Mechanical Engineering Building Redesign for Sustainability

University of Illinois

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ME 470 Design Group 17

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May 10th, 2010
Submitted to: Clay G. Nesler

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Executive Summary

The goal of this project is to increase the sustainability of the Mechanical Engineering Building (MEB) at the University of Illinois. Currently, MEB costs the University over $710,000 each year in steam, chilled water, electricity, potable water, and sanitation expenses [1]. We are recommending a number of upgrades to the building, in addition to cultural changes, to help reduce the costs of operating MEB.

The addition of extra insulation and controls for exhaust fans will save the greatest amount of energy. The project will cost $188,500 and produce savings of $46,000 annually with a payback period of 4.1 years. Putting computers in standby mode and reprogramming the handicap door will result in savings up to $8,800 annually, with a payback period of less than one year. The total savings from these improvements is estimated at $55,400. This is equivalent to a 7.8% reduction in utility costs.

The installation of a central Heating, Ventilation and Air Conditioning (HVAC) system will make MEB a more desirable place to learn. The cost of this project is $4.59 million, which includes digital controls. New windows, in addition to the previously described insulation and exhaust fan scheduling, should be implemented with a central HVAC system to reduce the payback period. The bundled project costs $5.52 million with a payback period of 44 years. The result is an annual savings of $68,030 from electricity, steam, and chilled water, representing a 9.5% reduction in utility costs. If the savings from the elimination of window air conditioners and the Carrier rooftop chiller is including, the annual savings jumps to $125,430.

Additional savings should result from changes to the clean room's operational schedule, plumbing improvements, and lighting retrofits. Further analysis needs is required to verify these preliminary findings.

Introduction

MEB at the University of Illinois at Urbana-Champaign (UIUC) is one of two buildings that house the Mechanical Science & Engineering Department (MechSE). MEB is home to the MechSE Department Head, and faculty and staff offices. However, the building's main function is to provide instructional and research space for the students and faculty.

Construction began on MEB in 1947 and was completed in 1951. The building was built in two phases. The south side of the building facing Green Street was completed first in 1950. A year later, the second phase on the north side was completed, which included additional faculty offices and laboratory space [2]. With central heating, MEB was quite advanced for buildings of its day. Today, none of the original ductwork functions, leaving only steam radiators for heat, and window air conditioner (AC) units for cooling. This method for conditioning generally leaves the building too hot, or too cold, making it uncomfortable for the occupants. According to John Prince of Facilities & Services (F&S), the lack of proper conditioning makes the building an unattractive space for holding classes [3]. Further adding to the building's problems, the windows are used to regulate the temperature, rather than the thermostats, venting conditioned air into the environment, increasing operating costs. Given the current economic climate, this is something the University cannot afford.

The purpose of this project is to identify ways of improving the energy efficiency and reducing the carbon footprint of MEB. The goal is to select a combination of projects that reduce energy usage by 20 percent annually, while maintaining a five year or less payback. The projects will focus on reducing the usage of steam, electricity, and chilled water, which together account for over three quarters of the building's annual utility bill [1]. The tasks we performed to identify potential projects are as follows:

- Gather information on the HVAC systems and building construction
- Model the building in eQUEST, an energy simulation software package
- Calibrate the model to match historical utility usage
- Create and run parametric studies for possible projects
- Perform a cost analysis on the proposed project's energy savings
- Recommend projects to reduce the building's energy consumption

eQUEST Procedure

eQUEST is an energy modeling software package that is supported through California's Energy Design Resources program. This program is funded through fees on California utility customers [4]. The software is based on the DOE2 engine written by James J. Hirsch & Associates with help from Lawrence Berkeley National Laboratory [4]. The development of the DOE2 engine was funded by the U.S. Department of Energy. eQUEST is distributed as freeware via the internet and will run on most PC's running Windows 98 or higher [5].

Creating a Building Shell

The first step in building an eQUEST model is the selection of the preferred user interface. There are three options: the Schematic Design (SD) wizard, the Design Development (DD) wizard, and the Detailed User Interface (DI). These three interfaces are listed in order of increasing complexity, which also corresponds to the degree of detail available in the model. We initially selected the DD wizard to model MEB since it simplified the creation of the building's core and provided a simple interface in which to model HVAC systems. The model was later transitioned to the DI where additional information was entered about the building systems. We also used the DI to eliminate errors in the model.

The DD wizard is run from a central Project Navigator interface. From this screen, one can edit and create building shells, air-side HVAC systems, as well as hot and chilled water loops. To begin creating a building shell, select the "Create New Shell" button to enter the wizard.

Screen One

This screen asks for basic information about the shell being created. This includes parameters such as the name of the shell, type of building, square footage, and number of floors in that shell.

Screen Two

The next screen in the wizard is where one specifies the shell footprint and thermal zone layout. eQUEST has the ability to import Computer Aided Design (CAD) drawings, which can then be traced to create a building's footprint and thermal zones, a feature we used in our model. The accuracy of the footprint and thermal zones should be verified before proceeding. Many parameters defined after this point will be erased if the footprint or zones are modified in the future. The floor-to-floor and floor-to-ceiling heights are also specified in screen two.

Screens Three & Four

In screen three, the building envelope construction is specified. The roof, above grade walls, and ground floor constructions are created on this screen. eQUEST automatically calculates the thermal conductivity of the envelope based on the values the user inputs. eQUEST includes a library of common building materials, however custom materials and constructions can be created in the DI. Screen four specifies the construction of interior walls and ceilings in a similar fashion.

Screens Five & Six

Screens five and six pertain to the construction and placement of doors and windows. In both screens, one can specify the type of glass or door, its size, and how many are on each face of the shell. Screen six also contains an option for custom door and window placement, which lets the user to specify the dimensions and placement of each door and window individually.

Screen Seven

Subsequently, the user is directed to screen seven, where the exterior and interior window shades are specified. The depth of any overhangs and fins on the exterior of the building can be set for each side of the shell. For interior shades, the type of shade and the percentage of time it is closed should be input. This is done for times when the building is occupied and unoccupied.

Screen Eight

Screen eight is for the creation of roof skylights. The user can select the type of skylight and define the percentage of the building's area that they cover. Custom skylight placement is also available.

Screen Twelve

Due to the options and building characteristics we have input into our model up until this point, eQUEST has omitted certain wizard screens. The wizard then transitions to screen twelve where the building operation schedule is defined. Up to three seasons can be specified, with building operation times for each day of the week, including holidays.

Screen Thirteen

The building area usage is specified on screen thirteen. The type of area is selected from a built-in list, which includes usages such as laboratory, office, kitchen, etc. The percentage of the total building square footage devoted to each use is required. Screen thirteen also contains the designed square footage per occupant, design ventilation per person in cubic foot per minute (CFM), and whether the area is a core or perimeter zone.

Screen Fourteen

On screen fourteen, thermal zones are grouped together and assigned to an HVAC system. A description of how to create an HVAC unit is described in the next section.

Screen Fifteen

Both interior and exterior non-HVAC end uses are specified on screen fifteen. Interior end uses include items such as ambient and task lighting, office equipment, cooking equipment, and other equipment that contributes to space thermal loads. For the end uses selected, the space loads in Watts per square foot [W/ft^2] must be specified for each usage area assigned in screen thirteen. This concludes the steps required to create a building shell in the DD wizard.

Creating an HVAC System

The process for creating an HVAC system using the DD wizard is as follows. In the Project Navigator screen, select the "Create New System" button to begin.

Screen One

In screen one, the system name, cooling source, heating source, and hot water source are specified. The type of HVAC system being modeled should also be indicated before continuing. Finally, the return air path is selected, along with the thermal zones that the system will be assigned to.

Screen Two

The seasonal thermostat setpoints are input on screen two for each of the previously defined operational schedules. This is done for when the building is both occupied and unoccupied. The designed supply temperatures for heating and cooling are also specified on screen two. Lastly, the minimum design airflow in CFM per square foot is specified.

Screen Four

Screen four contains the information on supply and return fans. For both fan types, the pressure head in static inches of water, efficiency (standard, high, or premium), and fan type can be input. For fan flow and outside air, eQUEST has an auto-sizing feature that automatically determines these values based on the other information defined by the user.

Screen Five

On screen five, the fan schedules are set for each of the previously defined operational schedules. This includes on and off times for each day of the week, including holidays.

Screen Seven

The last screen of the HVAC wizard is for baseboard heating and economizers, however steam radiators can only be modeled in the DI. At this point, we return to the Project Navigator screen. One can then create or edit building shells and HVAC systems.

Once all the desired building shells and HVAC systems have been created, the model can be to transitioned to the DI, if required. Before doing this, **it is crucial that a copy of the model is saved**. After the model is transitioned into the DI, it cannot be transitioned back into either wizard mode without erasing all changes made in the DI. Many times, the transition to the DI is necessary to solve errors or create a more detailed model.

Detailed User Interface

The first step in transitioning the model to the DI is solving the errors. To do this, the model is compiled and the errors are shown in the Building Description Language (BDL) Error Manager. Errors can be selected for additional information about the error and its origin. Once an error is corrected, it will no longer appear in the BDL Error Manager after the model is recompiled. It is not possible to run simulation results or parametric runs in eQUEST if there are any errors in the model. **Thus, it is very important to solve any errors before proceeding with the modeling.**

After solving the errors, the DI can be fully utilized. Through this interface, highly accurate models can be created for the most complex systems. We modeled each of the window AC units and the HVAC systems for both the clean rooms in the DI. This allowed for greater control over temperature setpoints, humidity, and heating and cooling coil parameters. The campus chilled water and steam loops were also created in the DI. Since both the chilled water and steam loops are campus-wide loops, we assumed that their capacities were essentially infinite. Meters were created for each loop to monitor usage, which in turn was converted to cost through utility rates provided by F&S [6]. To view the chilled water and steam usage, it was necessary to delete the chiller and boiler, which eQUEST created automatically.

Parametric Runs

After the calibration process is complete, the model is ready to accept parametric runs. Calibration is discussed in more detail in the next section. Through the Parametric Run Definition tool, one can create multiple parametric runs, each with its own unique conditions. A parametric run can modify several features in the model in a single run, which is done by adding multiple parametric components under the same parametric run. Parametric components can modify anything from the type of insulation, to the schedules of building systems, to the wattage of the lighting. When the creation of a parametric run is complete, a simulation is run to gage the potential impact on energy usage.

Table 1: Summary of the parameters changed in the parametric runs, and their new values

Parameter Changed	New Value
Window 1	SHGC 0.24, U-0.11
Window 2	SHGC 0.24, U-0.20
Window 3	SHGC 0.24, U-0.28
Window 4	SHGC 0.34, U-0.11
Window 5	SHGC 0.34, U-0.20
Window 6	SHGC 0.34, U-0.28
Window 7	SHGC 0.44, U-0.11
Window 8	SHGC 0.44, U-0.20
Window 9	SHGC 0.44, U-0.28
Insulation 1	R-10.3
Insulation 2	R-20
Exhaust Fan Scheduling	On from 7am-9pm
Central HVAC	VAV with DCV, provides heating and cooling

Table 1 summarizes the parametric runs that we ran in our model. We created nine different window types with varying Solar Heat Gain Coefficients and U-values to determine which combination provided the best energy savings. Two different levels of insulation were tried, each with different R-values. We also applied schedules to the exhaust fans in the building.

Finally, a Variable Air Volume (VAV) HVAC system with Demand Controlled Ventilation (DCV) was created. This system used chilled water and steam from the campus loops.

After the parametric runs were defined, we grouped them together to find the combination that saved the greatest amount of energy. Occasionally, a change was too substantial to easily create a parametric run. This was the case when switching the building from window AC units to central HVAC. To simulate this modification, a new model was created with the updated HVAC system and compared to the original model.

Results and Discussion

Model Calibration

In order to have meaningful results, the eQUEST model must be calibrated so the simulated results match the historical data. Calibration is performed after all the desired information has been input into the model. The process begins by running a simulation and graphing the results with the historical data. An accurate model will match the trends in the actual data. This means the ratio of the base loads to the peak loads will be the same in the model and historical data. When the ratios are not equal, parameters in the model, such as infiltration or assumed heat loads, are changed until the numbers converge. This process is accomplished mainly through trial and error. After the ratio of the base loads to the peak loads is accurate, the data from eQUEST can be scaled up to match the magnitude of the historical data. Generally, the model shows usage numbers that are 33-50% of actual usages. According to Brandon Tinianov and Alex Krickx from Serious Materials, this is the standard that the industry uses [7]. To scale up a model, results from eQUEST are multiplied by a constant number. This number is selected so that the simulated usage values each month roughly match the historical usage. This proved to be more difficult than originally expected due to some anomalies in the historical utility data, which are shown in Appendix E. When this occurred, we either averaged the usage amounts from multiple years, or made a guess on a reasonable utility usage.

Figure 1 is a plot of MEB's actual electricity usage for 2009 with the simulated energy usage from eQUEST for the same period. The simulated data is about 30 percent lower than the actual data. But, the ratio of the base loads to the peak loads is approximately equal in both the actual and simulated usages. The overall trend of the data also matches well. To finish calibration on electricity, we selected a scaling factor of 1.35, which brought the simulated results to the same level as the historical data. Figure 2 is the same as Figure 1, except the simulated usage values are scaled by our scaling factor, which gives an annual error of 0.9 %. The figure and percent error show that the model can very accurately predict savings in electricity.

Our model was much less accurate for steam. The actual usage for steam follows a step function. The usage of steam in the winter is roughly constant from October through March at 2,000 GBTU. In the summer months, April through September, usage is roughly constant at 750 GBTU. eQUEST did not follow the actual usage, and instead modeled the steam usage as a smooth, sloping curve. The actual usage and scaled eQUEST results are shown in Figure 3. We used a scaling factor of 2.9 for steam usage, which results in an annual error of 0.4%. Despite this low annual error, the monthly error ranges from -64 % to 70 %. This error is a consequence of our model not matching the trends of the actual data. Due to the large month error, savings from steam usage should be view with some degree of skepticism.

Finally, Figure 4 displays the actual usage and eQUEST's scaled results for chilled water usage. We used a scaling factor of 1.7, which gives an annual error of 7.3 %. Chilled water has a large annual error is because our model did not have the same base usage to peak usage ratio as the historical usage. This is why the scaled usage overestimates the usage in summer months, and underestimates usage in the winter months.

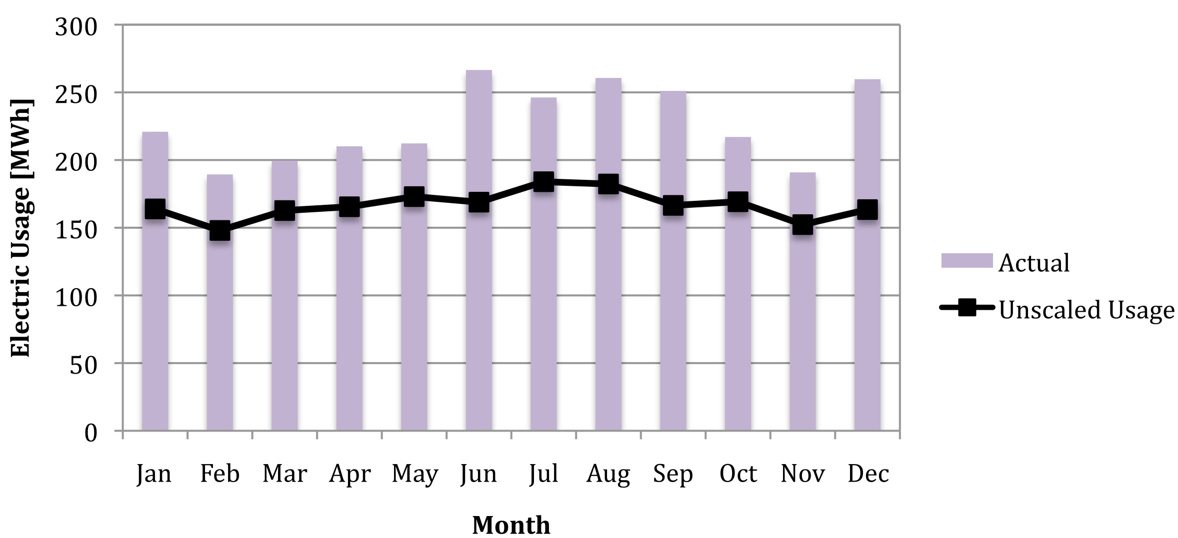

Figure 1: The actual electrical usage in 2009, compared with the simulated results from eQUEST

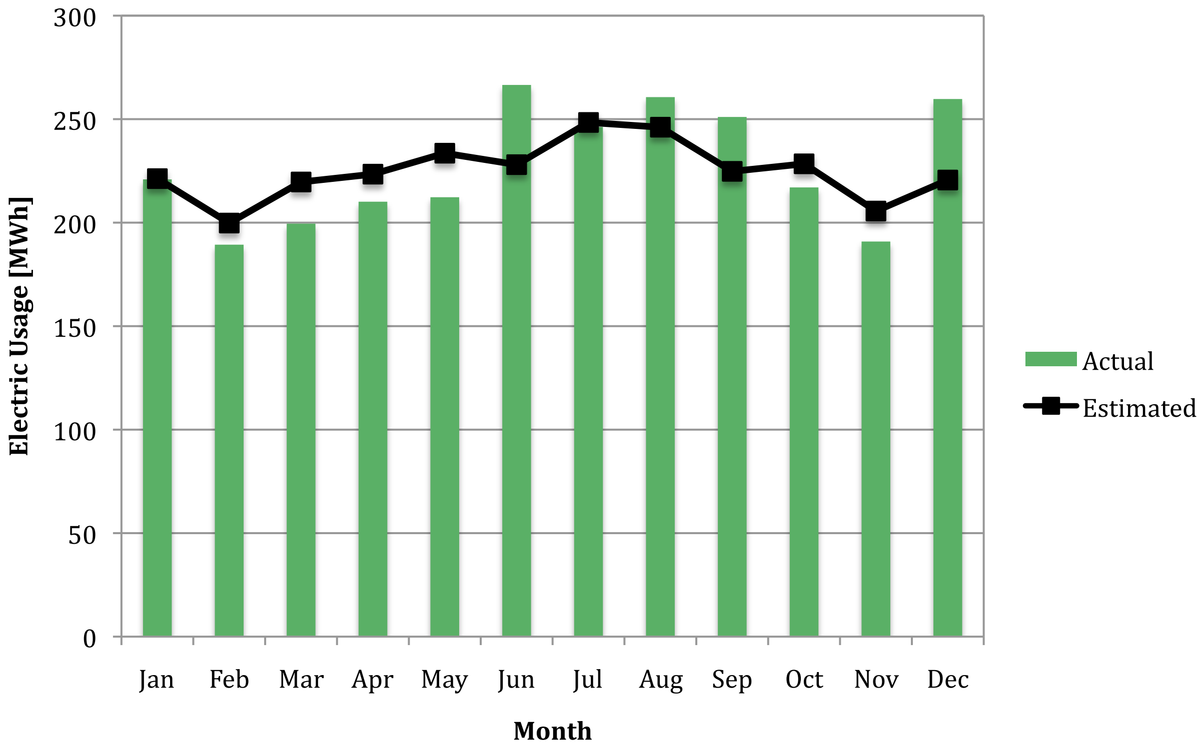

Figure 2: The actual electrical usage in 2009, compared with the scaled results from eQUEST

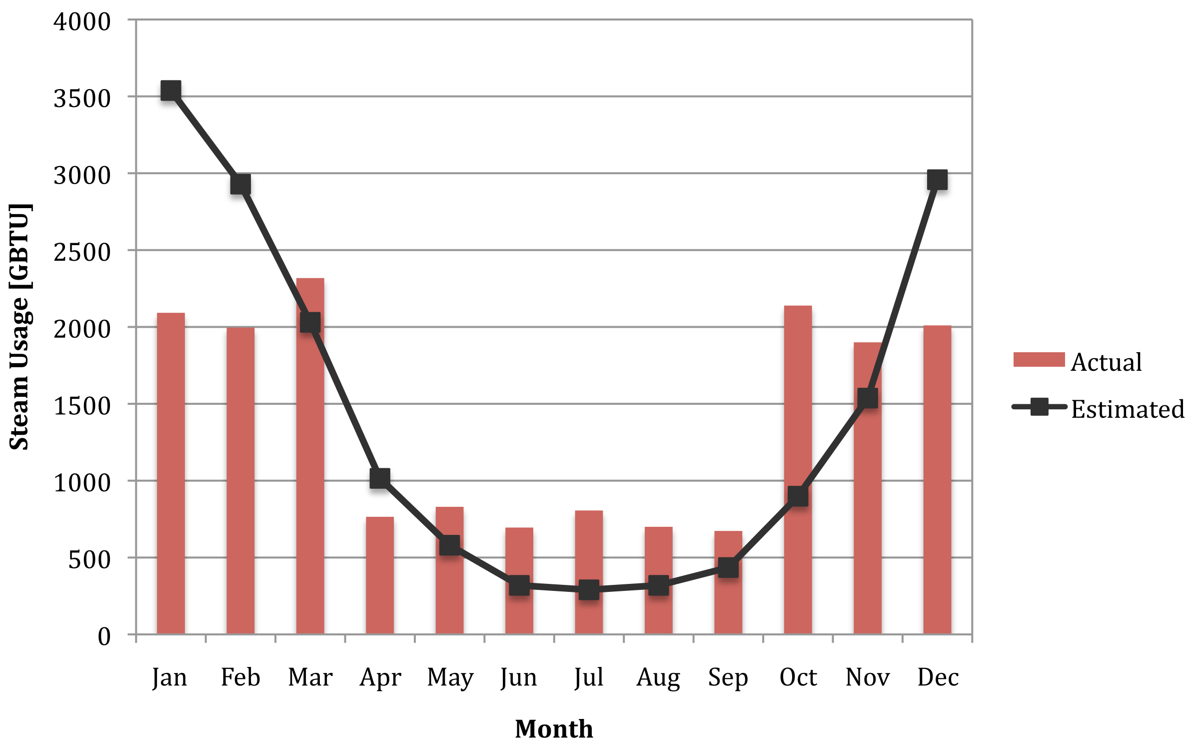

Figure 3: The actual steam usage in 2009, compared with the scaled results from eQUEST

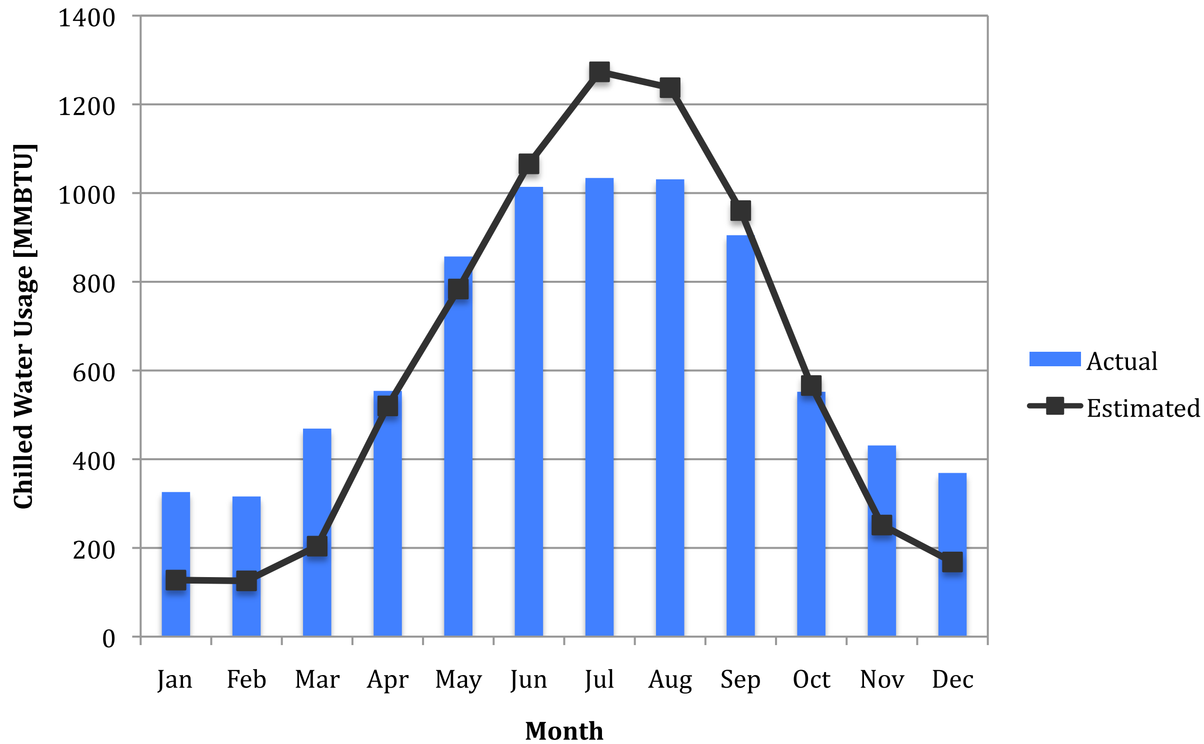

Figure 4: The actual chilled water usage in 2009, compared with the scaled results from eQUEST

Possible Solutions

To reduce the energy usage in MEB, we studied four main projects in detail. These projects are new, windows, additional insulation, exhaust fan scheduling, and the installation of a central HVAC system. The new windows and central HVAC system were studied at the request of the Sponsor. Four additional projects were investigated briefly for possible savings.

Windows

The windows in MEB today are the same windows that were installed when the building was built in the 1950's. Thus, the windows have been in use for around 60 years with little to no improvements made to a majority of them. All the windows in the building are double hung, single-paned with a wood frame. Additionally, the frames for many of the windows are in poor condition, consisting of rotting or peeling wood. Weatherstripping is absent from a large number of the windows, and if present, is in poor condition like the window frames. The lack of weatherstripping, coupled with the use of window AC units in many of the rooms leads to a high infiltration value for the whole building. To determine the exact value of infiltration, it is necessary to pressure test MEB, something we were unable to accomplish, thus the exact value of infiltration remains unknown. In comparison to many of the other buildings on campus, especially a more modern one, MEB unquestionably has a higher infiltration value.

The technical specifications of the windows are not known accurately. The building drawings do not reveal any additional information about the windows that could not be gained by looking at them in person. However, an average single-pane, wood frame window with clear glass has an overall heat transfer coefficient (U-value) of 0.90 BTU/hr*F*ft^2, and a Solar Heat Gain Coefficient (SHGC) of 0.70 [8,9,10]. To limit the amount of heat leaving or entering the building through a window, the U-value should be a small number, closer to zero. The SHGC is a number from 0 to 1 that measures how much heat from the sunlight enters a building. Glass with a high SHGC lets more solar heat into a building. These poor performance numbers, coupled with the large amount of windows in MEB (188 total windows totaling 13,100 ft^2) leads to huge energy losses, raising the cost to operate the building.

In our eQUEST model, we experimented with several glass types, inputting various U-values and SHGC to find the combination that maximized the energy savings. The different glass type we tried is listed in Table 1. The best combination was a center-of-glass U-value of 0.11 and a SHGC of 0.44. We contacted Serious Materials for a quote on new windows for MEB that matched this specification. They recommended their 525 Series double-hung windows, which have a full-frame U-value of 0.26 and a SHGC of 0.41 [11]. According to Karen Vaites from Serious Materials, this full-frame performance is roughly equivalent to the improved glass we modeled in eQUEST inside the old, wood frames [12]. The 525 Series windows are double-pane, fiberglass frame windows with super-insulating glass. They also contain a suspended film between the two glass panes, and are filled with an inert gas.

Table 2: Summary of the simulated savings from installing new windows

WINDOWS			
Electricity (MWh)	$11,940	161	6.0%
Steam (MMBTU)	$18,010	1,044	6.2%
Chilled Water (MMBTU)	$2,080	194	2.7%
Total Savings ($)	$32,030		

Serious Materials' initial cost estimate was $65 per square foot, which equates to a total cost of approximately $852,000 to replace all the windows in MEB, including labor. These windows would produce annual savings of 161,000 kWh, or $11,940 in electricity, 1,044 MMBTU, or $18,010 in steam, and 194 MMBTU, or $2,080 in chilled water, for a total project savings of $32,030. This is equivalent to a 6.0% reduction in electricity usage, 6.2% reduction in steam usage, and a 2.7% reduction in chilled water usage. The savings are summarized in Table 2. In addition, Figures 5-7 show graphically the reduction in usage per month in electricity, steam, and chilled water. The addition of windows leads to a large decrease in usage for all three of these utility areas over the baseline model. A reduction of 338,970 tons of carbon dioxide would also be realized each year. Using simple payback, which is the time needed to recover any initial investment, the payback period for new windows is 26.6 years, well over the five year requirement for projects on campus. However, these windows are eligible for tax credits under certain circumstances, which would help reduce the payback period. Additionally, when the new windows were modeled in eQUEST, the infiltration was not altered. In reality, when new windows are put into MEB, the infiltration will decrease, saving additional energy, further reducing the payback.

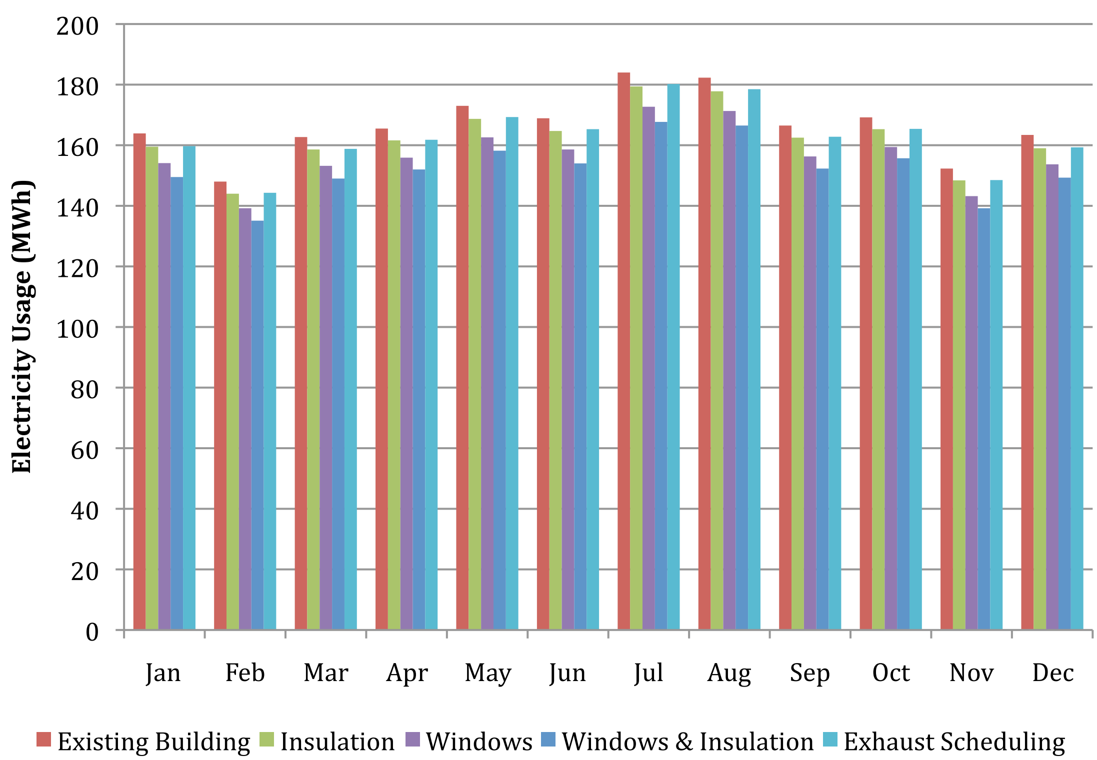

Figure 5: Results from Parametric Runs showing the simulated electrical savings

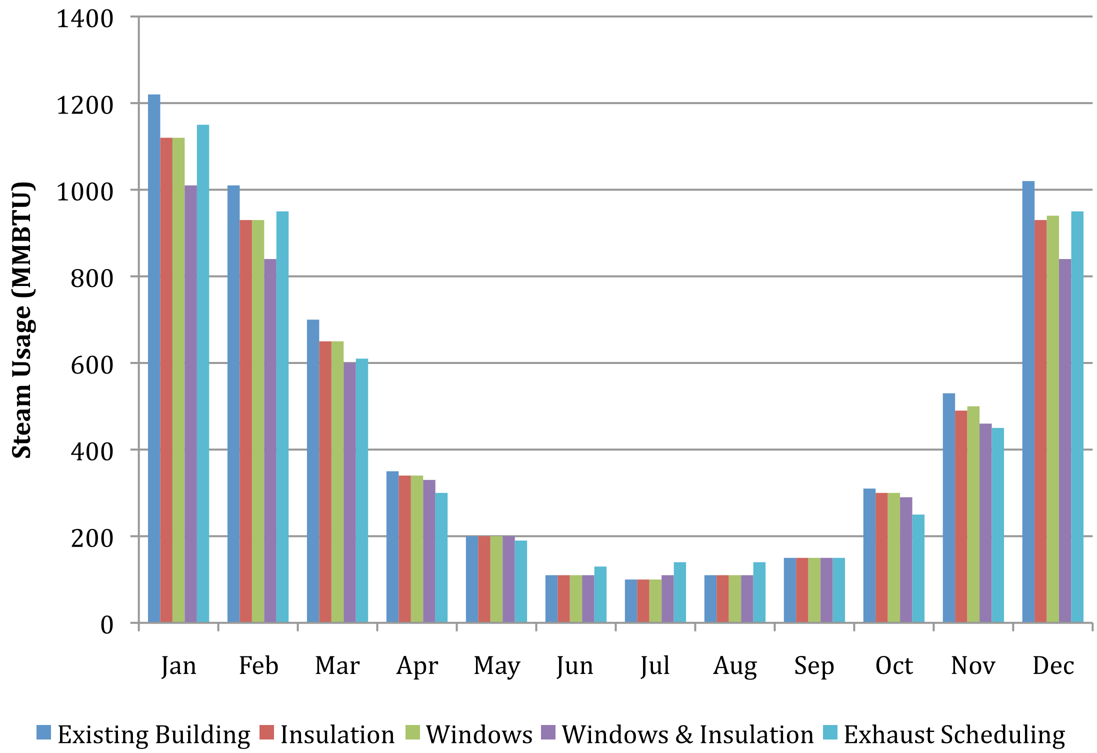

Figure 6: Results from Parametric Runs showing the simulated steam savings

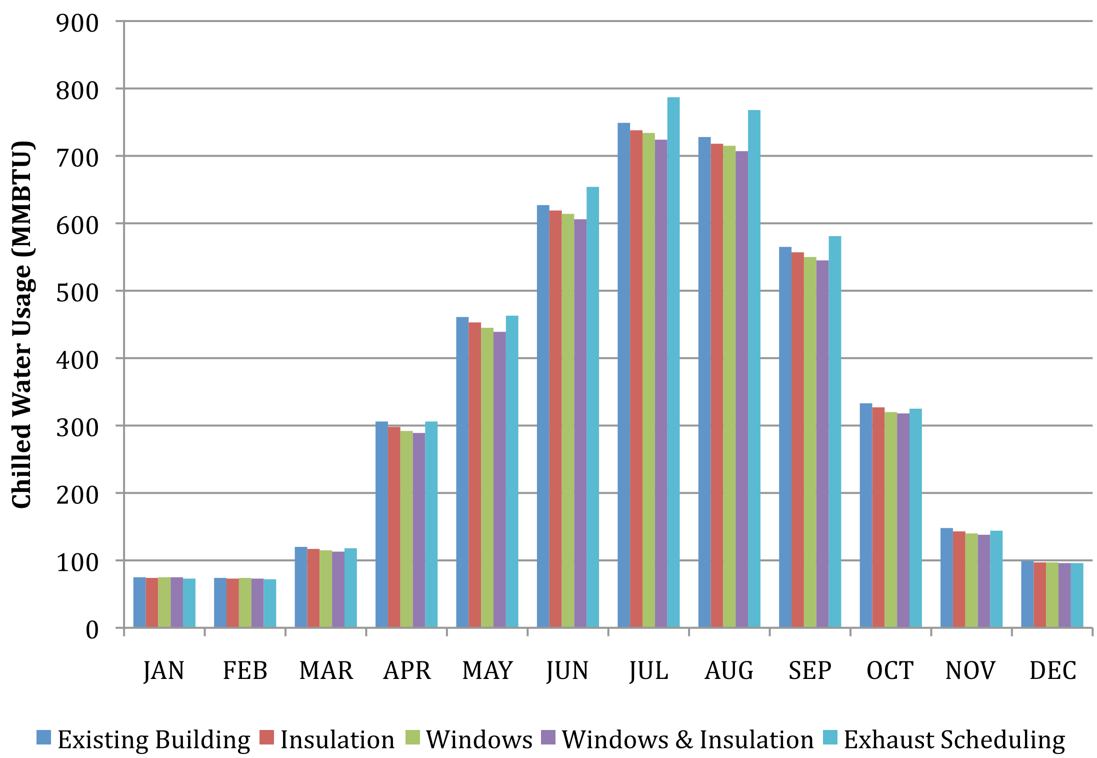

Figure 7: Results from Parametric Runs showing the simulated chilled water savings

Envelope Insulation

When MEB was built, no insulation was added to the exterior walls of the building. The walls in MEB are made up of three layers: face brick, concrete blocks, and plaster. An architectural drawing of the walls is shown in Figure 8. The face brick, shown in red, is the exterior of the building. The concrete blocks, shown in green, are located just inside the brick. Finally, the plaster makes up the visible interior wall. Based on this drawing, there are no air gaps between any of the three components of the exterior wall. According to eQUEST, the R-value of the wall is R-3 hr*F*ft^2/BTU. Performing this calculation by hand, we obtained an R-value of R-2.62 by using tables to find each material's R-value [13]. To put this number in perspective, some types of cardboard have R-values of up to R-4 [14]. Furthermore, the Department of Energy recommends that new constructions have an R-value between R-13 and R-15 [15]. The building currently falls well below these standards, leaving a large amount of room for improvement.

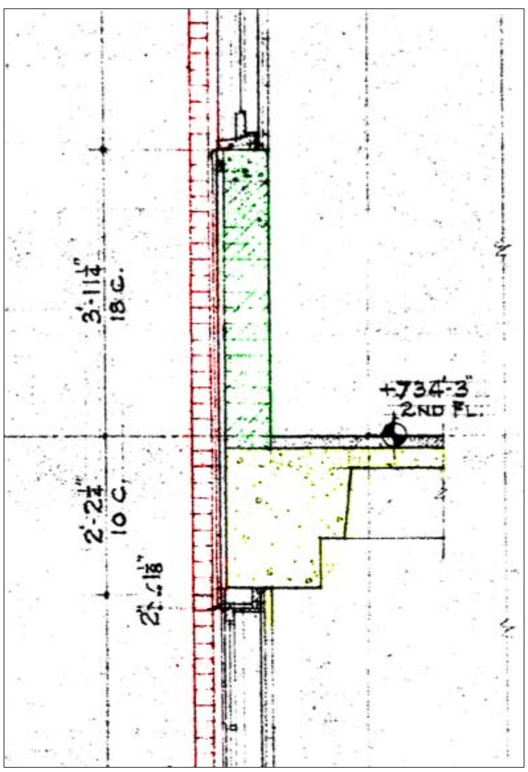

Figure 8: Architectural drawing of the exterior walls

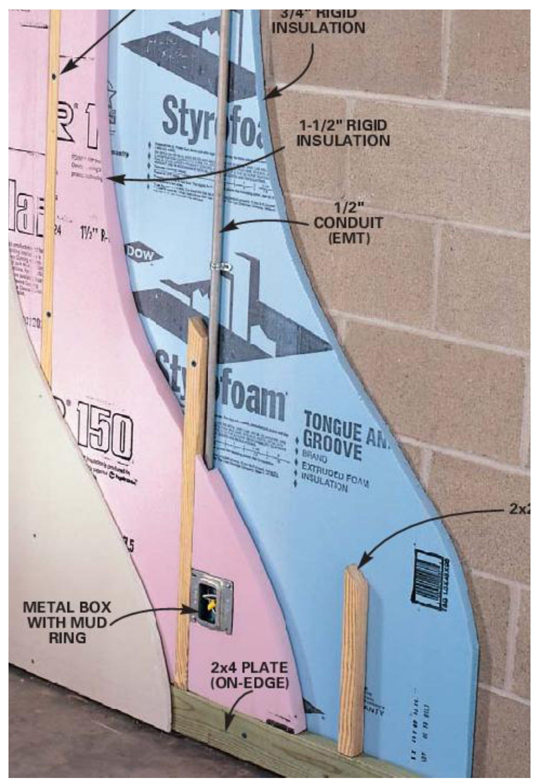

Figure 9: An example of the furring process

The solution we recommend is to add additional insulation to the inside of the exterior walls through a process known as furring. Essentially, this process creates a new interior wall through the addition of material on the inside of the exterior wall. An example of a furring process is shown in Figure 9. In this picture, multiple layers of insulation are added on the inside of a cinder block wall, and then covered with drywall. For MEB, rigid foam insulation would be secured to the inside of the current exterior walls using fasteners. Next, drywall would be attached to the insulation and painted. We recommend using insulation with an R-value of R-10 because it provides excellent energy savings with low material costs. We modeled higher R-values in eQUEST, but they provided negligible savings over the R-10 insulation. The drywall adds an additional R-0.45, bringing the new wall R-value to approximately R-13.3, a fourfold improvement over the current building.

We estimate the insulation will cost $5.85 per square foot, which includes materials and labor. This estimate was calculated using RSMeans [16]. Using the total square footage of the interior of the exterior walls, we found the total cost of the project to be $138,500. The increased insulation was found to create an annual reduction of 68 kWh, or $5,020 in electricity, 1,102 MMBTU, or $19,020 in steam, and 121 MMBTU, or $1,300 in chilled water, for a total annual savings of $25,340. This corresponds to a 2.5% reduction in electricity, 6.5% reduction in steam, and a 1.7% reduction in chilled water. Table 3 summarizes the simulated energy savings. Figures 5-7 show the savings over the current building graphically for electricity, steam, and chilled water. There would also be a reduction of 142,400 tons of carbon dioxide annually due to the lower energy usage. This project has a payback period of 5.5 years using simple payback.

Table 3: Summary of the simulated savings from installing additional insulation

INSULATION			
Electricity (MWh)	$5,020	68	2.5%
Steam (MMBTU)	$19,020	1,102	6.5%
Chilled Water (MMBTU)	$1,300	121	1.7%
Total Savings ($)	$25,330		

There are other issues to consider with adding additional insulation. The first issue is the loss of classroom or office space due to the increased thickness of the walls. Assuming two inches of additional insulation, ½ inch of drywall, and a ½ inch safety factor, the square footage loss in the building would be minimal, only 700 square feet. For an almost 200,000 square foot building, this represents a loss of less than one percent of the available space. The second issue is the type of insulation to use in the building. We originally researched injectable foam insulation. This insulation is pumped into an air gap inside the existing exterior walls, where it expands, taking up all available space. Unfortunately, MEB has no air gap in the walls, eliminating the possibility of using injectable foam insulation. Another option is to add an additional wall on the outside of the building. This would maintain the building's square footage, while still providing extra insulation. We did not have adequate time to research this option, and it remains an interesting method to be pursued in future studies.

Exhaust Fan Scheduling

MEB contains 22 exhaust fans that serve both the laboratories and the restrooms. These fans run 24 hours per day, 365 days per year, even if people are not present in the building. When experiments are ongoing, or people are using the restrooms, these exhaust fans serve a valid purpose. When these activities are not occurring, the exhaust fans only vent conditioned air into the atmosphere. This practice wastes money because the University is paying to condition the outside air, rather than the air inside the building.

Our solution is to schedule the exhaust fans to only run during hours of the day when people are using the building. More specifically, we chose to have the fans run from 7am to 9pm, except for those serving the clean rooms, which will be left untouched. These times allow the exhaust fans to turn on before a vast majority of the occupants arrive in the building. The 9pm time for shutting off the exhaust fans is quite aggressive, considering that researchers and students have been known to work in substantial numbers until at least midnight. A more accurate study should be conducted to determine the best time to turn off the fans, and how to override the scheduled turn-off times when people are working after hours.

To schedule the fans, digital controls need to be installed, since the exhaust fans currently do not have any. Each exhaust fan needs to have two points monitored, the status and on/off, for a cost of $1,000 per point. In addition, control panels are required, at a cost of $1,200 per panel. The control panels are capable of controlling five exhaust fans. Thus, the total cost of the project is $50,000, which covers materials and installation. This project's projected annual savings are 62 kWh, or $4,580 (2.3% reduction) in electricity, and 1,160 MMBTU, or $20,020 (6.9% reduction) in steam. The chilled water usage for this project increased by 173 MMBTU, or $1,860 (2.4% increase) per year. We feel the chilled water usage rose because when the exhaust fans do not run, heat builds up in the rooms, creating a need for additional cooling. The total annual project savings is $22,740. The savings is summarized in Table 4. Figures 5-7 show that exhaust fan scheduling produces savings in electricity and steam, but an increase in chilled water usage. An annual savings of 129,900 tons of carbon dioxide would also be saved. Using the simple payback method, the exhaust fan scheduling would pay back in 2.2 years.

Table 4: Summary of the simulated savings from scheduling the exhaust fans

SCHEDULING			
Electricity (MWh)	$4,580	62	2.3%
Steam (MMBTU)	$20,020	1,160	6.9%
Chilled Water (MMBTU)	($1,860)	-173	-2.4%
Total Savings ($)	$22,740		

There are additional measures that could be taken to further reduce energy usage through the regulation of exhaust fans. As mentioned above, we did not modify the exhaust fans in either of the building's two clean rooms. There is speculation that these fans could be reduced to half of their normal operating CFM's during the night time hours, which would save a significant amount of money on a system that draws in 100% outside air. It is important to note that some of the exhaust fans in MEB are aggregate type fans, meaning they serve multiple spaces at the same time. While these are cheaper to install, there is no way to exhaust just one of the spaces served, it is either all or nothing. Though the installation process is invasive, exploring the use of dampers with on and off switches for these exhaust ducts might be worthwhile on the fans that serve the greatest number of rooms.

Computer Standby

Turning off, or putting computers into standby mode when they are not in use is an easy way to save money and reduce energy consumption. An average computer uses 70 W when idle, but only 2 W when in standby mode [17]. Thus, if a computer were put into standby mode when it is not in use for an extended period of time, such as 30 minutes, it would save 68 W. It is estimated that MEB contains 300 computers between all the classrooms, laboratories, and faculty and staff offices.

To calculate potential energy savings, we assumed that all the computers in MEB are on at least eight hours per day, and that currently, no one puts their computer into standby mode. Additionally, it was assumed that 20 percent of computers are left on all day. We estimate that computers in use during the eight hour workday could be put into standby mode 25 percent of the time, and those left on at night could also be put into standby mode without a major inconvenience. Under these assumptions, the monthly electrical usage would drop by 2,120 kWh, which is equivalent to $155. According to research done by the *MEL Sustainability* senior design team, the cost to implement this solution is $8 per computer, which is roughly a one year payback [18].

We did not investigate this method thoroughly, and a more accurate estimate of computer usage should be used in the calculation of the payback period. However, this quick estimate shows that a simple, low-cost change can result in energy savings.

Reprogram Handicap Door

MEB's handicapped accessible door is located on the north side of the building and presently engages whenever the door is pushed open. Since the north side of the building is conditioned, each time someone enters or leaves the building through this door, conditioned air is flushed from the building. We recommend reprogramming the door to only provide an assisted opening when the button is pressed, assuming there would be no degradation in the functionality of the door, and it meets all required building codes. While we did not study this energy savings measure in detail, the *MEL Sustainability* team demonstrated that in MEL significant savings of up to $7,000 per year were possible through this minor change [18]. Savings in MEB will differ from savings in MEL, but it demonstrates a proof-of-concept that energy savings is possible.

Recycling Bins

Increasing the sustainability of MEB means reducing its impact on the environment. Presently, there are no recycling bins located in MEB, meaning that plastic containers, aluminum cans, glass bottles, paper, and other recyclables are being thrown away, ending up in landfills. Combined recycling and trash receptacles run up to $1000 per unit [19]. The installation of these units would not payback by themselves due the increased costs associated with recycling. However, if the goal is to make the building more sustainable, installing recycling bins is the right thing to do.

Lighting

Upgrading the lighting in a building is a simple and quick way to reduce energy consumption with a short payback period. We did not research potential savings from switching the T12 fluorescent bulbs in MEB to T8's since F&S is currently in the process of performing this upgrade.

However, adding occupancy and daylight controls to the lighting has the potential to generate energy savings. There are some rooms in MEB that contain occupancy controls thanks to the Student Sustainability Committee, however increasing the amount of these sensors would help reduce unnecessary consumption of electricity [20]. Occupancy sensors can save an average of 16% in electrical costs each year [21]. Installing daylight controls on these lights in addition to occupancy controls could result in electrical savings up to 30 percent [21]. If the baseline electrical load per month were 200 MWh, a 30% savings would represent an annual reduction in electrical costs of over $53,000, which represents a 7.5% savings in MEB's total utility bill each year.

Potable Water

Opportunities exist to reduce potable water consumption in MEB. We did not study savings from potable water, these are just observations from investigating the building. The toilets, urinals, and faucets look to be original fixtures from the 1950's, unless a handicapped stall was put in. Low-flow fixtures were installed in any new or modified stalls. Older toilets use at least 3.5 gallons per flush, while newer toilets use 1.6 gallons per flush [22]. Replacing the original toilets with modern, low-flow toilets with dual flush capability will reduce water consumption in the building. The bathroom sinks are also an area for possible savings. Upgrading current aerators to those that allow flows of just 0.5 gallons per minute should be investigated.

Some of the laboratories in MEB use potable water for experiments or to cool equipment. When water is used to cool the laboratory equipment, it is sent down the drain after it is used. The installation of a heat exchanger with a glycol loop, or using a different, more efficient way of cooling the equipment would reduce potable water consumption. The clean room has a water deionizer, which uses over 7,000 gallons of water every two days. Almost 60 percent of this water is rejected down the drain [23]. Research should be conducted to see if a more efficient deionizer is cost effective to purchase, or if the rejected water can be used for other purposes, such as watering the grounds, flushing toilets, or providing cooling to laboratory equipment.

Central HVAC

MEB's poor occupant comfort makes the building an undesirable place to hold classes, perform research, or have an office. Installing a central HVAC system would eliminate many of these issues and increase the habitability of the building.

The Current Building

As stated in the introduction, both steam radiators and window AC units provide heating and cooling for MEB. This method for conditioning the building does not regulate the temperature very accurately, and produces a high infiltration value since outside air can blow through the window AC units. MEB contains 114 window AC units, which are used to cool laboratories, offices, and classrooms in the south side of the building. Each unit has an average life of five to seven years, with a replacement cost of $1,200 per unit [24]. This value includes the cost of the unit, labor, and installation costs associated with the unit. Assuming a five year lifetime for the window AC units, the annual cost to the University is $27,400 in replacement and maintenance expenses. Removing the window AC units would eliminate this annual cost.

There are additional benefits that accompany the installation of a central HVAC system. The main benefits are as follows:

- Enhanced control of HVAC systems
- Dramatically reduced infiltration
- Increased occupant comfort
- Better indoor air quality
- Reduced carbon dioxide levels
- Improved temperature consistency
- Reduction in noise levels
- Higher efficiency and easier maintenance

It is difficult to put a dollar value on many of these improvements, since they pertain to improving the comfort of the occupants, rather than saving money.

Installation and Operational Costs

We estimate the initial cost of installing a central HVAC system is $4.59 million. This number includes the cost of the Air Handling Unit (AHU) and return fans, the campus chilled water connection fee, and digital controls. The AHU and return fan costs were based on a conservative estimate of $82 per square foot, provided by John Prince [3]. The unit will be serving approximately 50,300 square feet, giving a cost of $4.14 million dollars for the AHU and return fans. The campus chilled water connection fee is based on the delta T of the chilled water before and after leaving the building, and the tonnage of the AHU. In our eQUEST model, we set the delta T to 16 degrees Fahrenheit and let eQUEST auto-size the tonnage. A 16 degree delta T was selected because it is required by the campus chilled water plant. The estimated tonnage of the AHU by eQUEST was 215.88, which will cost $431,800 to connect to the chilled water loop, based on a connection fee of $2,000 per ton [25]. Finally, the HVAC system requires 20 control points, a control panel, two variable frequency drives, and web graphics. The cost of these controls is $36,000, bringing the total cost of the project to the $4.59 million quoted earlier.

The central HVAC system will have an impact on MEB's operating costs. According to eQUEST, the electrical usage will increase by 114 MWh, or 4.2%, steam usage will decrease by 2,352 MMBTU, or 14.0%, and chilled water usage will increase by 1,989 MMBTU, or 27.3%. The savings in utility costs is detailed in Table 5 below. The increase in electricity and chilled water is expected due to the installation of large fan motors for the AHU and return fans, and chilled water coils to meet the cooling needs.

Table 5: Summary of the simulated savings from the installation of a central HVAC system

HVAC			
Electricity (MWh)	($8,410)	-114	-4.2%
Steam (MMBTU)	$40,590	2,352	14.0%
Chilled Water (MMBTU)	($21,360)	-1,989	-27.3%
Total Savings ($)	$10,820		

There are additional savings beyond the utility costs. As mentioned, the University will have a savings of $27,400 per year in replacement and maintenance cost associated with the window AC units. Additionally, approximately $30,000 per year is spent maintaining an aging rooftop chiller that cools the tool research lab. Placing this room on the campus chilled water loop will eliminate this annual maintenance cost, bringing the total annual savings of the project to $68,220. However, the annual savings do not justify the project cost due to the 67.3 year payback. Even so, the increase in occupant comfort, lower noise level, reduced maintenance costs, and a myriad of other benefits all point to the installation of a new central HVAC system.

Potential Savings

Bundling projects, such as window replacement, with the central HVAC system has the potential to reduce the payback period, and produce additional energy savings over the installation of just a central HVAC system. We studied the effects of bundling combinations of new windows, additional insulation, and exhaust fan scheduling with a central HVAC system using eQUEST. The results are shown below in Table 6.

Table 6: Summary of the simulated savings from the installation of various projects with a central HVAC system

Project Combination (Existing Building as Baseline building)	Total Project Cost (million)	Total Project Savings	Payback (yrs)
HVAC	$4.59	$68,210	67.3
HVAC + Scheduling	$4.59	$90,850	50.5
HVAC + Windows	$5.35	$91,100	58.7
HVAC + Insulation	$4.71	$84,070	56.0
HVAC + Scheduling + Windows	$5.35	$110,620	48.4
HVAC + Scheduling + Insulation	$4.71	$105,880	44.5
HVAC + Insulation + Windows	$5.52	$107,610	51.3
HVAC + Scheduling + Windows + Insulation	$5.52	$125,430	44.0

From Table 6, it is clear that bundling projects together generally reduces the payback period and increases the total savings. The added savings can also be seen in Figures 10-12, which show savings in electricity, steam, and chilled water, respectively. For example, when windows or insulation are installed, there are savings in all three utilities. However, when windows and insulation are installed together, there is even greater savings. These bundles also reduce the campus chilled water connection fee, which is based on the tonnage of the AHU. New windows and insulation reduce energy losses through the building envelope, allowing for a smaller AHU to be installed. This lowers the initial cost of installing the central HVAC system.

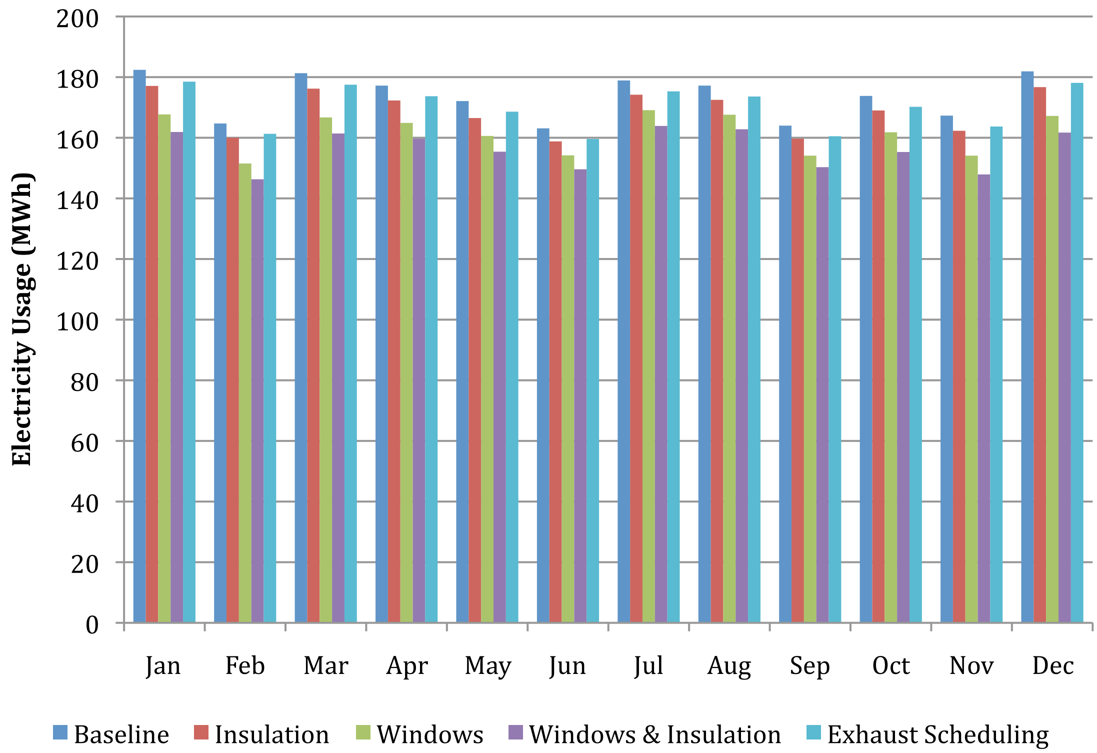

Figure 10: Results from Parametric Runs with central HVAC showing the simulated electricity savings

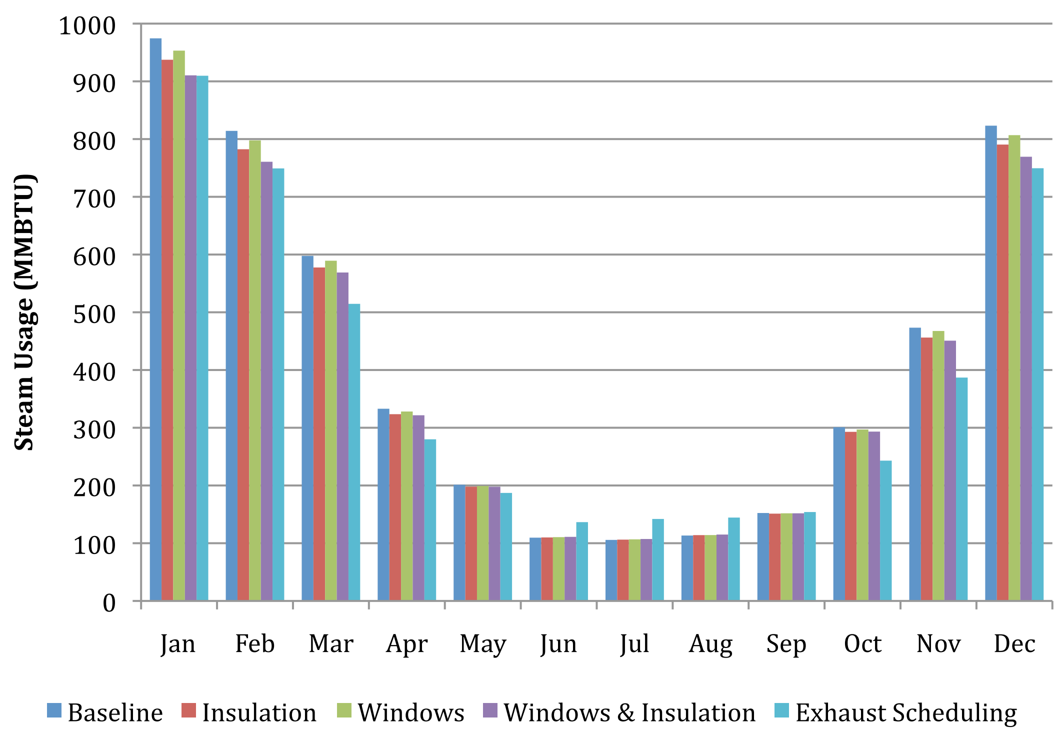

Figure 11: Results from Parametric Runs with central HVAC showing the simulated steam savings

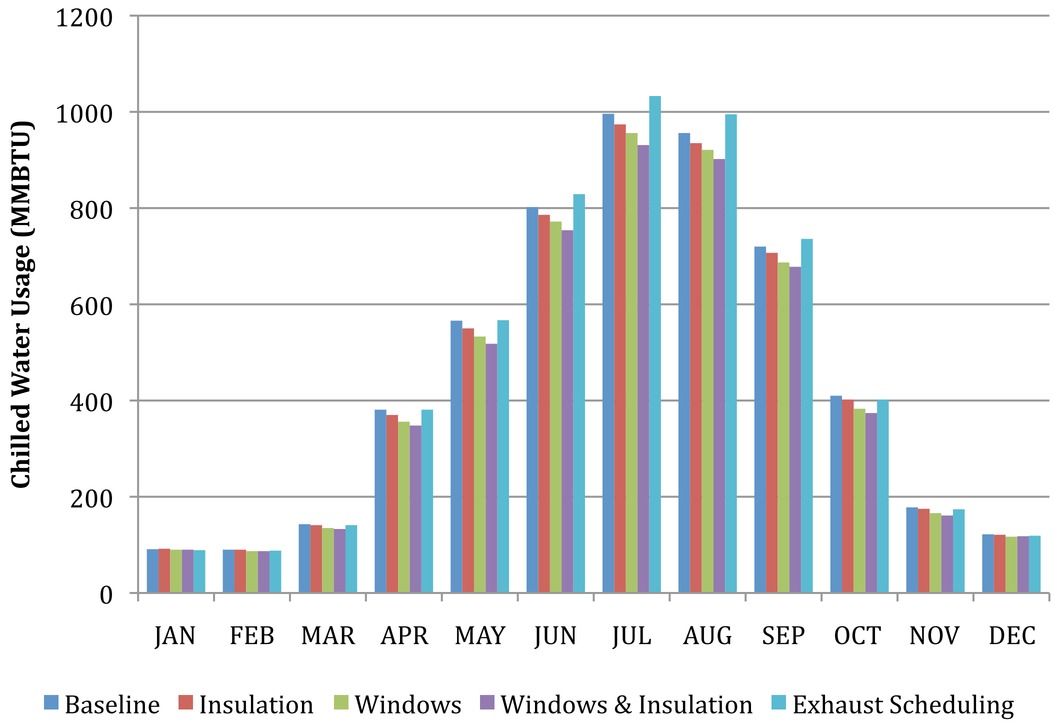

Figure 12: Results from Parametric Runs with central HVAC showing the simulated chilled water savings

The bundle with the lowest payback period and the greatest total savings is the combination of all three projects. Bundling new windows, additional insulation, and exhaust fan scheduling together reduces the payback period from 67.3 year to 44 years, an improvement of 35%. Electrical usage drops by 225 MWh, or $16,660 (8.3%), steam usage drops by 4,049 MMBTU, or $69,860 (24.0%), and chilled water usage increases by 1,722 MMBTU, or $18,500 (23.6%), for a total annual savings of $68,020 in utility costs. This represents a decrease in 9.5% over the current building's costs. When the additional savings from the removal of the window AC units and the rooftop chiller are included, the annual savings grows to $125,430. The project also reduces the amount of carbon dioxide produced annually by 473,100 tons. The total project cost for this bundle is $5.52 million.

Recommendations

Despite its current condition, there are a number of simple projects that will reduce the energy consumption of MEB in the short-term. Furthermore, a number of large, long-term projects have been identified for their potential to reduce energy costs and increase the sustainability of the Mechanical Engineering Building.

Short Term

Insulation and exhaust fan scheduling should be implemented in MEB. The combined project will cost $188,500 and payback within 4.1 years. This will lead to savings of $46,600 in utility costs and a 272,300 ton reduction in carbon dioxide emissions each year. The decrease in utility costs represents a 6.5% reduction from current levels. This assumes that utility rates stay constant in the future. If the rates go up, the savings will only increase.

After a small amount of additional research is conducted, we recommended that computer hibernation, reprogramming of the handicap door, and the installation of recycling bins be implemented if the assumptions behind the savings do not change drastically. Savings of $1,800 per year are possible through the hibernation of computers, paying back in one year. Up to a $7,000 annual savings is possible by reprogramming the handicap door to only provide an assisted opening when the button is pressed. The total savings from implementing all projects is estimated at $55,400, or a 7.8% reduction in utility costs.

A study should investigate the feasibility behind making changes in the clean room's operation. This includes changing the temperature and humidity at night and when the room is not in use, in addition to lowering the CFM's during these times. The study should also determine if low-flow aerators, dual-flush toilets, and other plumbing upgrades should be made to the building's lavatories.

Long Term

The long-term recommendation is to install a central HVAC system and new windows (and insulation and exhaust fan scheduling if they have not been implemented). The cost of this project is $5.33 million ($5.52 million with insulation and exhaust fan scheduling). This will improve the environment inside the building, making it a more attractive space to hold classes, conduct research, and for offices. Significant energy savings will also result from this project. Utility costs will decrease by $68,030 per year over the current building, and carbon dioxide emissions will decrease by 473,100 tons annually. This represents a savings of 9.5% over the current utility bill. When all the potential savings are included, such as computer hibernation and the removal of window AC units, the total annual savings increases to $134,230 in utility and operational costs.

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Appendix A: Building Floor Plans

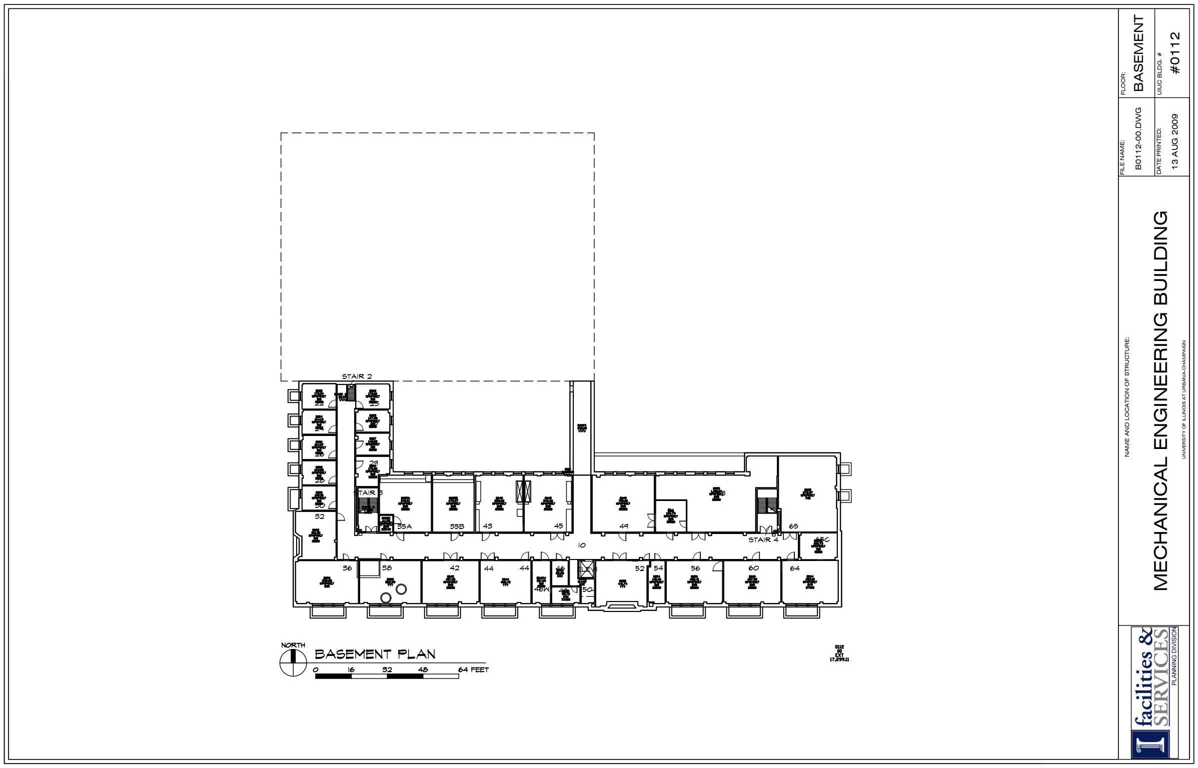


Figure 13: Basement floor plan

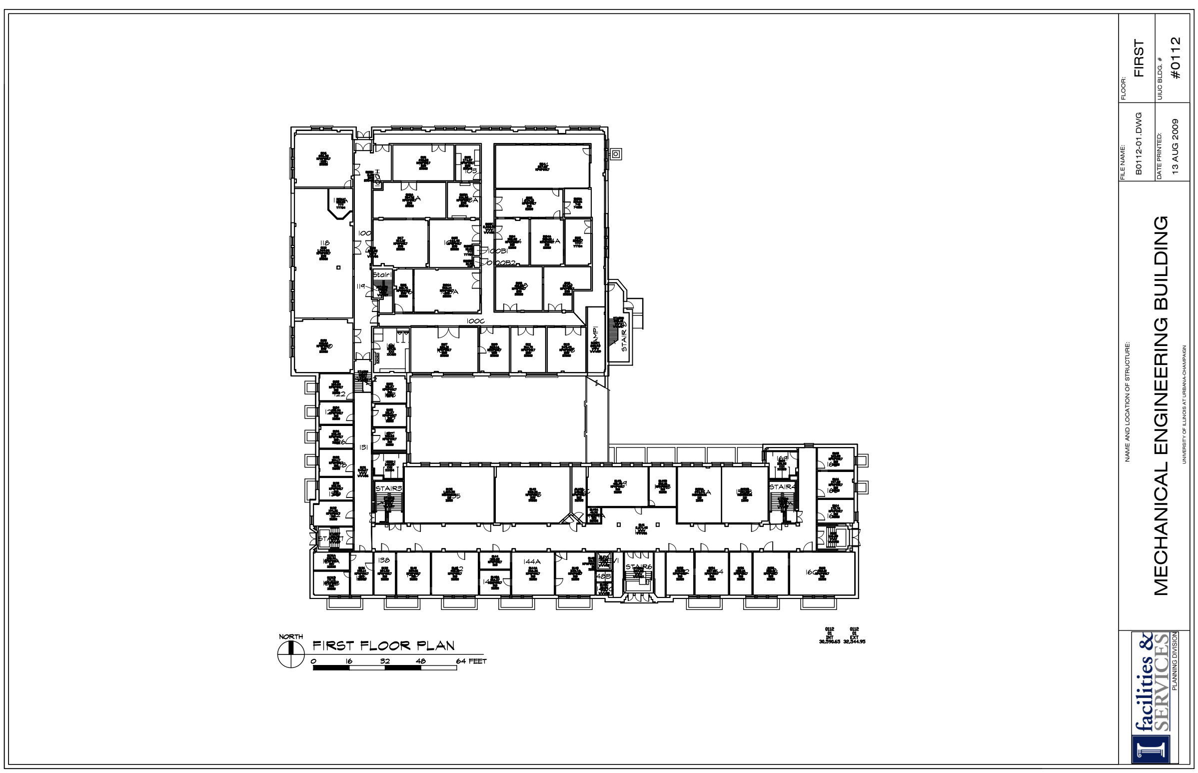


Figure 14: First floor plan

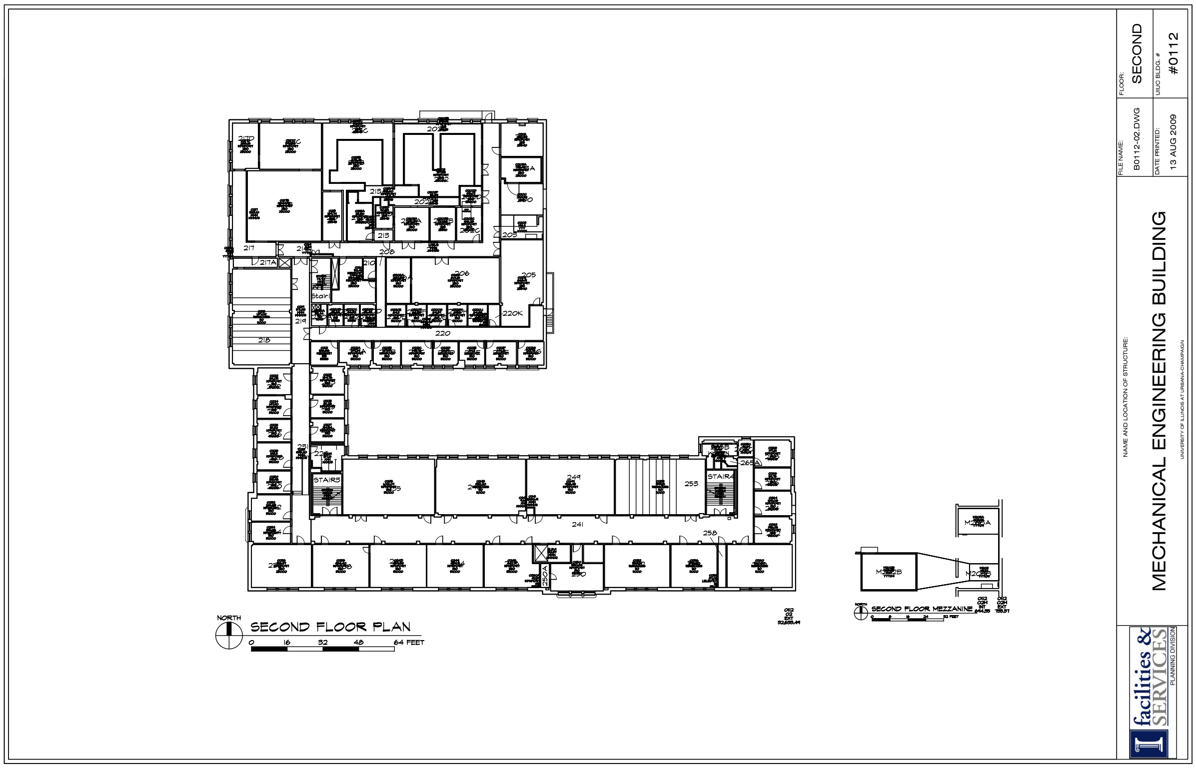


Figure 15: Second floor plan

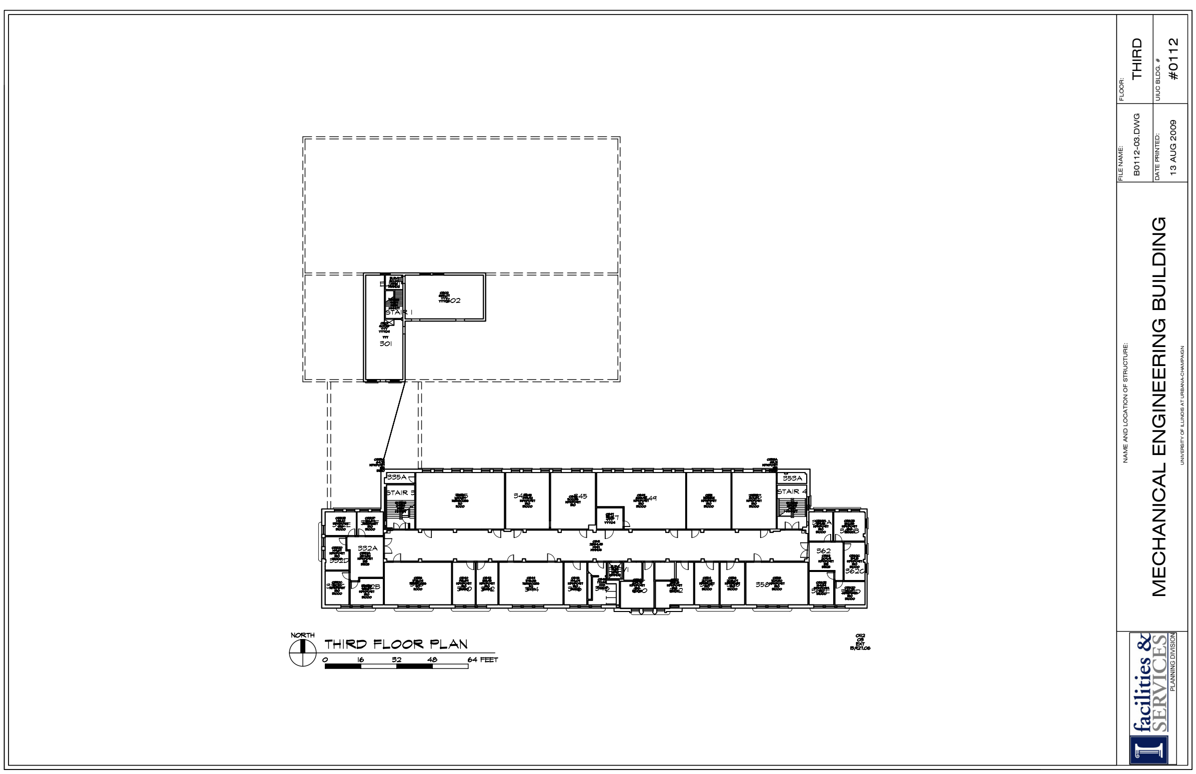


Figure 16: Third floor plan

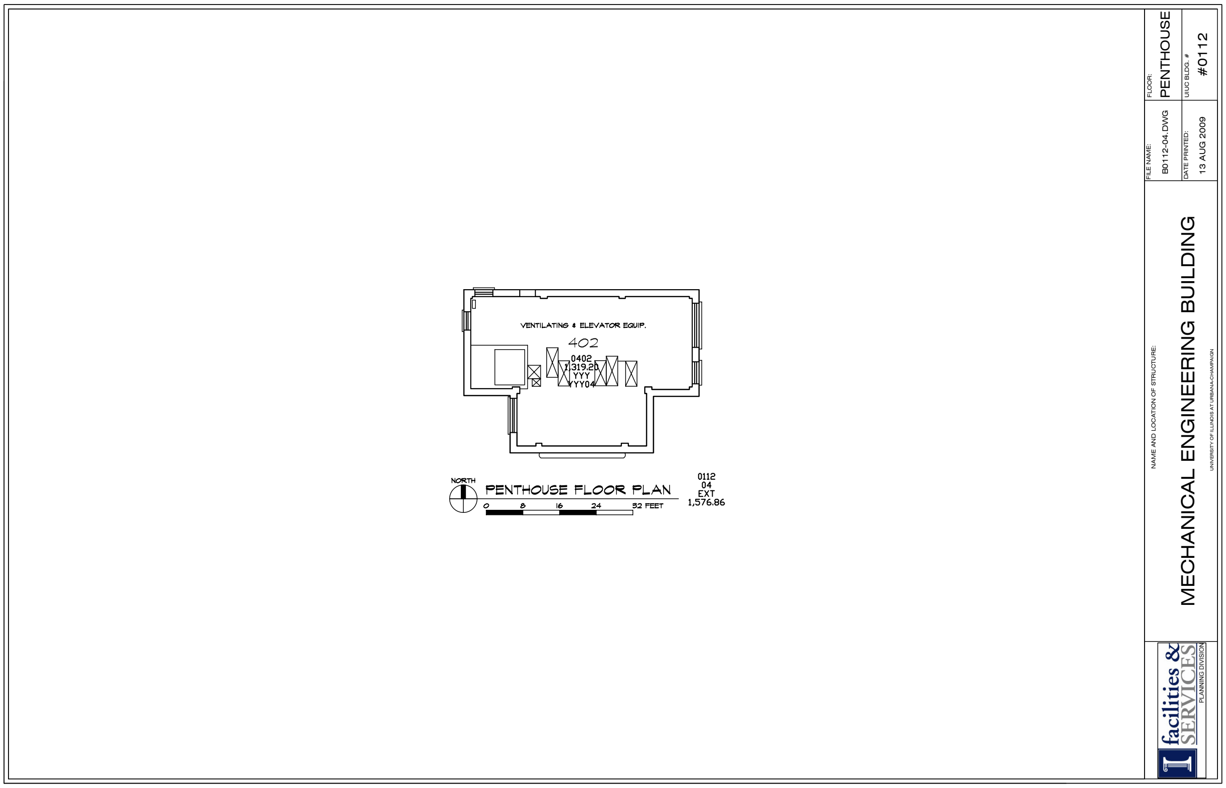


Figure 17: Penthouse floor plan

Appendix B: Baseline Building Savings

Table 7: Summary of the cost, savings, and payback periods for project combinations

Project Combination	Total Project Cost	Total Project Savings	Payback (yrs)
Scheduling	$50,000	$22,730	2.2
Windows	$852,000	$32,030	26.6
Insulation	$138,500	$25,330	5.5
Scheduling + Windows	$809,185	$42,410	19.1
Scheduling + Insulation	$188,500	$46,600	4.0
Insulation + Windows	$990,500	$58,090	17.1
Scheduling + Windows + Insulation	$1,040,500	$76,210	13.7

Table 8: Electricity, steam, and chilled water savings from exhaust fan scheduling and new windows

SCHEDULING AND WINDOWS			
Electricity (MWh)	$16,540	224	8.3%
Steam (MMBTU)	$36,030	2,088	12.4%
Chilled Water (MMBTU)	($990)	-92	-1.3%
Total Savings ($)	$51,580.00		

Table 9: Electricity, steam, and chilled water savings from exhaust fan scheduling and insulation

SCHEDULING AND INSULATION			
Electricity (MWh)	$9,590	130	4.8%
Steam (MMBTU)	$38,030	2,204	13.1%
Chilled Water (MMBTU)	($1,020)	-95	-1.3%
Total Savings ($)	$46,600		

Table 10: Electricity, steam, and chilled water savings from insulation and new windows

INSULATION AND WINDOWS			
Electricity (MWh)	$17,100	231	8.6%
Steam (MMBTU)	$38,030	2,204	13.1%
Chilled Water (MMBTU)	$2,960	275	3.8%
Total Savings ($)	$58,090		

Table 11: Electricity, steam, and chilled water savings from exhaust fan scheduling, insulation, and new windows

SCHEDULING, WINDOWS, AND INSULATION			
Electricity (MWh)	$21,670	293	10.9%
Steam (MMBTU)	$55,380	3,209	19.1%
Chilled Water (MMBTU)	($840)	-78	-1.1%
Total Savings ($)	$76,210		

Appendix C: Baseline Building Savings with HVAC

Table 12: Electricity, steam, and chilled water savings from central HVAC and exhaust fan scheduling

HVAC AND SCHEDULING			
Electricity (MWh)	($4,090)	-55	-2.1%
Steam (MMBTU)	$60,700	3,518	20.9%
Chilled Water (MMBTU)	($23,170)	-2,157	-29.6%
Total Savings ($)	$33,440		

Table 13: Electricity, steam, and chilled water savings from central HVAC and new windows

HVAC AND WINDOWS			
Electricity (MWh)	$6,010	81	3.0%
Steam (MMBTU)	$44,440	2,576	15.3%
Chilled Water (MMBTU)	($16,760)	-1,561	-21.4%
Total Savings ($)	$33,690		

Table 14: Electricity, steam, and chilled water savings from central HVAC and insulation

HVAC AND INSULATION			
Electricity (MWh)	($2,560)	-35	-1.3%
Steam (MMBTU)	$48,540	2,813	16.7%
Chilled Water (MMBTU)	($19,320)	-1,799	-24.7%
Total Savings ($)	$26,660		

Table 15: Electricity, steam, and chilled water savings from central HVAC, new windows, and scheduling

HVAC, WINDOWS AND SCHEDULING			
Electricity (MWh)	$10,340	140	5.2%
Steam (MMBTU)	$62,670	3,632	21.6%
Chilled Water (MMBTU)	($19,790)	-1,843	-25.3%
Total Savings ($)	$53,220		

Table 16: Electricity, steam, and chilled water savings from central HVAC and exhaust fan scheduling

HVAC, INSULATION AND SCHEDULING			
Electricity (MWh)	$1,770	24	0.9%
Steam (MMBTU)	$68,310	3,959	23.5%
Chilled Water (MMBTU)	($21,600)	-2,011	-27.6%
Total Savings ($)	$48,480		

Table 17: Electricity, steam, and chilled water savings from central HVAC, new windows, and insulation

HVAC, WINDOWS AND INSULATION			
Electricity (MWh)	$12,340	167	6.2%
Steam (MMBTU)	$52,640	3,051	18.1%
Chilled Water (MMBTU)	($14,770)	-1,375	-18.9%
Total Savings ($)	$50,210		

Table 18: Electricity, steam, and chilled water savings from central HVAC, windows, insulation, and scheduling

HVAC, WINDOWS, INSULATION, AND SCHEDULING			
Electricity (MWh)	$16,660	225	8.3%
Steam (MMBTU)	$69,860	4,049	24.0%
Chilled Water (MMBTU)	($18,500)	-1,722	-23.6%
Total Savings ($)	$68,020		

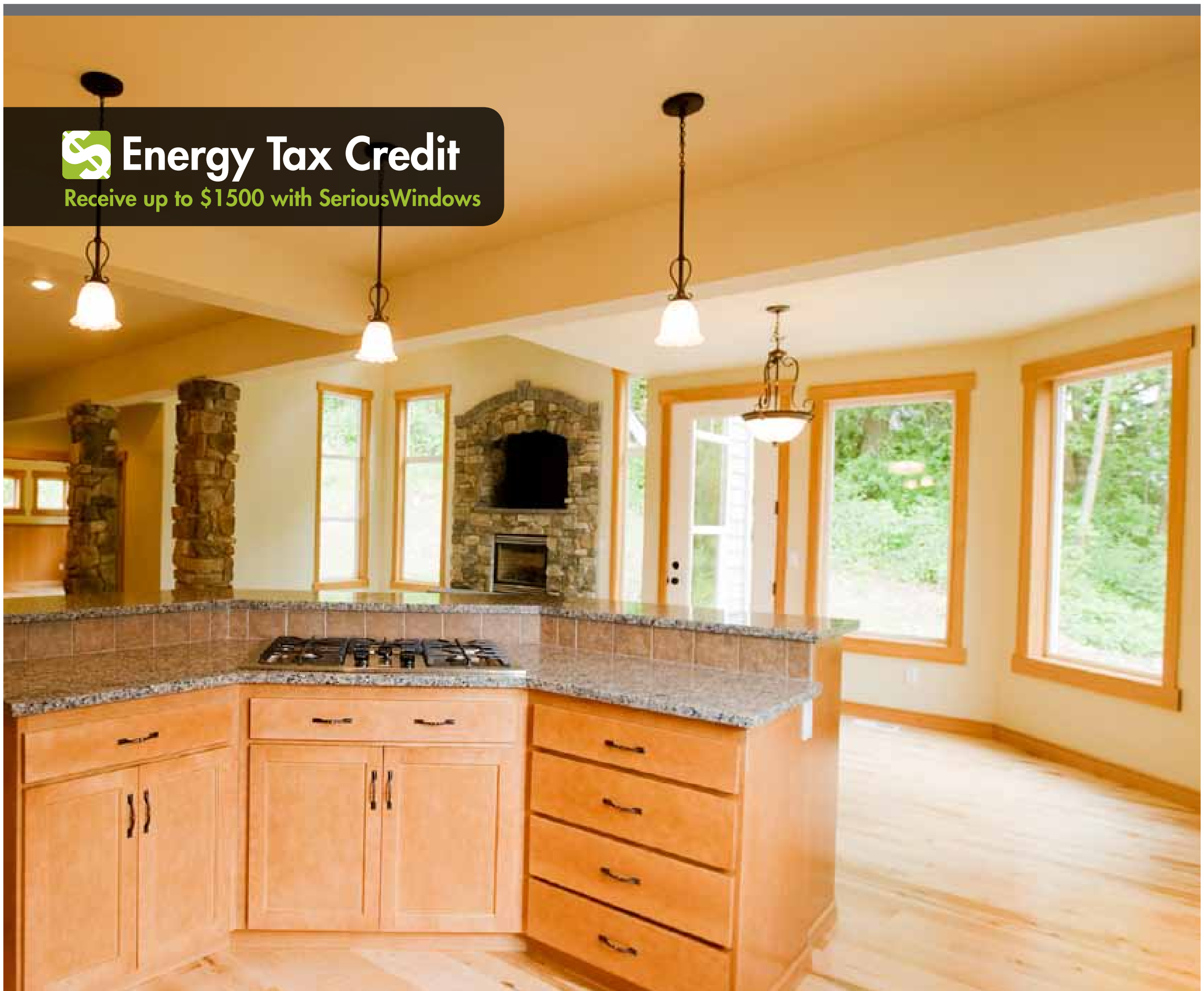
Appendix D: SeriousWindows 525 Information Sheet

SERIOUS MATERIALS

SeriousWindows™ 525

SAVES MORE ENERGY THAN ANY OTHER WINDOW. PERIOD.

R-5.9 UP TO 2X BETTER Energy Star®



SeriousWindows 525 Series

SeriousWindows 525 are our best value fiberglass windows, delivering the thermal and structural performance you need, at an affordable price. These low maintenance windows require no sanding nor painting and can be installed in new construction and remodeling/replacement applications. SeriousWindows 525 hand-crafted, custom made windows have an optional wood interior which delivers the beauty of wood on the inside with the durability of fiberglass on the outside.

Benefits of SeriousWindows 525:

- Thermal performance up to R-5.9
- 99.5% UV protection to reduce fading and interior damage
- Reduced interior condensation
- Virtually maintenance free
- Unique design keeps the window warmer in the winter and cooler in the summer
- Design and architectural freedom allowing for more glass in your windows
- Can contribute to LEED credits

SeriousWindows™ 525

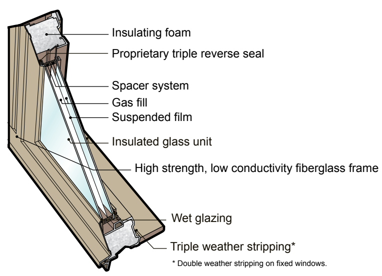
SAVES MORE ENERGY THAN ANY OTHER WINDOW. PERIOD.

R-5.9 UP TO 2X BETTER Energy Star®

High Performance Fiberglass Windows

SeriousWindows 525 Series environmentally friendly fiberglass frame offers greater strength and durability than wood or vinyl products. In addition, these windows resist fading, chipping, cracking, expansion and contraction. It is available in a variety of pre-finished colors as well as natural, stainable wood interiors.

Technical Specifications



A unique combination of 9 key technologies including a fully insulated frame, suspended film, and our unique warm edge spacer system

SeriousWindows 525 Performance Specs:

Styles	SeriousGlass 8 LSHG				SeriousGlass 5 HSHG			
	U-Value	R-Value	SHGC	VT	U-Value	R-Value	SHGC	VT
Fixed Picture	0.17	5.9	0.25	0.44	0.22	4.5	0.50	0.65
Double Hung	0.22	4.5	0.22	0.40	0.26	3.8	0.41	0.53
Single Hung	0.20	5.0	0.23	0.42	0.24	4.2	0.43	0.56
Casement/Awning	0.21	4.8	0.22	0.39	0.25	4.0	0.39	0.50
Horizontal Sliding	0.20	5.0	0.24	0.43	0.25	4.0	0.42	0.56
Sliding Patio Door	0.20	5.0	0.23	0.41	0.25	4.0	0.42	0.56

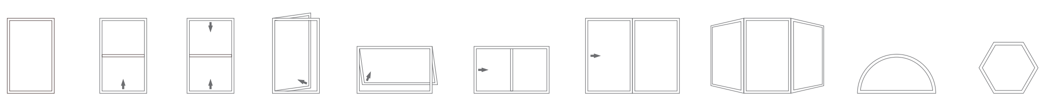
SeriousGlass 8 LSHG:

Offering best value R-values and low solar heat gain at an affordable price, SeriousGlass LSHG features low-E coated glass, a single suspended film and inert gas fill.

SeriousGlass 5 HSHG:

For designs seeking high solar heat gain, SeriousGlass HSHG features an insulating glass unit with a single suspended coated film and inert gas fill.

Frame Material / Style



Window Type: Fixed Picture, Single Hung, Double Hung, Casement, Awning, Sliding, Sliding Patio Door, Bow/Bay, Half Circle/Arch, Geometric Shapes

Jamb Extensions

4 9/16, 6 9/16, Pine and Oak

Frame Style

Nail fin, block frame, brick mould, brick mould with nail fin

Grille Options

SeriousWindows 525 Series offer interior and exterior grille options* in a range of colors and patterns.

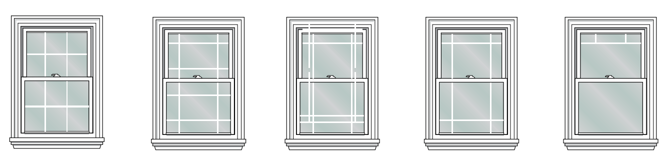
Interior (composite)

Interior grille matches interior paint and color.
For interior veneers, grille is ready to stain.

Exterior (metal)

Exterior grille matches exterior paint color.

** Custom grille designs available*



Colonial, Queen Anne, Prairie, Single Line Prairie, Craftsmen

Color Options

Interior — Color / Finish: White, Beige, Sandstone, Dark Brown, Slate, Oak, Fir[1]

Exterior Color — Color / Finish: White, Beige, Sandstone, Dark Brown, Slate

** Custom exterior colors available*

Hardware[2]

Standard: White, Beige, Coppertone, Chestnut, Black

Optional: Oil Rubbed Bronze, Western Pewter, Brushed Antique Brass, Brushed Nickel

[1] Available in picture, casement and awning window styles only. [2] Sliding patio doors available with white or Chestnut hardware only.

Appendix E: Utility Usage

Table 19: Utility usage for electricity, steam, and chilled water from December 2005 to November 2009

Month	Year	Electricity (kWh)	Steam (klbs)	Chilled Water (MMBTU)
DEC	2005	150,814	-	427
JAN	2006	147,774	-	422
FEB	2006	149,794	-	345
MAR	2006	162,494	-	411
APR	2006	150,614	-	439
MAY	2006	172,094	-	476
JUN	2006	211,474	-	795
JUL	2006	223,774	-	921
AUG	2006	238,474	-	997
SEP	2006	235,394	-	715
OCT	2006	174,254	-	637
NOV	2006	185,314	-	524
DEC	2006	219,874	0.57	550
JAN	2007	192,314	-	512
FEB	2007	171,874	-	349
MAR	2007	187,474	2.38	453
APR	2007	215,654	1.47	434
MAY	2007	242,454	-	712
JUN	2007	252,594	-	557
JUL	2007	262,514	-	594
AUG	2007	280,954	-	378
SEP	2007	197,794	-	378
OCT	2007	200,254	-	341
NOV	2007	177,674	0.11	434
DEC	2007	179,594	608	310

Month	Year	Electricity (kWh)	Steam (klbs)	Chilled Water (MMBTU)
JAN	2008	220,894	799	551
FEB	2008	189,354	523	214
MAR	2008	199,514	906	397
APR	2008	210,114	834	499
MAY	2008	212,274	885	568
JUN	2008	241,154	-	860
JUL	2008	312,034	-	840
AUG	2008	268,114	-	964
SEP	2008	235,034	-	682
OCT	2008	210,174	-	561
NOV	2008	208,854	-	288
DEC	2008	259,714	2715	369
JAN	2009	155,454	2092	326
FEB	2009	215,674	1996	316
MAR	2009	219,214	2318	469
APR	2009	191,860	765	554
MAY	2009	232,474	830	857
JUN	2009	266,514	695	1014
JUL	2009	246,214	806	1034
AUG	2009	260,634	700	1031
SEP	2009	249,534	673	905
OCT	2009	210,134	2139	552
NOV	2009	190,874	1900	431