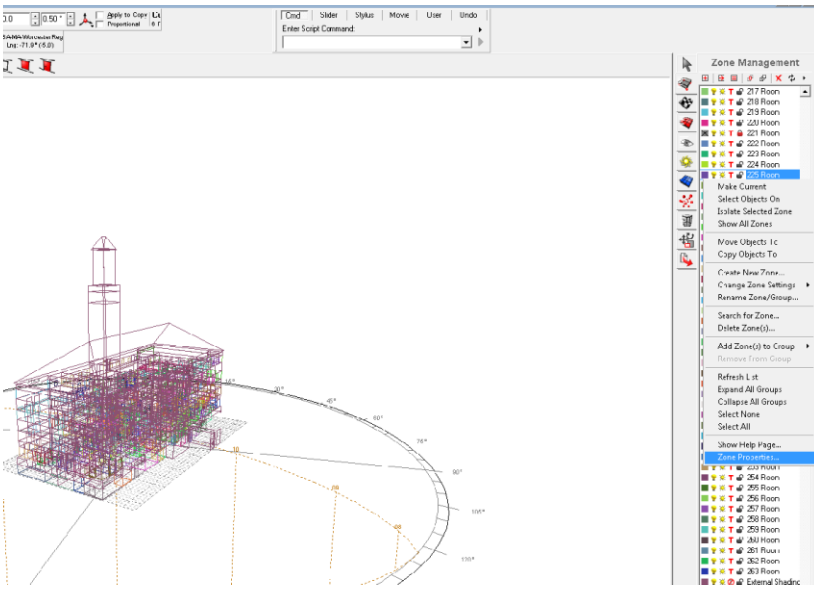




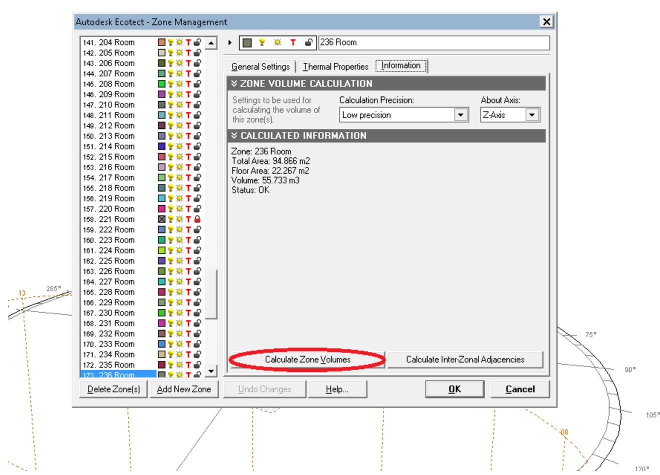
Appendix E: FAQ sheet for Ecotect Troubleshooting

What do I do if the volumes of my rooms aren't showing up?

Ecotect does not automatically calculate the volumes of your rooms for .gbXML imported files. Right click the a room under the "Zone Management" tab on the right side of the screen (you must be in 3D Project View to do this). Select "Zone Properties." A screen will pop up.

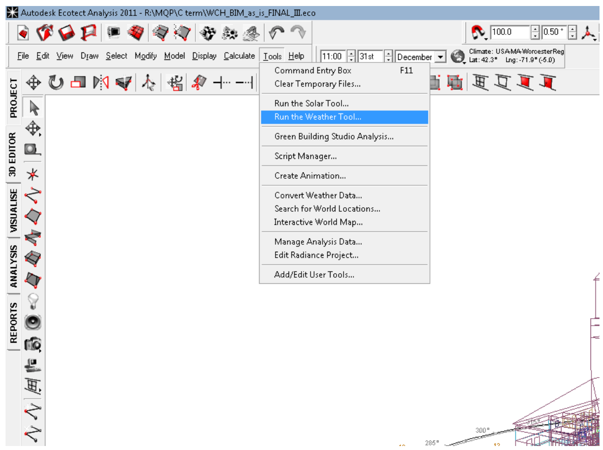


Under "Information," click "Calculate Zone Volumes." Make sure the calculation is in low precision and on the Z-axis. Ecotect will then proceed to calculate the zone volumes of all the rooms in Ecotect.

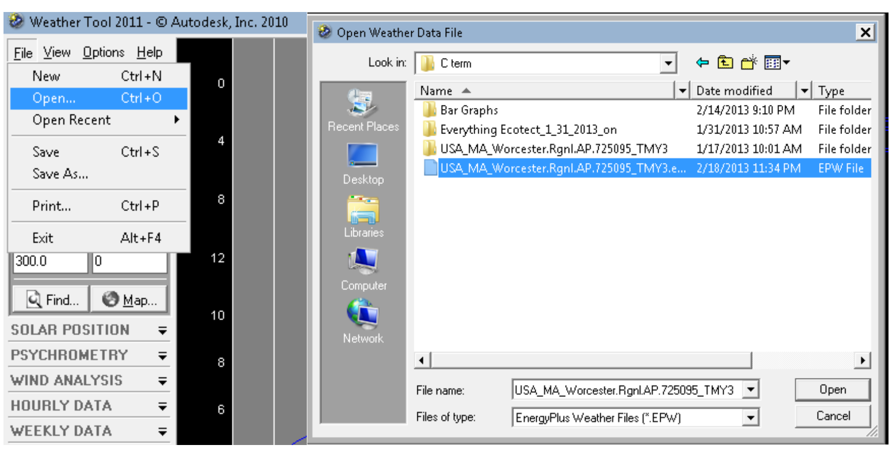


How do I get weather data that Ecotect doesn't have?

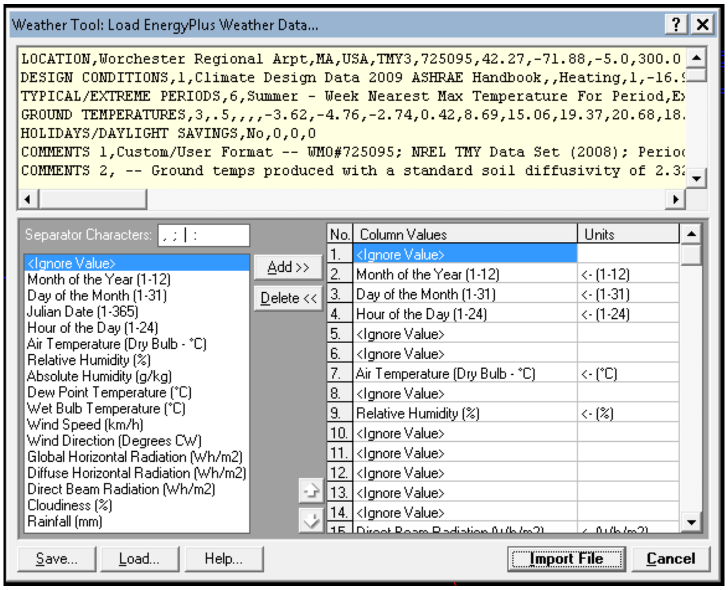
You can load weather data stored on Ecotect Software or retrieved elsewhere. To find your own weather data and convert it into Ecotect-compatible weather data, download an .EPW weather file from the Department of Energy closest to the location of your building. Go to http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm?CFID=5114309&CFTOKEN=dd111ab4e7411606-F0AF16B7-5056-BC19-1528FBDADE8CA5A8 to find the appropriate location and download a .zip that you need to unzip. Next, click "Run the Weather Tool" under the "Tools" tab. A pop-up screen will appear.



In the pop-up screen, select "File" and "Open." You will be prompted to select a .WEA file. Change this to select a .EPW file and search for the file from the DOE under where you saved it.

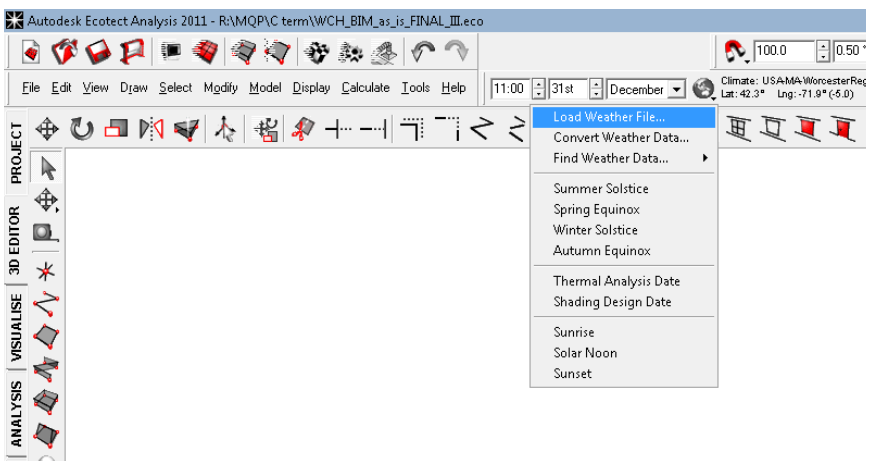


Select the file and open it. You will be prompted to import the file. Click "Import File" and the file will be usable weather data. Close out of the Weather Tool to return to Ecotect.

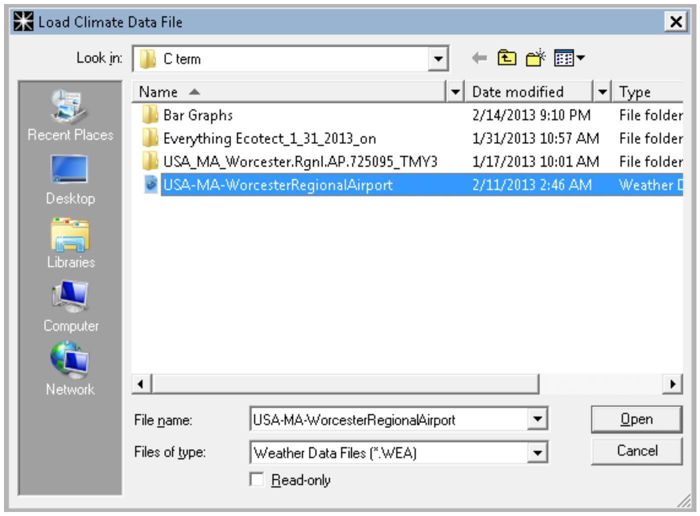


How do I load my weather file?

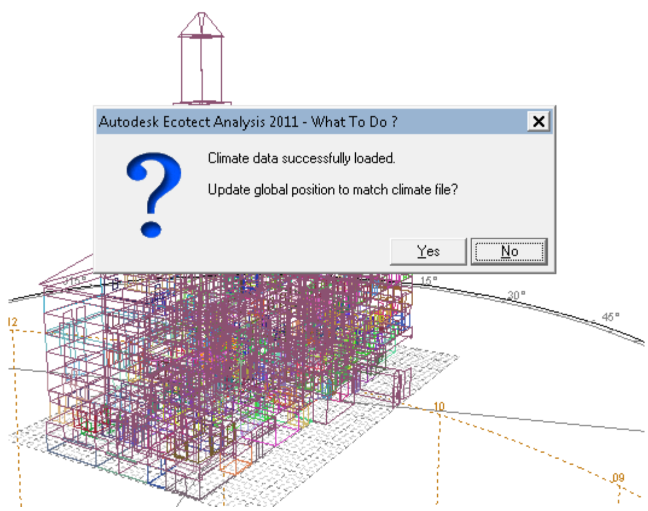
Click the Globe at the top of the screen and select "Load Weather File." You will be prompted to select your saved .WEA file.



Select the weather file under where you saved it. Make sure you select .WEA for files you are looking for. Select "Open" to load the weather file to Ecotect.

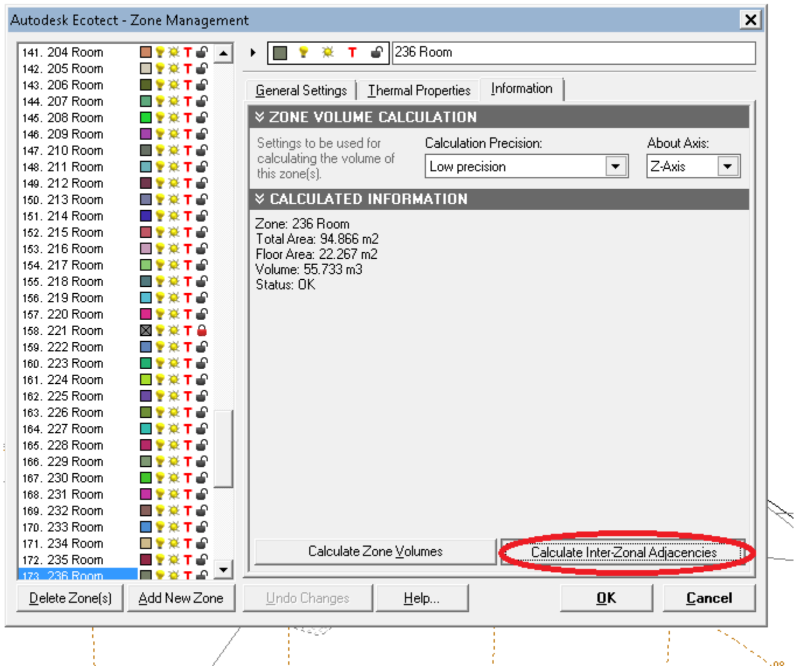


Ecotect will confirm that the climate data has been loaded to your file. It will also ask if you want to update the geographical location of your building to where your weather data is located. If your building is NOT in that spot, select no! If you do select yes, you will have to find the exact coordinates of your building again.

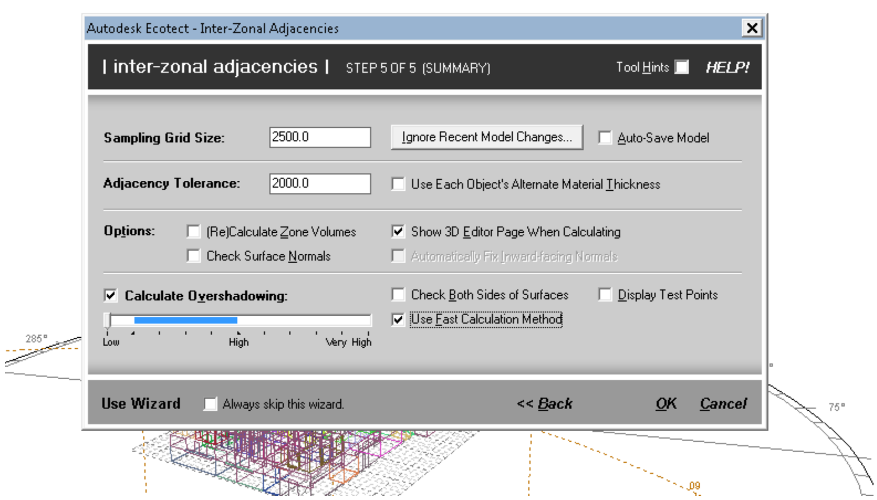


What are inter-zonal adjancencies? How do I calculate them?

Interzonal adjacencies occur when two objects intersect between multiple thermal zones. This is typically not a problem when the interzonal adjacency is a ceiling and/or a floor. However, Ecotect will not allow you to conduct Thermal Analysis without checking for inter-zonal adjacencies. To do so, bring up the Zone Management window and click “Calculate Inter-Zonal Adjacencies” under the “Information” tab.



You should get prompted with the Inter-Zonal Adjacencies Wizard that will guide you through a 5-step process for setting up the Inter-Zonal Adjacency calculations. If it does not, it will bring you straight to the summary page. Especially for large buildings, be sure to select the lowest and farthest settings you can select. If you calculate overshadowing, make sure to check off "Use Fast Calculation Method."

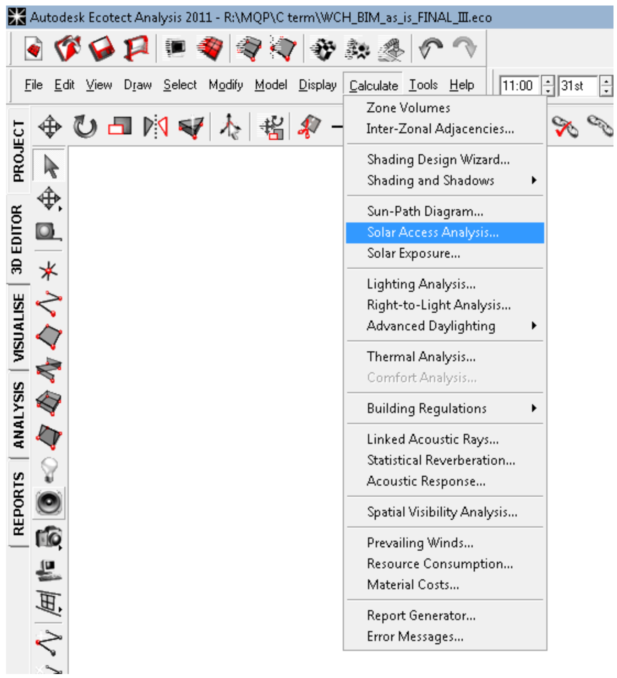


Using these settings should not make an impact on the results. If error messages show up for pieces of the ceiling or floor, ignore the messages and proceed with calculations.

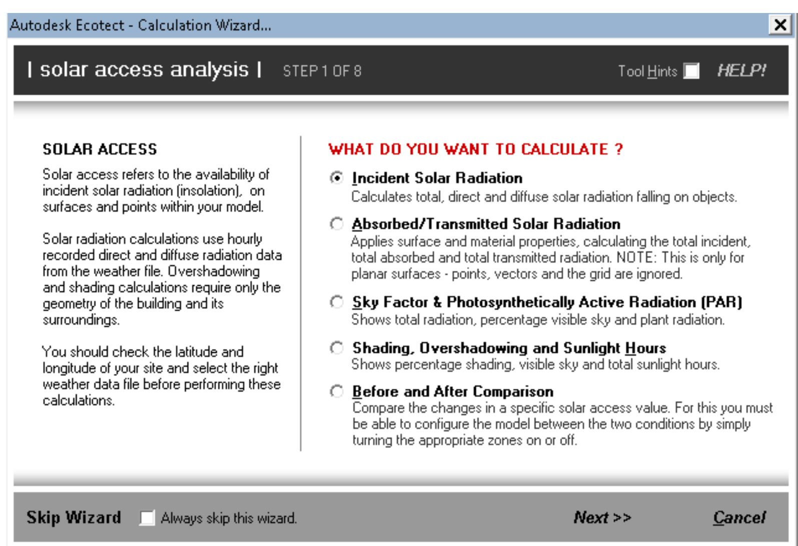
How do I do a Solar Access Analysis? What kind of Solar Access Analysis should I do?

Note that Solar Access Analysis calculations typically take between one hour to four hours to run for a building a similar size as Worcester City Hall. No other computer functions can be used while running this calculation.

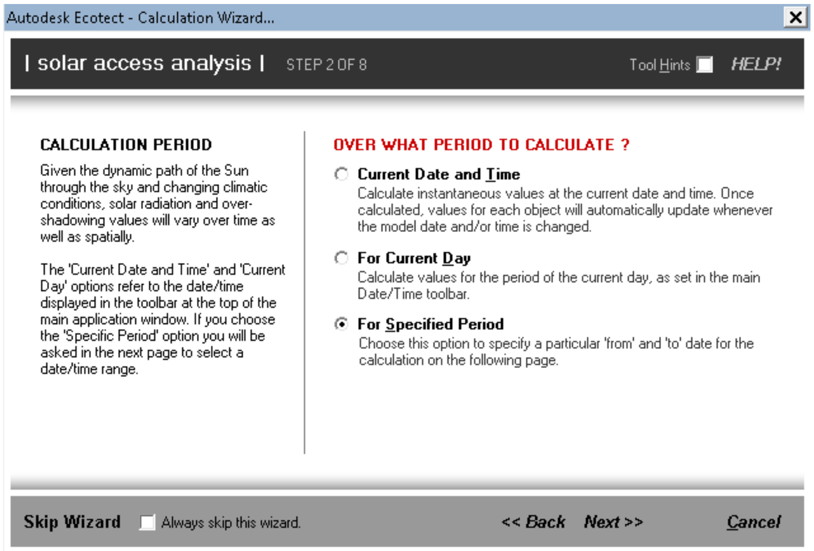
To perform a Solar Access Analysis, select “Calculate” on the top ribbon and click “Solar Access Analysis.” You will get prompted with a Solar Access Wizard to set your calculation requirements.



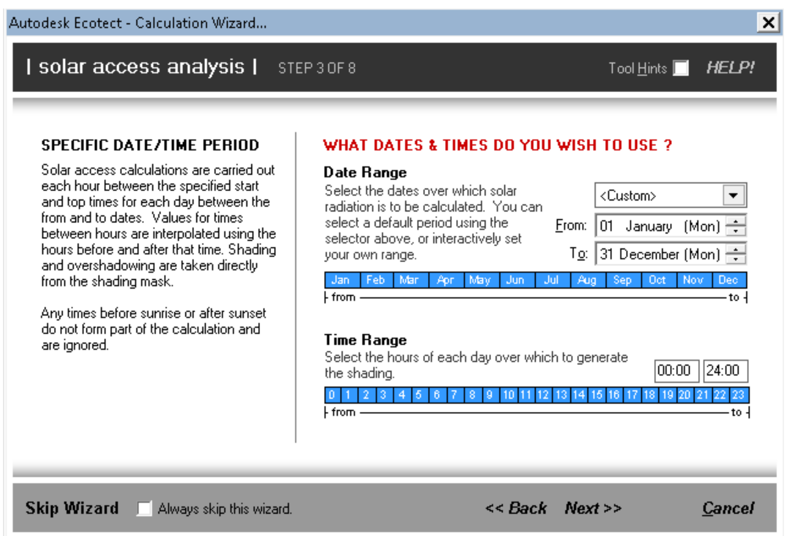
The Wizard consists of an 7-step process. First, select “Incident Solar Radiation” because you’re only interested in the solar radiation falling on the surface of the building. Click “Next.”



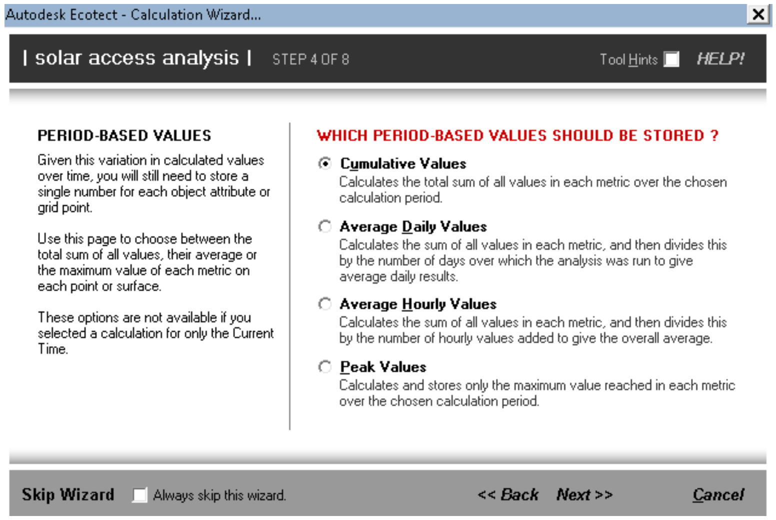
On the next screen, select “For Speficied Period” for the Calculation Period. You will be given a range to choose from on the next prompt. Click “Next.”



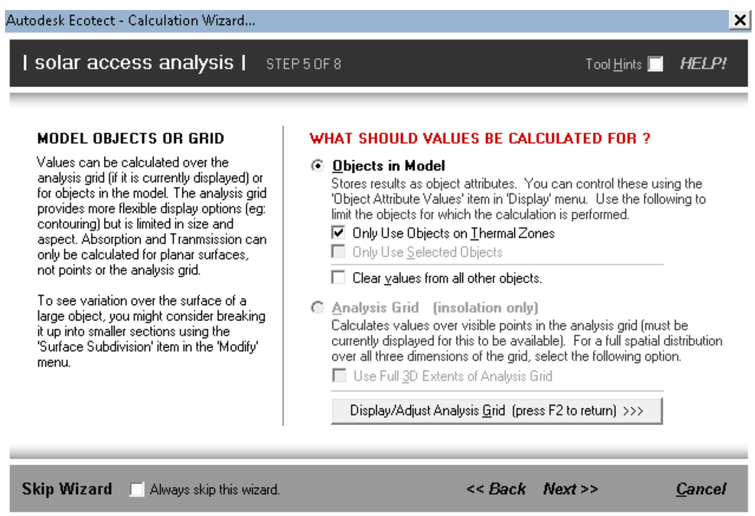
Now you can choose the parameters to calculate. Highlight the dates and time you would like to include in blue and click “Next.”



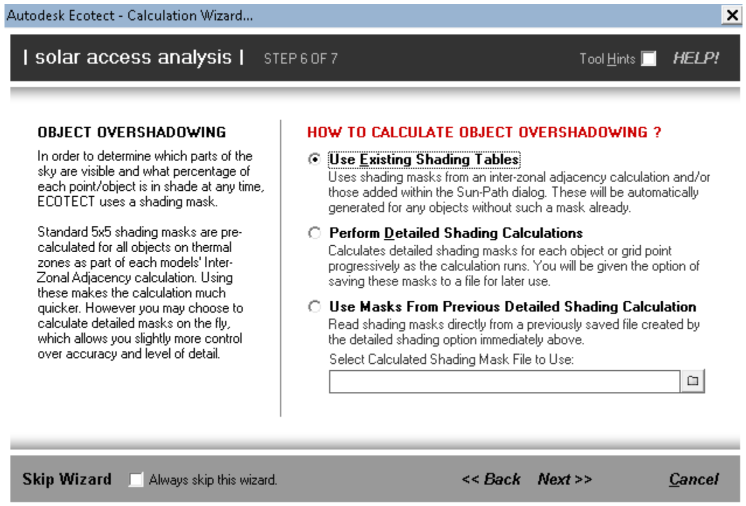
Next you can select what kind of outputs you want displayed when done. Select “Cumulative Values” and click “Next.”



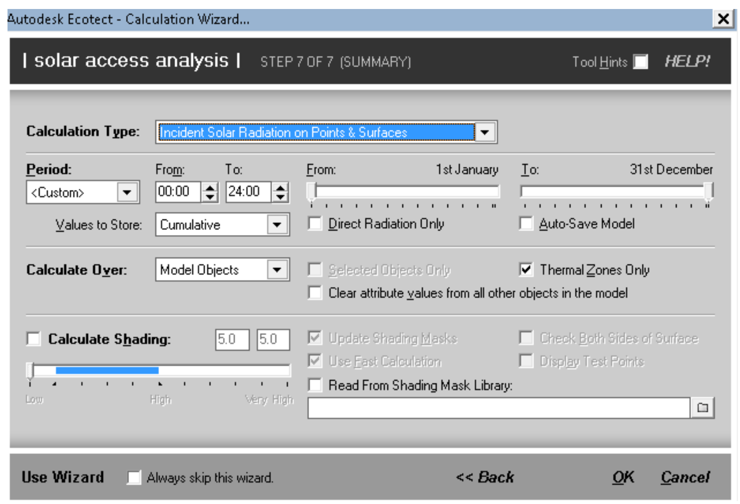
You can choose what values to calculate for. If your exported model already has rooms defined, it has Thermal Zones and you can calculate “Objects in Model” and select “Only Use Object on Thermal Zones.” Click “Next.”



Next it will ask how to calculate the object overshadowing. Use the Existing Shading Tables if you already calculated this in the Inter-Zonal Adjacencies and click “Next.”



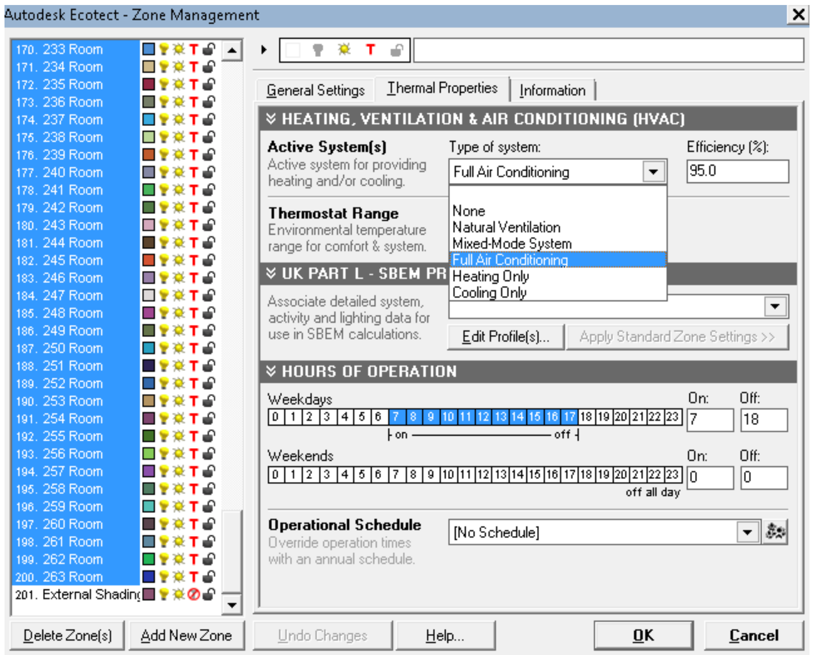
Last is the summary page. Check all of the parameters before clicking “Ok.”



Why do I have zeroes for heating and cooling values when I run a thermal calculation?

There probably isn't any heating or cooling system assinged to the rooms. You can change this by right clicking a room in the Zone Management tab and clicking "Zone Properties."

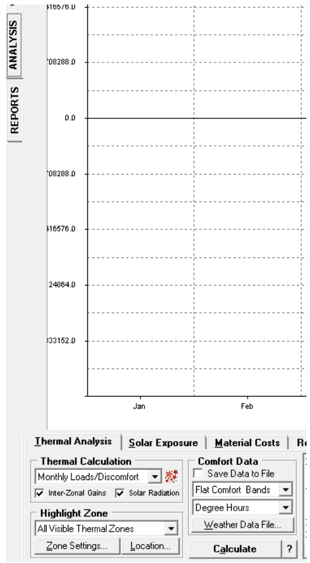
Highlight all the rooms you want affected by clicking and dragging OR by pressing Ctrl+ click individual rooms. Select the type of system you want for the room. Click "Ok."



You can also change many other functions under this tab that are important to a thermal analysis, such as the Hours of Operation on weekdays and weekends and the thermostat range.

How do I calculate the amount of heating and cooling it takes to keep the building at a comfortable temperature?

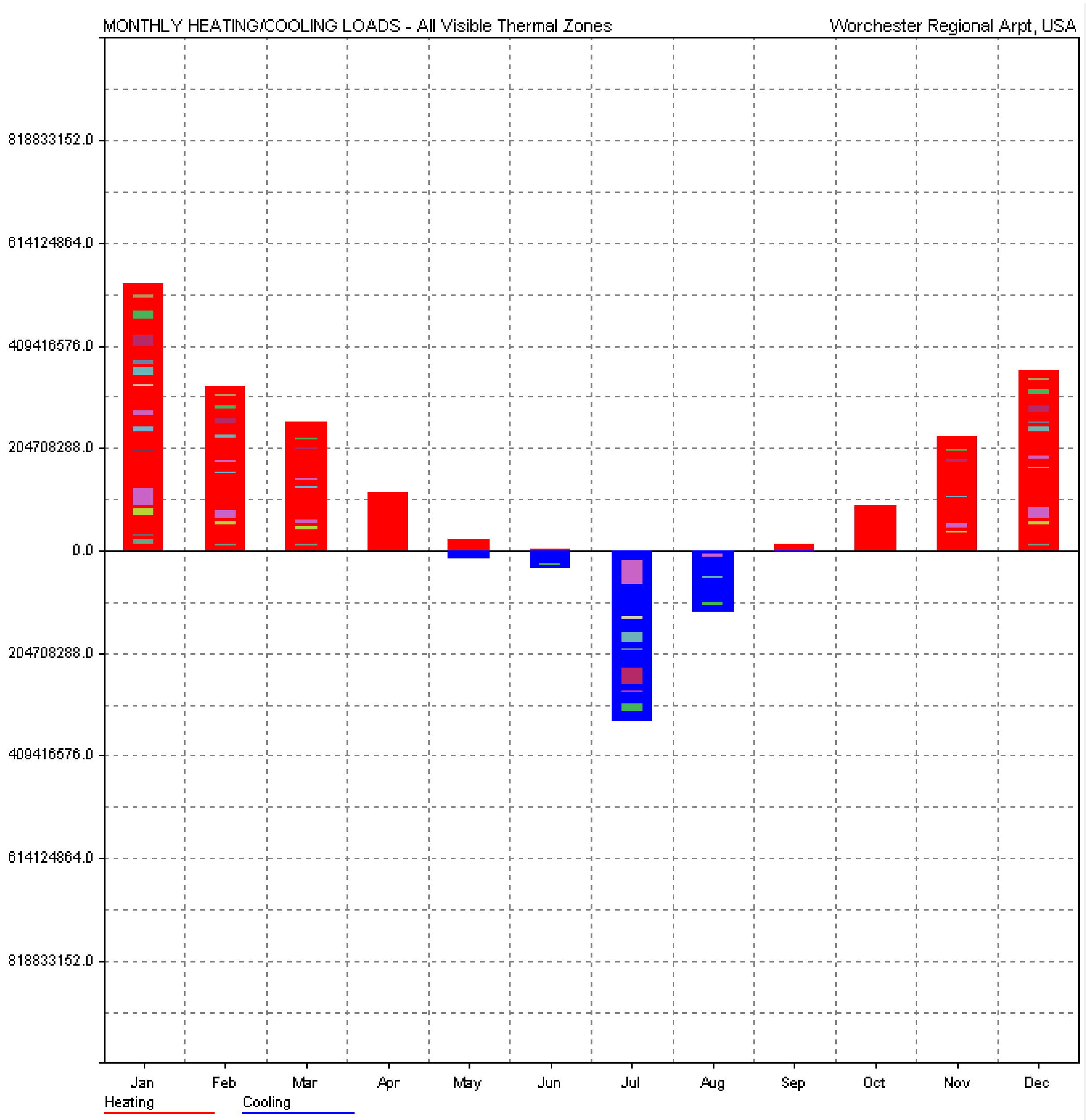
After setting the building's parameters, such as the type of system, the hours the building would be operating, and the lowest and highest temperature the building can get, you can get results for heating and cooling loads. Under the "Analysis" tab on the left side ribbon, select the "Thermal Analysis" tab and select "Monthly Loads/Discomfort" under Thermal Calculation.



This will give the amount of energy required to keep the building at a comfortable temperature (your thermostat range). Check the boxes below to include Inter-Zonal Gains and Solar Radiation; they are both big factors that in the thermal calculation. Have the model calculate "All Visible Thermal Zones" with "Flat Comfort Bands" and "Degree Hours" and then Calculate.

Appendix F: Ecotect Tables and Graphs depicting Heating and Cooling Results for Simulated Existing Conditions and Preliminary Recommended Adjustments

Initial Conditions



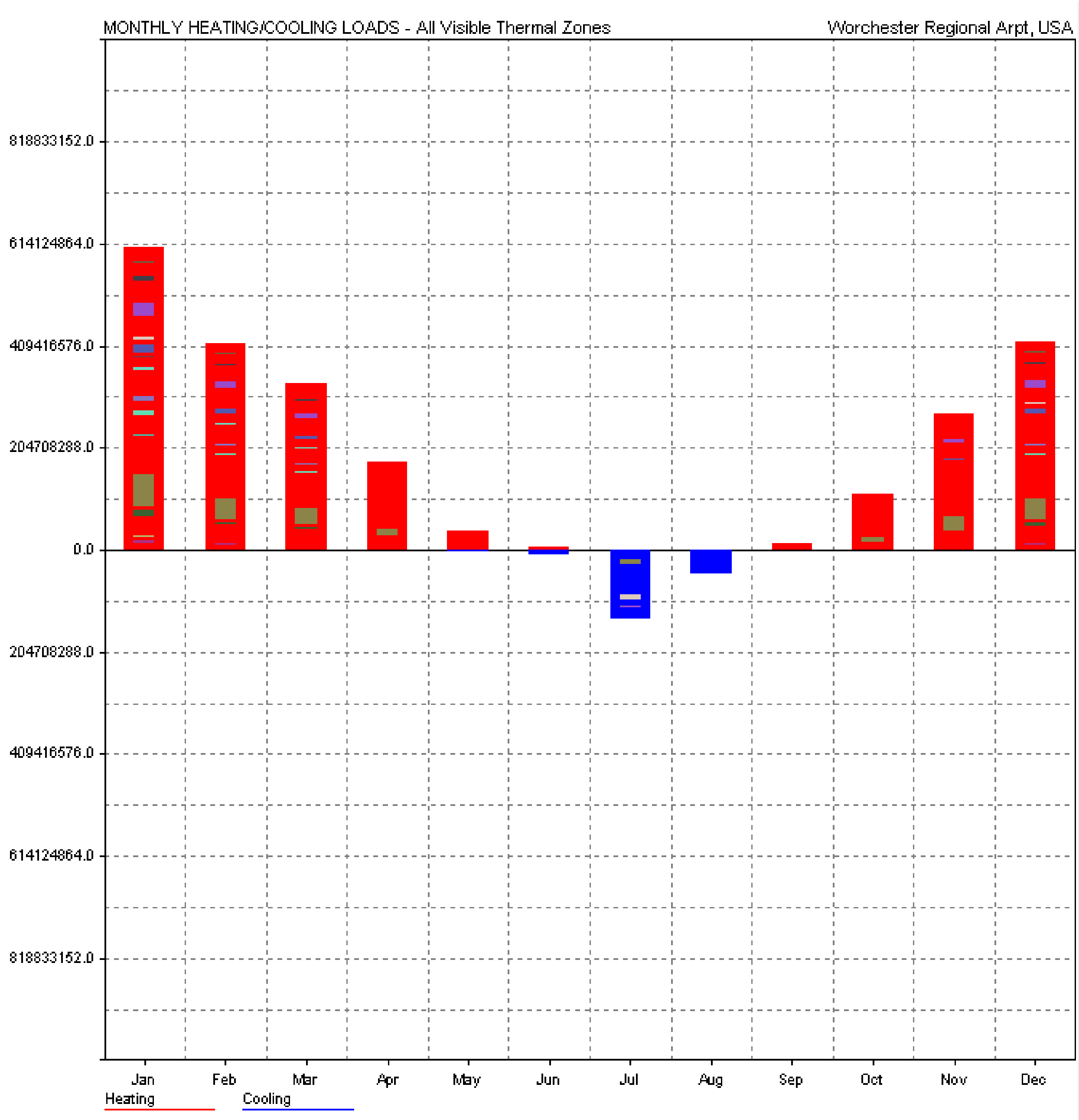
Initial Conditions

Max Heating: 4903293.5 Btu/hr at 08:00 on 23rd January

Max Cooling: 4510378.0 Btu/hr at 11:00 on 19th July

MONTH	HEATING (Btu)	COOLING (Btu)	TOTAL (Btu)
Jan	524537888	0	524537888
Feb	319294496	0	319294496
Mar	249932576	0	249932576
Apr	107503064	39631	107542688
May	19311004	17738554	37049556
Jun	2325556	46383944	48709500
Jul	72393	381576736	381649120
Aug	818514	166433792	167252304
Sep	9726014	3014227	12740242
Oct	81911336	0	81911336
Nov	218605392	0	218605392
Dec	350236384	0	350236384
TOTAL	1884274560	615186816	2499461376

Single Window Panes replaced with Double Pane



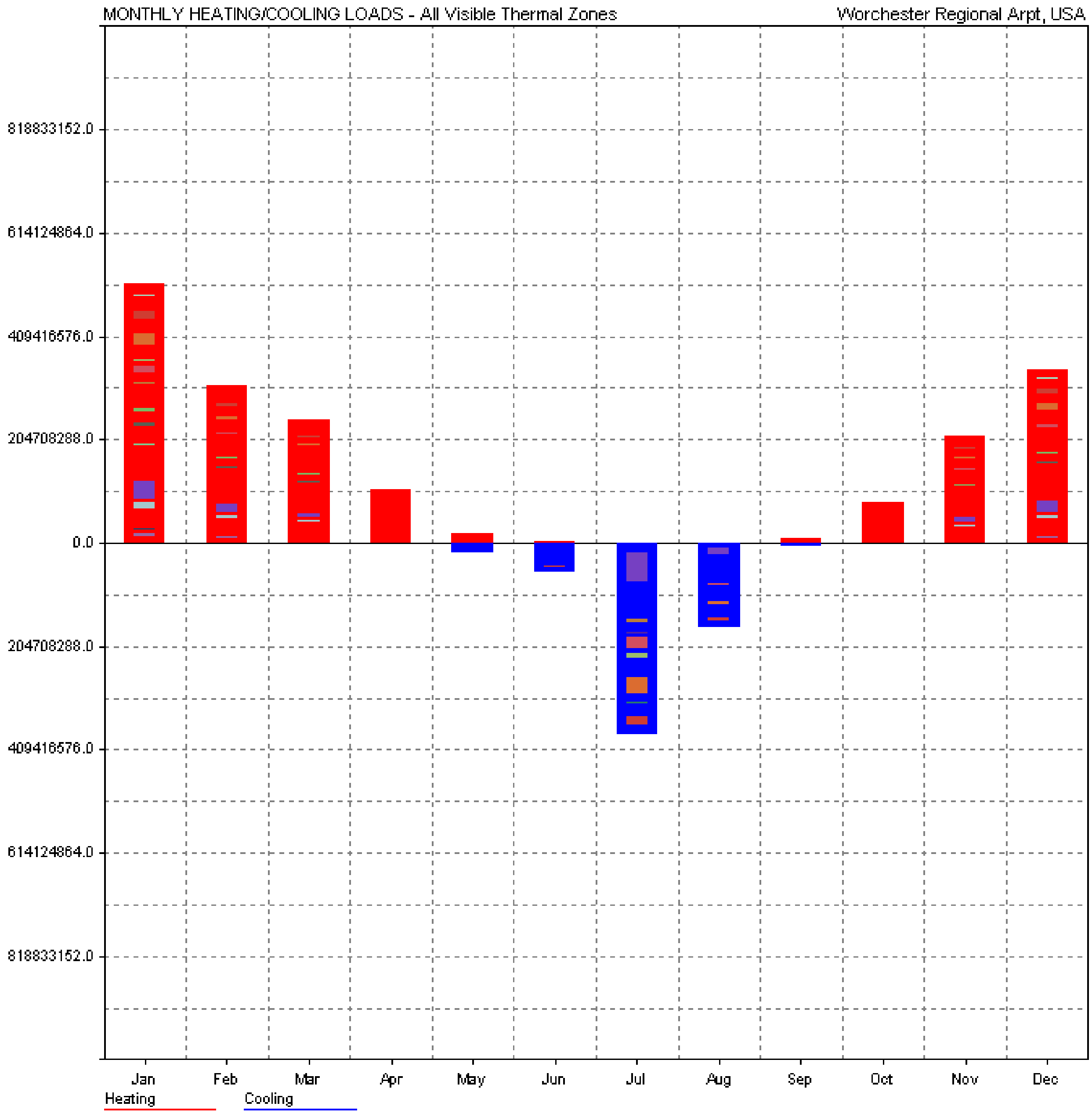
Single Window Panes replaced with Double Pane

Max Heating: 4666135.5 Btu/hr at 08:00 on 23rd January

Max Cooling: 1661680.0 Btu/hr at 11:00 on 24th July

MONTH	HEATING (Btu)	COOLING (Btu)	TOTAL (Btu)
Jan	606246080	0	606246080
Feb	414714944	0	414714944
Mar	335662688	0	335662688
Apr	176055328	562668	176618000
May	39710216	4330134	44040352
Jun	7230920	10252252	17483172
Jul	667485	139317360	139984832
Aug	1135165	47786764	48921928
Sep	13669064	638987	14308051
Oct	112164744	0	112164744
Nov	272763104	0	272763104
Dec	417876992	0	417876992
TOTAL	2397896704	202888160	2600784640

1 inch of insulation (R $\approx$ 4) added to the 2nd floor



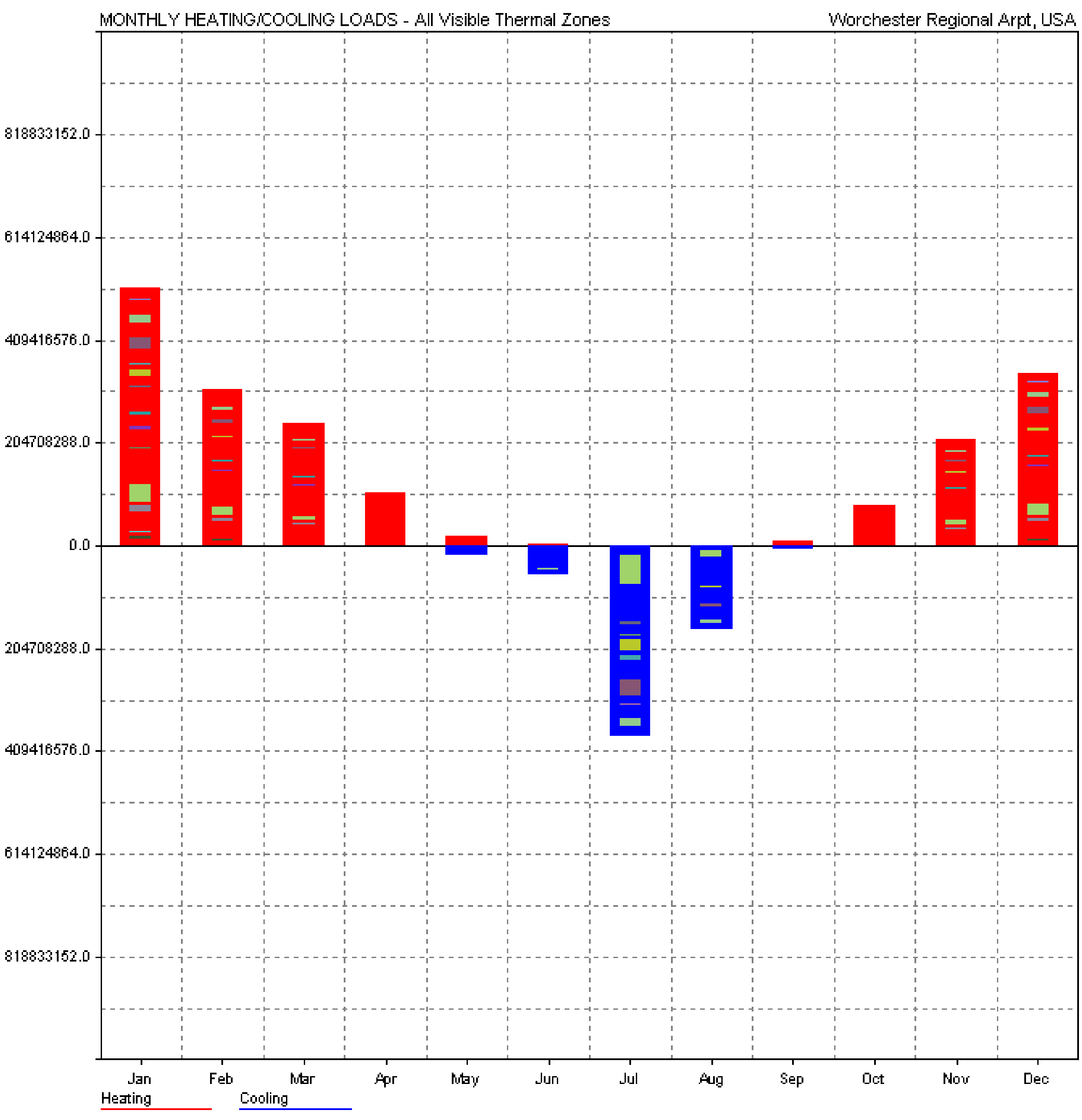
1 inch of insulation (R ≈ 4) added to the 2nd floor

Max Heating: 5047892.5 Btu/hr at 00:00 on 0th January

Max Cooling: 2745321.0 Btu/hr at 00:00 on 0th January

	HEATING	COOLING	TOTAL
MONTH	(Btu)	(Btu)	(Btu)
------------	-----------	----------	-----------
Jan	680500928	0	680500928
Feb	457299968	0	457299968
Mar	357528640	3835	357532480
Apr	191937728	1002422	192940144
May	46447152	7319040	53766188
Jun	9976286	15759135	25735420
Jul	1117902	196503424	197621328
Aug	1669372	64093040	65762412
Sep	17195678	702342	17898020
Oct	125427080	11720	125438808
Nov	307040128	0	307040128
Dec	473117088	0	473117088
------------	-----------	----------	-----------
TOTAL	2669258240	285394912	2954653184

2 inches of insulation (R $\approx$ 8) added to the 2^{nd} floor



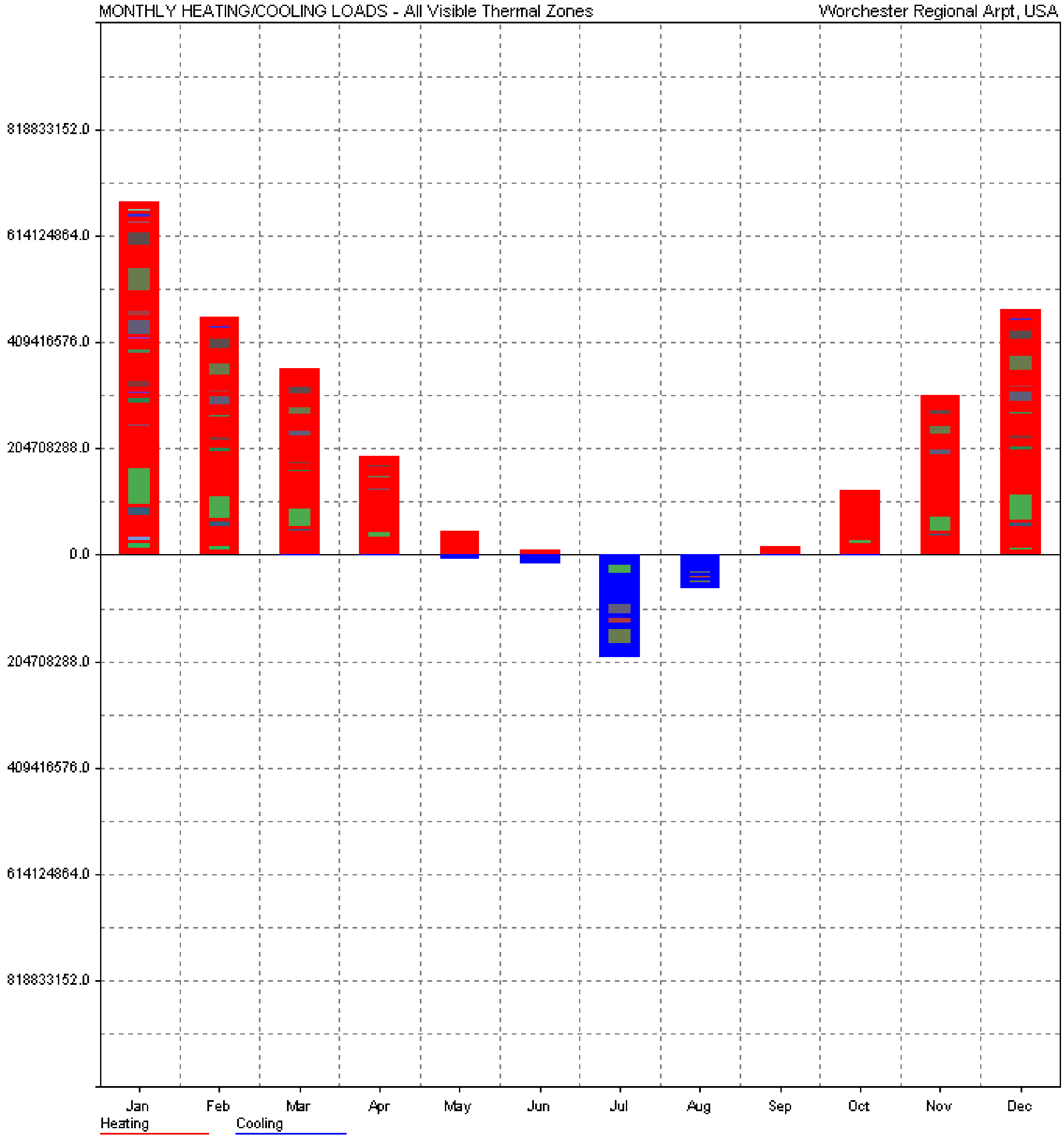
2 inches of insulation (R $\approx$ 8) added to the 2nd floor

Max Heating: 5047892.0 Btu/hr at 00:00 on 0th January

Max Cooling: 2745325.5 Btu/hr at 00:00 on 0th January

MONTH	HEATING (Btu)	COOLING (Btu)	TOTAL (Btu)
Jan	680500224	0	680500224
Feb	457298944	0	457298944
Mar	357527872	3835	357531680
Apr	191936816	1002422	192939232
May	46446412	7319040	53765448
Jun	9975972	15759144	25735116
Jul	1117768	196504240	197622016
Aug	1669284	64093308	65762588
Sep	17195172	702342	17897514
Oct	125426400	11720	125438120
Nov	307039616	0	307039616
Dec	473116576	0	473116576
TOTAL	2669251072	285396032	2954647040

3 inches of insulation (R $\approx$ 12) added to the 2nd floor



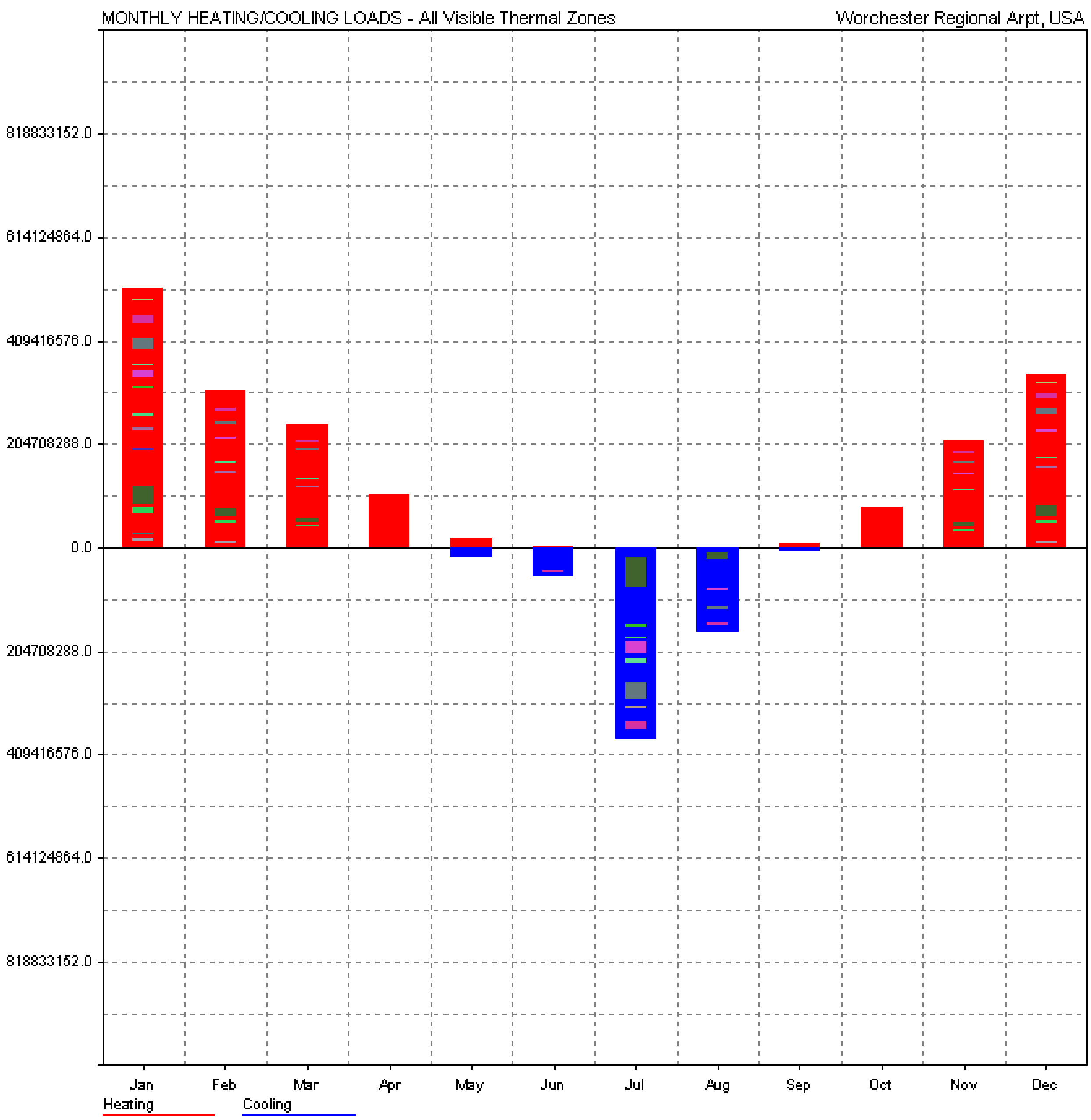
3 inches of insulation (R $\approx$ 12) added to the 2nd floor

Max Heating: 5048025.0 Btu/hr at 08:00 on 23rd January

Max Cooling: 2745350.8 Btu/hr at 11:00 on 10th July

MONTH	HEATING (Btu)	COOLING (Btu)	TOTAL (Btu)
------------	-----------	----------	-----------
Jan	680519808	0	680519808
Feb	457313440	0	457313440
Mar	357539584	3835	357543424
Apr	191943728	1002422	192946144
May	46448200	7319040	53767236
Jun	9976317	15759152	25735470
Jul	1117800	196505712	197623520
Aug	1669281	64093600	65762884
Sep	17195684	702342	17898026
Oct	125430848	11720	125442568
Nov	307049632	0	307049632
Dec	473130784	0	473130784
------------	-----------	----------	-----------
TOTAL	2669335040	285397824	2954732800

3 inches of insulation (R $\approx$ 12) added to the 3rd floor



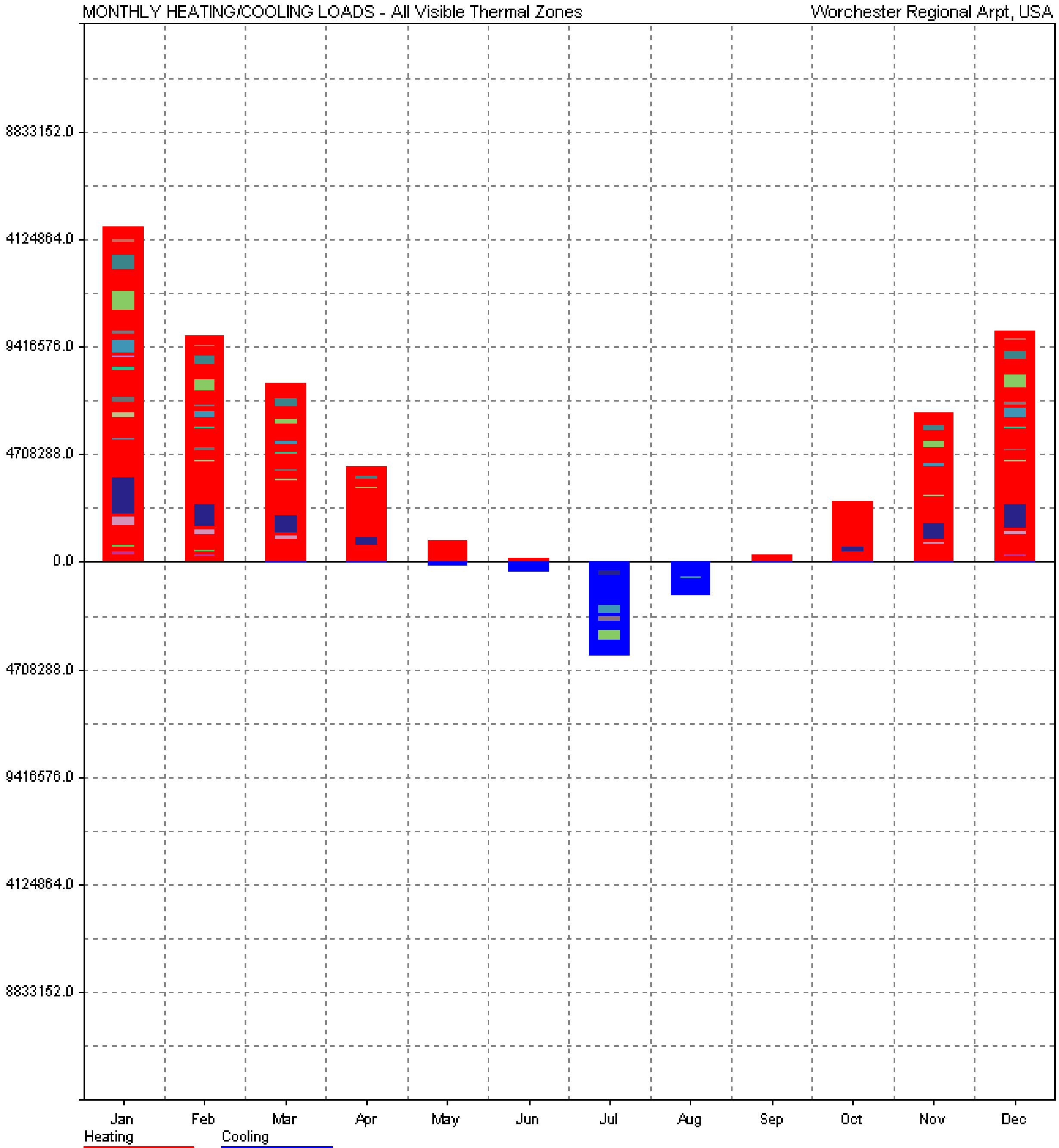
3 inches of insulation (R $\approx$ 12) added to the 3rd floor

Max Heating: 5032558.5 Btu/hr at 08:00 on 23rd January

Max Cooling: 2743829.8 Btu/hr at 11:00 on 10th July

MONTH	HEATING (Btu)	COOLING (Btu)	TOTAL (Btu)
------------	-----------	---------- -	----------
Jan	679080640	0	679080640
Feb	456239040	0	456239040
Mar	356623136	3835	356626976
Apr	191378512	1002422	192380928
May	46266112	7319040	53585152
Jun	9937705	15761544	25699250
Jul	1120022	196496160	197616176
Aug	1662876	64085432	65748308
Sep	17102286	702342	17804628
Oct	125041520	11720	125053248
Nov	306293088	0	306293088
Dec	472084768	0	472084768
------------	-----------	----------	-----------
TOTAL	2662829824	285382464	2948212224

3 inches of insulation (R ≈ 12) added to the 4th floor



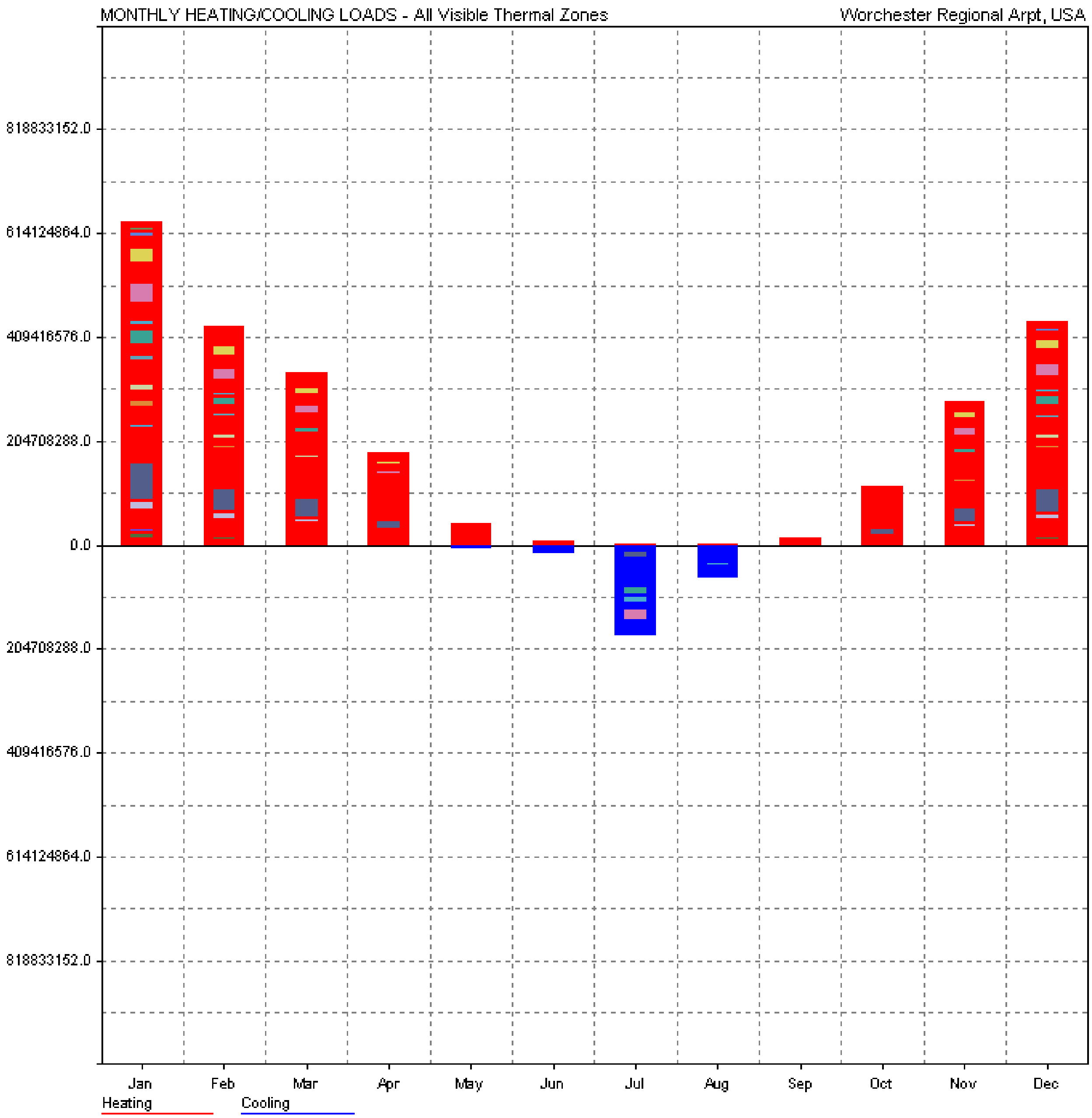
3 inches of insulation (R $\approx$ 12) added to the 4th floor

Max Heating: 4920636.5 Btu/hr at 08:00 on 23rd January

Max Cooling: 2278385.2 Btu/hr at 11:00 on 10th July

MONTH	HEATING (Btu)	COOLING (Btu)	TOTAL (Btu)
------------	-----------	---------- -	----------
Jan	637255744	0	637255744
Feb	430068864	0	430068864
Mar	340804672	36776	340841440
Apr	180458256	1061090	181519360
May	41638640	8022566	49661204
Jun	7647815	18887066	26534880
Jul	727550	178921136	179648688
Aug	1015042	64020404	65035448
Sep	14537866	1870582	16408449
Oct	115248920	207739	115456664
Nov	284210368	44212	284254592
Dec	439969152	6101	439975264
------------	-----------	----------	-----------
TOTAL	2493582848	273077696	2766660608

3 inches of insulation (R $\approx$ 12) added to the 5th floor



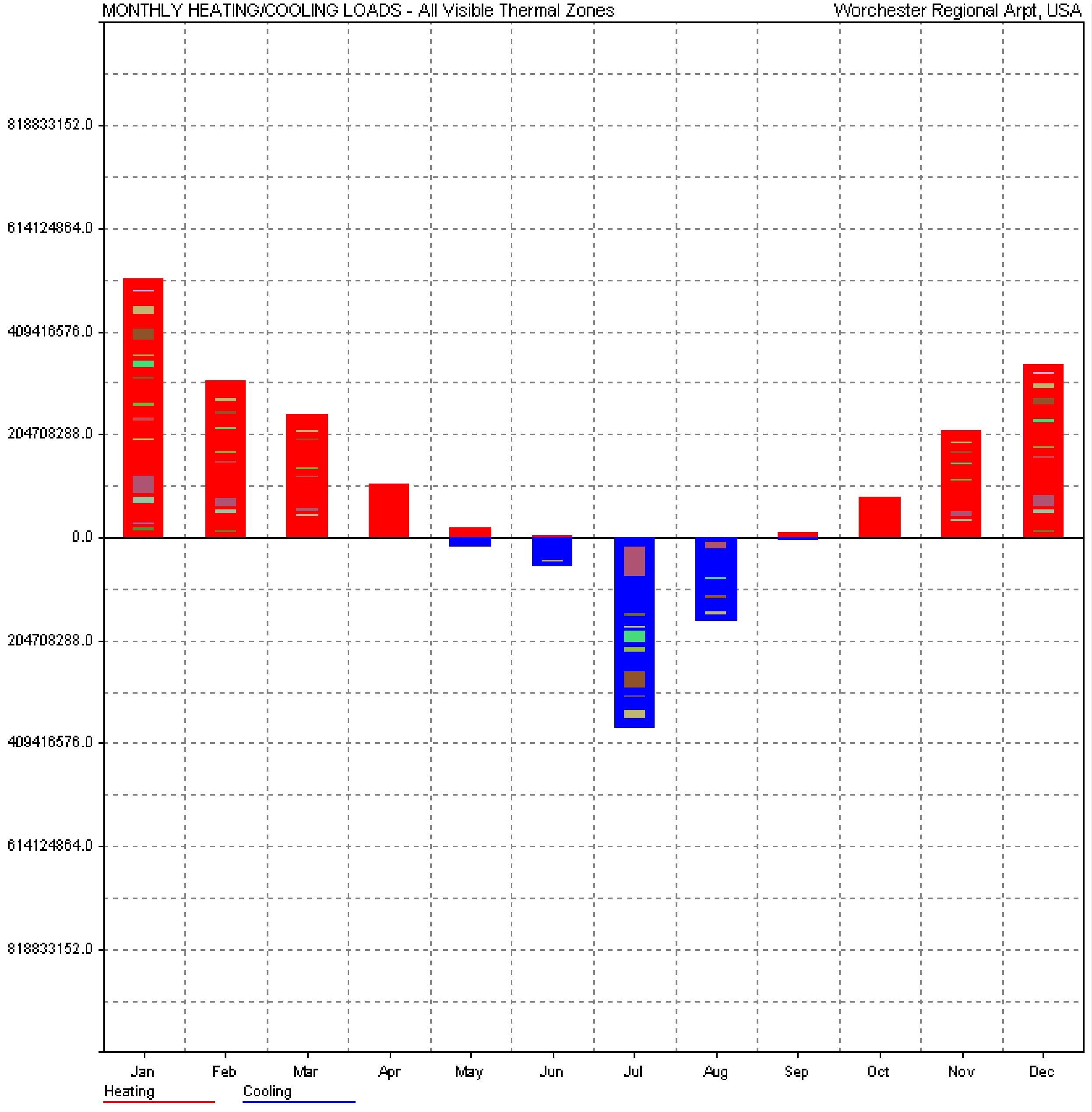
3 inches of insulation (R $\approx$ 12) added to the 5th floor

Max Heating: 4920645.5 Btu/hr at 08:00 on 23rd January

Max Cooling: 2278391.8 Btu/hr at 11:00 on 10th July

MONTH	HEATING (Btu)	COOLING (Btu)	TOTAL (Btu)
------------	-----------	---------- --	---------
Jan	637265024	0	637265024
Feb	430076000	0	430076000
Mar	340810496	36776	340847264
Apr	180462256	1061092	181523344
May	41640016	8022622	49662636
Jun	7648224	18887110	26535334
Jul	727605	178920496	179648096
Aug	1015077	64016692	65031772
Sep	14538474	1870583	16409056
Oct	115251664	207739	115459408
Nov	284214880	44212	284259104
Dec	439975200	6101	439981312
------------	-----------	----------	-----------
TOTAL	2493625088	273073472	2766698496

1 inch of insulation (R $\approx$ 4) added to the 6th floor



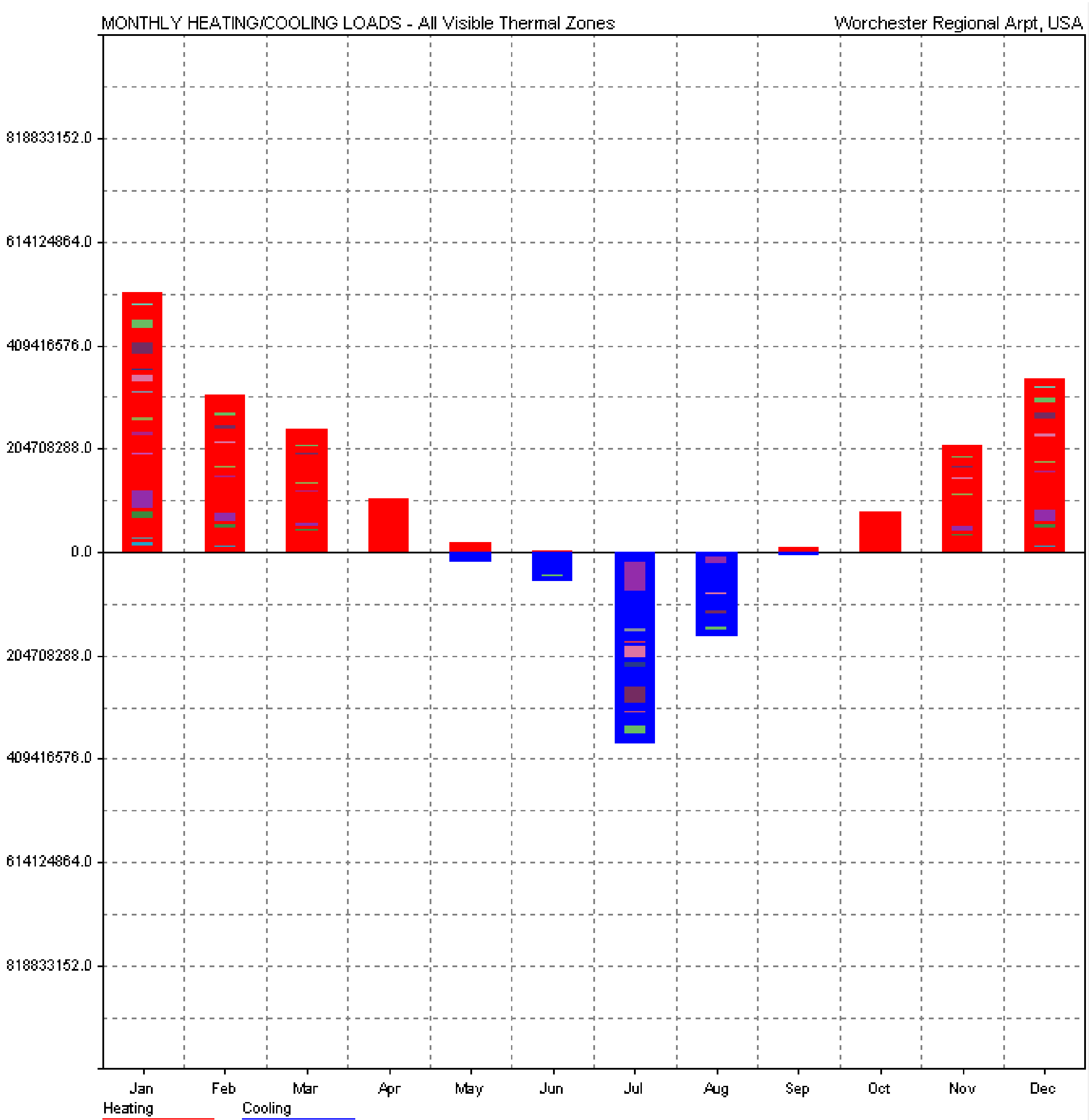
1 inch of insulation (R $\approx$ 4) added to the 6th floor

Max Heating: 5047893.0 Btu/hr at 00:00 on 0th January

Max Cooling: 2745319.8 Btu/hr at 00:00 on 0th January

	HEATING	COOLING	TOTAL
MONTH	(Btu)	(Btu)	(Btu)
------------	-----------	---------- -	----------
Jan	680501056	0	680501056
Feb	457300096	0	457300096
Mar	357528800	3835	357532640
Apr	191937936	1002422	192940352
May	46447240	7319040	53766280
Jun	9976327	15759121	25735450
Jul	1117913	196502992	197620896
Aug	1669380	64092996	65762372
Sep	17195738	702342	17898080
Oct	125427176	11720	125438896
Nov	307040256	0	307040256
Dec	473117120	0	473117120
------------	-----------	----------	-----------
TOTAL	2669258752	285394432	2954653184

2 inches of insulation ($R \approx 8$) added to the 6th floor



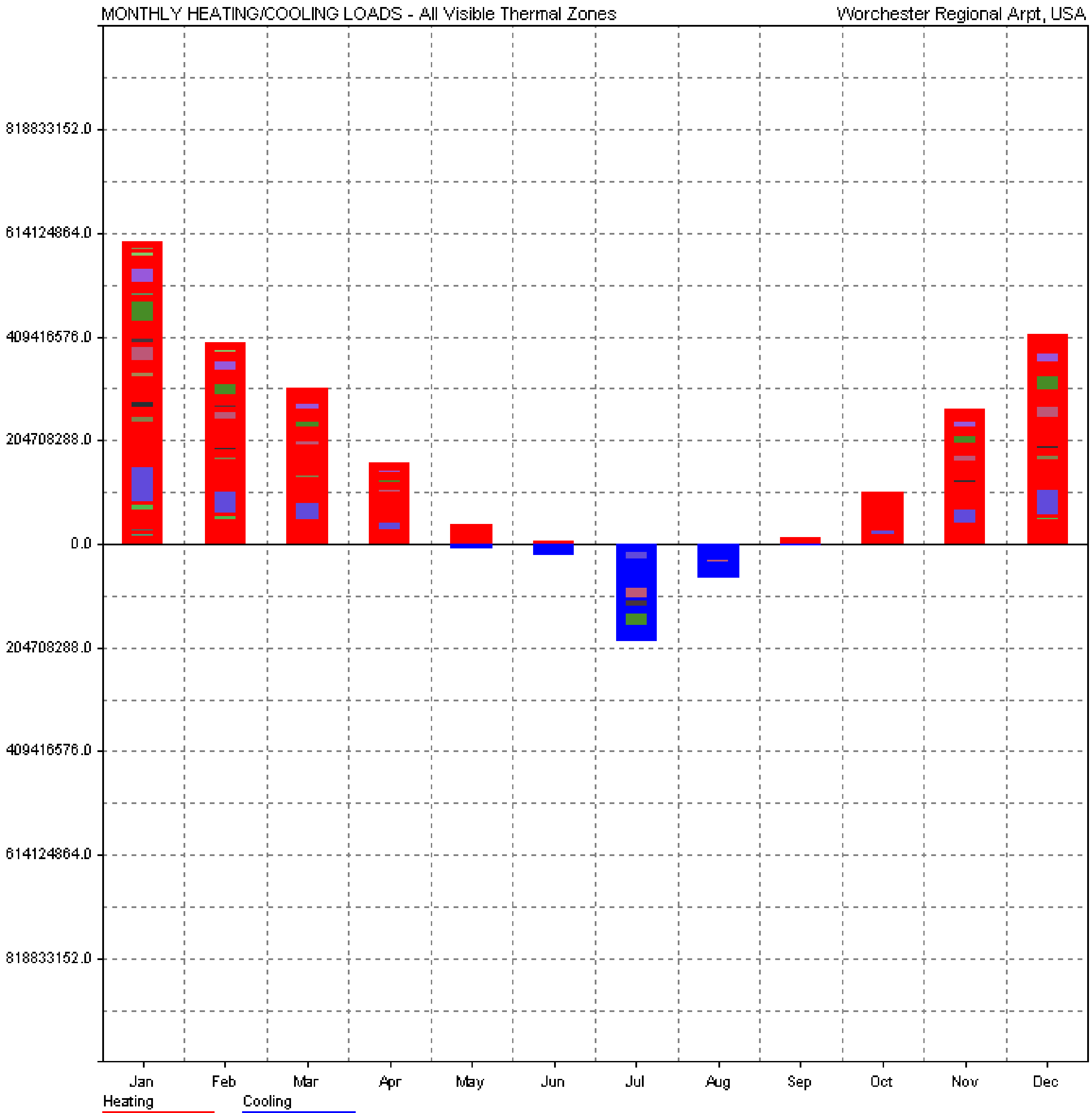
2 inches of insulation (R $\approx$ 8) added to the 6th floor

Max Heating: 5047893.0 Btu/hr at 00:00 on 0th January

Max Cooling: 2745319.8 Btu/hr at 00:00 on 0th January

MONTH	HEATING (Btu)	COOLING (Btu)	TOTAL (Btu)
Jan	680501056	0	680501056
Feb	457300096	0	457300096
Mar	357528800	3835	357532640
Apr	191937936	1002422	192940352
May	46447240	7319040	53766280
Jun	9976327	15759121	25735450
Jul	1117913	196502992	197620896
Aug	1669380	64092996	65762372
Sep	17195738	702342	17898080
Oct	125427176	11720	125438896
Nov	307040256	0	307040256
Dec	473117120	0	473117120
TOTAL	2669258752	285394432	2954653184

3 inches of insulation (R $\approx$ 12) added to the 6th floor



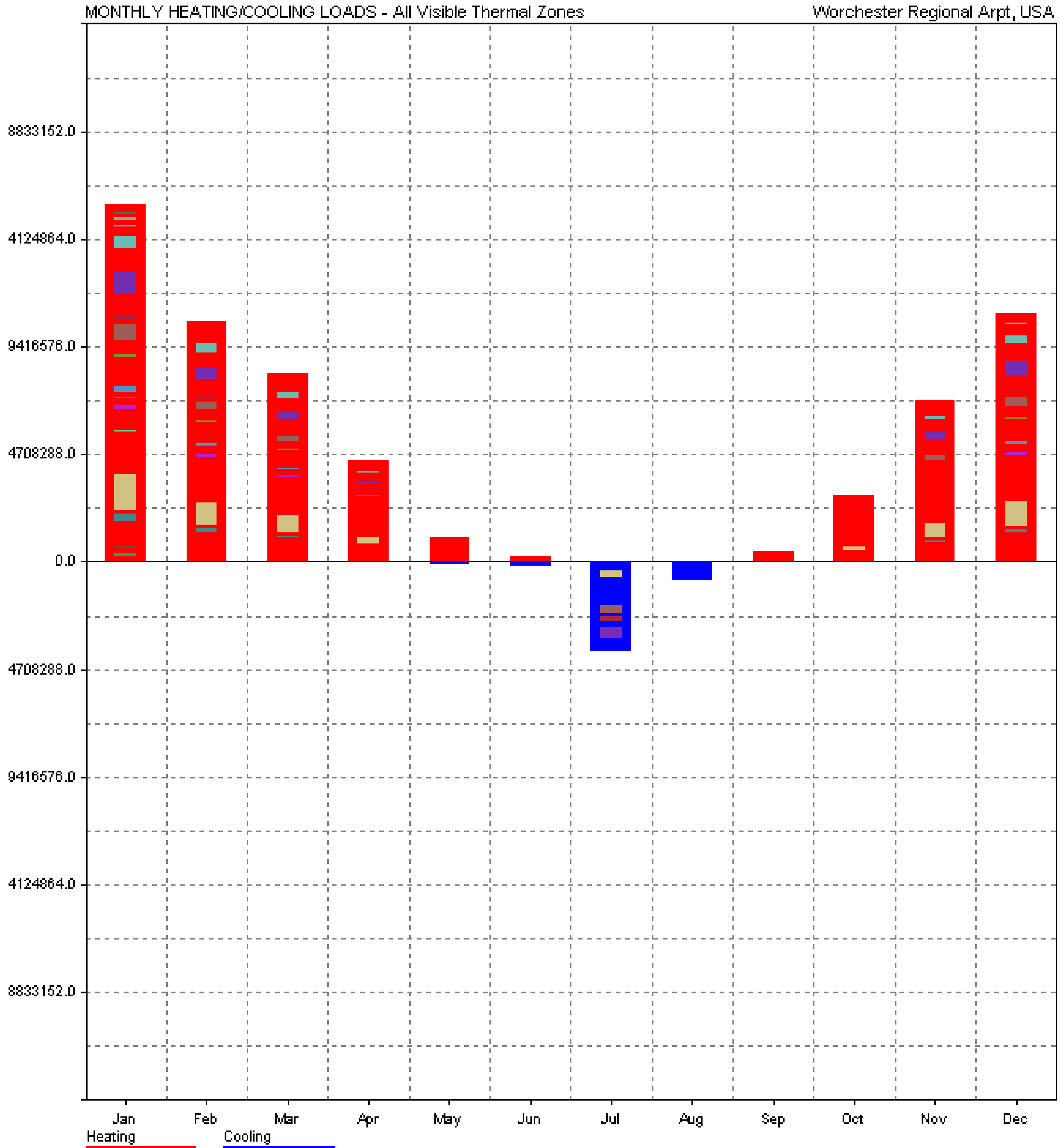
3 inches of insulation (R $\approx$ 12) added to the 6th floor

Max Heating: 5047893.0 Btu/hr at 00:00 on 0th January

Max Cooling: 2745319.8 Btu/hr at 00:00 on 0th January

MONTH	HEATING (Btu)	COOLING (Btu)	TOTAL (Btu)
------------	-----------	---------- --	---------
Jan	680501056	0	680501056
Feb	457300096	0	457300096
Mar	357528800	3835	357532640
Apr	191937936	1002422	192940352
May	46447240	7319040	53766280
Jun	9976327	15759121	25735450
Jul	1117913	196502992	197620896
Aug	1669380	64092996	65762372
Sep	17195738	702342	17898080
Oct	125427176	11720	125438896
Nov	307040256	0	307040256
Dec	473117120	0	473117120
------------	-----------	---------- -----------	
TOTAL	2669258752	285394432	2954653184

Thermostat range raised from 68-75 to 68-76



Thermostat range raised from 68-75 to 68-76

Max Heating: 5045516.5 Btu/hr at 00:00 on 0th January

Max Cooling: 2672468.0 Btu/hr at 00:00 on 0th January

MONTH	HEATING (Btu)	COOLING (Btu)	TOTAL (Btu)
------------	-----------	---------- -	----------
Jan	680375168	0	680375168
Feb	457241920	0	457241920
Mar	357926112	3595	357929728
Apr	192539360	487852	193027216
May	47658544	4936210	52594752
Jun	10476495	7525424	18001920
Jul	1143590	168427360	169570944
Aug	2031627	36012140	38043768
Sep	18161184	66874	18228058
Oct	126248696	2774	126251464
Nov	307163200	0	307163200
Dec	473031104	0	473031104
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TOTAL	2673997056	217462240	2891459328

Thermostat range raised from 68-75 to 69-76

Max Heating: 5127912.0 Btu/hr at 08:00 on 23rd January

Max Cooling: 2672468.0 Btu/hr at 11:00 on 10th July

MONTH	HEATING (Btu)	COOLING (Btu)	TOTAL (Btu)
Jan	697417536	0	697417536
Feb	471841856	0	471841856
Mar	372063680	3619	372067328
Apr	204740496	489511	205230000
May	53842856	4936392	58779252
Jun	12941462	7523888	20465350
Jul	1719799	168365760	170085568
Aug	3068534	35949196	39017728
Sep	22490064	66757	22556820
Oct	138119104	5193	138124288
Nov	322577152	0	322577152
Dec	488613440	0	488613440
TOTAL	2789436160	217340320	3006776320

Appendix G: Oil Usage Data on the City of Worcester in FY 2010, 2011, 2012, and part of 2013

CITY HALL OIL USAGE AND COSTS FOR FY10-FY13

FY13

DATE	QUANTITY	COST	COST / Gal	Mbtu generated	$/Mbtu
7/6/2012	227	814.02	$ 3.59	31.5097619	25.8339
7/5/2012	200.8	737.14	$ 3.67	27.87295238	26.44643
7/9/2012	194.2	702.03	$ 3.61	26.95680952	26.04277
7/11/2012	192.4	699.76	$ 3.64	26.70695238	26.20142
7/13/2012	211.4	773.09	$ 3.66	29.34433333	26.34546
TOTALS	**1025.8**	**$ 3,726.04**	**$ 3.63**	**142.3908095**	26.1677

FY12

DATE	QUANTITY	COST	COST / Gal	Mbtu generated	$/Mbtu
10/19/2011	4500	14056.65	$ 3.12	624.6428571	22.5035
12/12/2011	3980.8	12072.57	$ 3.03	552.5729524	21.84792
1/11/2012	3519.6	11471.08	$ 3.26	488.554	23.47966
1/11/2012	4100	13362.72	$ 3.26	569.1190476	23.47966
2/6/2012	4100	13389.37	$ 3.27	569.1190476	23.52648
3/7/2012	3934.2	13087.9	$ 3.33	546.1044286	23.96593
6/20/2012	199.9	713.84	$ 3.57	27.74802381	25.7258
6/22/2012	278.1	965.29	$ 3.47	38.60292857	25.00562
6/25/2012	181.7	632.13	$ 3.48	25.22169048	25.06295
6/29/2012	201.6	698.54	$ 3.46	27.984	24.96212
TOTALS	**24995.9**	**$ 80,450.09**	**$ 3.22**	**3469.668976**	23.18668

FY11

DATE	QUANTITY	COST	COST / Gal	Mbtu generated	$/Mbtu
3/29/2011	4076.5	$ 13,063.14	$ 3.20	565.8570238	23.08558
2/23/2011	4002	$ 11,886.74	$ 2.97	555.5157143	21.39767
2/9/2011	4007.2	$ 11,637.71	$ 2.90	556.2375238	20.9222
1/20/2011	4590.5	$ 12,916.29	$ 2.81	637.205119	20.27022
1/10/2011	4013.3	$ 10,654.11	$ 2.65	557.0842619	19.12477
12/9/2010	4493.8	$ 11,534.24	$ 2.57	623.7822381	18.49081
10/7/2010	6010.8	$ 14,391.06	$ 2.39	834.3562857	17.2481
TOTALS	**31,194**	**$ 86,083.29**	**$ 2.76**	**4330.038167**	19.88049

FY10

DATE	QUANTITY	COST	COST / Gal	Mbtu generated	$/Mbtu
3/29/2010	4091.5	$ 8,993.94	$ 2.20	567.9391667	15.8361
3/5/2010	4355.2	$ 9,347.13	$ 2.15	604.5432381	15.46147
2/17/2010	4546.6	$ 9,323.71	$ 2.05	631.111381	14.77348
1/28/2010	4400.6	$ 10,263.08	$ 2.33	610.8451905	16.80144
1/22/2010	4000.1	$ 9,035.03	$ 2.26	555.2519762	16.27195
12/30/2009	4037	$ 8,143.44	$ 2.02	560.3740476	14.53215
10/13/2009	320.2	$ 653.29	$ 2.04	44.44680952	14.69824
TOTALS	**25,751**	**$ 55,759.62**	**$ 2.17**	**3574.51181**	15.59923

	QUANTITY	COST			Mbtu generated		Variance
Average	27,313.7	$ 74,097.67			3791.406317		N/A
Ecotect- initial	N/A	N/A			2929.014		0.22746

Appendix H: Proposal to Sponsors

Worcester City Hall MQP Proposal

MQP Group Members: Samantha Varnerin, Josh Brodin

MQP Group Advisors: Professor Guillermo Salazar, Professor Frederick Hart

The "Worcester City Hall: Energy Analysis and Building Information Modeling" project will be an effort to bring a historical building up to more modern and sustainable standards using Building Information Modeling and Energy Analysis software. This effort will be undertaken by two students from the WPI community, Samantha Varnerin and Josh Brodin, as an attempt to fulfill their Major Qualifying Project (MQP) requirement. Ideally, the execution of this project will identify potential energy improvements that can be made on Worcester City Hall. A complete list of tasks and projected finish dates are outlined in Table 1, and they are also outlined in the following:

First, the MQP project members plan to educate themselves on how to conduct an energy analysis. This will include research on how past energy analysis were conducted, especially ones that involved BIM software. Through this, the project members will decide on an energy software package that best fits the scope of the energy analysis.

While doing this research, the project members will begin to analyze the plans, specifications, and other available information about the building. Other actions include visiting the Worcester Historical Society, gathering past bills for the building's electrical use, and collecting any other paper and electronic resources available that will help build the BIM envelope for the building. Once enough information about the building has been obtained, the group members will define the layout of the Worcester City Hall for an energy analysis using Building Information Modeling (BIM) software. The preferred software for this use is Revit Architecture. The envelope will be created so the energy-related components within the City Hall can be evaluated for performance using an energy analysis software package.

Once the BIM is built and analyzed using the energy analysis software, the group members will research feasible potential improvements to Worcester City Hall. They will report the various solutions that can be applied to improve the City Hall as well as the financial and environmental impacts of those solutions. These analyses will be as in-depth as time allows. In addition, the group members will also recommend potential uses for their model. The computer model will be available to the Worcester City Hall staff and any future WPI MQP groups. Solutions for the energy analysis and future BIM uses will be sent to the sponsors and any other appropriate authorities for review and possible implementation.

Task	Projected Start Date	Projected Finish Date
Define project task and scope	8/31/2012	9/14/2012
Gather information on conducting energy analyses	8/31/2012	9/21/2012
Choose an energy analysis software package	9/07/2012	9/21/2012
Analyze plans and specifications of building	9/27/2012	10/12/2012
Create BIM envelope using Revit Architecture	10/23/2012	11/21/2012
Preliminary energy analysis outputs	11/21/2012	12/10/2012
Progress meeting preparation and information gathering	12/10/2012	12/14/2012
Edit BIM	12/14/2012	1/10/2013
Energy analysis and comparison to actual costs	1/14/2012	1/21/2013
Modify model for precision	1/22/2013	1/29/2013
Modify model for efficiency	1/30/2013	2/22/2013
Cost analysis for efficient model	2/08/2013	2/22/2013
Identify future uses of BIM Model	2/10/2013	2/19/2013
Prepare report and presentation for Worcester City Hall	02/19/2013	2/28/2013

Table 1: List of tasks and projected finish dates.

In order to accomplish this project efficiently and accurately, the group members may ask for access to the following resources:

- **All available information from Worcester City Hall regarding the building.** This would include access to the AutoCAD files, information on the materials of the building, etc.
- **Records of the City Hall's energy costs** for the past three years.
- **Contacts for Honeywell, Guth De Conzo, and any other companies associated with recent renovations** for Worcester City Hall that can give the MQP group more information on the building should they have questions related to the building's renovations or design.
- **Access to the City Hall.** The MQP group will communicate when they need access to the building.

Appendix I: List of Names of Files and Documents Used for this Project

The files listed in this appendix are located within the folder titled "Worcester City Hall Project Files" that came with this report.

-City Hall BIM Model.rvt

-Ecotect Files (File Folder):

The following .eco files also come with the .adj and .shd files that our group generated.

- 1 inch of insulation added to the 2nd floor
- 1 inch of insulation added to the 6th floor
- 2 inches of insulation added to the 2nd floor
- 2 inches of insulation added to the 6th floor
- 3 inches of insulation added to the 2nd floor
- 3 inches of insulation added to the 3rd floor
- 3 inches of insulation added to the 4th floor
- 3 inches of insulation added to the 5th floor
- 3 inches of insulation added to the 6th floor
- 3 inches of insulation to every floor and double pane windows
- City Hall Model – not modified
- Model with double pane windows

-Excel Spreadsheets (File Folder):

- Average Number of people working for the City of Worcester by year
- City Hall Oil Usage with conversions to MBTU
- Energy usage by month of initial model and modified models
- Room labels and people content

-Files from Worcester City Hall (File Folder):

The following files were given to our group by our sponsors at Worcester City Hall.

- City Hall floor plans and existing conditions (file folder)
  - A 1–1,2,3 Elevations.dwg
  - A 1-1 West Elevation.pdf
  - A 1-2 East Elecation.pdf
  - A 1-3 North & South Elevations.pdf
  - City Hall Existing Conditions Site Plan.dwg
  - Existing Floor Plan 0.dwg

    - Existing Floor Plan 1.dwg
    - Existing Floor Plan 2.dwg
    - Existing Floor Plan 3.dwg
    - Existing Floor Plan 4.dwg
    - Existing Floor Plan 5.dwg
- Floor Plans old (file folder)
    - A1.0 Basement Plan.pdf
    - A1.1 First Floor Plan.pdf
    - A1.1 West Elevation.pdf
    - A1.2 East Elevation.pdf
    - A1.2 Second Floor Plan.pdf
    - A1.3 North & South Elevations.pdf
    - A1.3 Third Floor Plan.pdf
    - A1.4 Fourth Floor Plan.pdf
    - A1.5 Attic Plan.pdf
- Plaza Deck (file folder)
    - 975020-A1.pdf
    - 975020-A2.pdf
    - 975020-A3.pdf
    - 975020-A4.pdf
    - 975020-A5.pdf
    - 975020-A6.pdf
    - 975020-A7.pdf
    - 975020-A8.pdf
    - 975020-A9.pdf
    - 975020-C1.pdf
    - 975020-D1.pdf
    - 975020-D2.pdf
    - 975020-G1.pdf
    - 975020-L1.pdf
    - 975020-S1.pdf
- Windows (file folder)
    - A 2-1 Revised Window Schedule.dwg
    - A 2-1 REVISED WINDOW SCHEDULE.pdf
    - A 2-1 REVISED WINDOW SCHEDULE A 2.pdf
    - A 2-1 Window Schedule.dwg
    - A 3-1 Full Size Window Details.dwg
    - A 3-1 FULL SIZE WINDOW DETAILS A-E.pdf
    - A 3-1 FULL SIZE WINDOW DETAILS F-J.pdf
    - A 3-1 FULL SIZE WINDOW DETAILS K-P T&U.pdf
    - A 3-1 FULL SIZE WINDOW DETAILS RSQV.pdf

- A 3-1 Window Details.dwg
- A 4-1 Window Details.dwg
- A 4-2 Window Details.dwg
- A 4-3 Window Details.dwg
- A 4-4 Window Details.dwg
- A 4-4 WINDOW DETAILS A-4
- Windows details (file folder)
    - SKA-003 – Details 3 10 on Drawing A4-1 SKA-3(1).pdf
    - SKA-004 – Details 3 & 5 on Drawing A4-2 SKA-4(1).pdf
    - SKA-005 – Details 7 9 on Drawing A4-2 SKA-5(1).pdf
    - SKA-006 – Details 12 on Drawing A4-2 SKA-6(1).pdf
    - SKA-007 – Detail 1 on Drawing A4-3 SKA-7(1).pdf
    - SKA-008 – Details 5 & 6 on Drawing A4-3 SKA-8(1).pdf
    - SKA-009 – Detail 9 on Drawing A4-3 SKA-9(1).pdf
    - Wreath Hanging Eye Hook Options.pdf