Mechanical Engineering Building Redesign for Sustainability

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Executive Summary

This project has the aim to provide background research for a renovation proposal for the Mechanical Engineering Building (MEB) at the University of Illinois. The concern of this research is to recommend ways in which the energy efficiency and occupant comfort of MEB may be improved.

Using Trane TRACE modeling software to analyze all utility savings from building improvements, we simulated the addition of a central heating, ventilation and air conditioning (HVAC) system on the south side of the building, roofing insulation, exterior wall panel insulation, double and triple pane windows, and more efficient lighting fixtures. Utility savings for more efficient plumbing fixtures were estimated using other methods.

When comparing improvement packages, we compared each package to the model of the existing building as well as to the model with the new HVAC system. Since comfort was a main concern for this project every package has the HVAC system in place. We would not recommend any renovation without it since it is crucial to improving occupant comfort.

After analyzing the results, we recommend two different options: the configuration with the greatest energy savings and the configuration with the shortest payback when compared to the new HVAC model.

The energy savings package contains a variable air volume HVAC system, T8 fluorescent lighting, 4-inch wall panel insulation, spray roof insulation, and triple pane windows. This comes in at a total cost of $3.2 million with a yearly savings of $116,000 and payback of 27.6 years compared to the existing building. Compared to installing the HVAC system alone it saves $135,000 and has a payback of 5.54 years.

The shortest payback model contains the same improvements as the energy savings package but leaves the current windows intact. The result is a $2.6 million bill with a yearly savings of $80,000 and payback of 32.86 years when compared to the existing building. When compared to the building with the modeled HVAC system the savings is $99,000 a year with a payback of 1.79 years.

Although this report strives to be as thorough as possible there are unexplored sources for improving energy efficiency. Namely, late in the project the idea was introduced to use the steam condensate from the radiators as a terminal reheats for the HVAC system. This and other options should be analyzed further.

Introduction

Purpose and Goals

The purpose of this project is to provide the Facilities and Services department at the University of Illinois with information regarding possible building renovations to the Mechanical Engineering Building. The reason for these renovations will be to increase the energy efficiency of the building as well as the comfort of building occupants.

Building History

The building was originally completed in 1951. At the time it was completed it used a central heating system which at the time was relatively new. It is long since defunct; however, this means there is space for new air ducts where the ducts were from the old system. This allows for the installation of a new HVAC system with little structural change.

Since its completion, it has undergone many renovations. Most notable is the addition of the clean room on the north side of the building as well as the addition of a few other smaller air handling units servicing various sections of the north building.

In its current state, the MEB is terribly uncomfortable. There is no central HVAC system on the south side of the building; all that exists are window air conditioning units and steam radiators. The only ventilation in those areas is through the building envelope; hence, it is especially stuffy and hot in the circulation areas. The insulation is calculated to be not even a third of most modern buildings. Also, since there exists no central control for all the systems, there are many times when heating and cooling systems are running simultaneously which, when combined with the poor insulation, is an enormous waste of energy.

Previous Project

There have been many building redesign projects very similar to this one and during spring of 2009 there was a building redesign project assigned to MEB. Technically, this project is a continuation of that one; however, we used their work merely as a resource for general information [3]. None of their results were used in the evaluation of possible renovations for our project. This is because we used a different modeling program and a more recent RSMeans cost data book, modeled some different improvements, and most importantly we had a different goal.

The previous project's aim was to produce a recommended improvement package that reduced energy use by twenty percent while having a payback of five years. The improvements modeled included a new HVAC system similar to the one modeled in this project. It also included the addition of exhaust fan scheduling, new windows, wall insulation, removing the rooftop chiller, putting computers in standby when not in use, and reprogramming the handicap door [2].

Although this current project did not model reprogramming the handicap door and putting computers in standby, they were estimated to have an annual savings of $8,800. Although this still helps, it is not a significant amount of savings. We also did not model removing the rooftop chiller and scheduling the exhaust fans. Upon talking to the clean room laboratory director, Michael Hansen, we found either of those actions would disrupt the clean room system too greatly.

Solution Strategy

The first step to tackling this problem was to gather information about MEB. We accomplished this through first acquiring building schematics of the original building and the renovations. Then, we toured the building and compared our observations to the drawings. We also talked to building officials to get a better idea of specific systems within the building such as the clean room. Lastly, we performed a blower test on two of the windows to find an accurate infiltration rate.

Next, a virtual building model was created using Trane TRACE software provided to us by John Prince of Facilities and Services. We used the information we gathered to make an accurate model of the existing building, all the while comparing the model output to actual utility use.

Then, we brainstormed and researched improvements that could be made to the building. We assessed first whether the improvement was possible to implement. Then we found cost data through contractors or RSMeans [10]. Finally, we gathered the information necessary to find the savings caused by the improvement, which in most cases was input into TRACE.

TRACE ran simulations of the existing building with individual improvements added on to it and then with multiple improvements together to find if there were any synergies between them. This gave the utility use for the simulated building with the improvements.

Using the utility consumption output by TRACE as well as the pricing information gathered earlier, we performed economic analysis on each improvement and improvement package to find if it was economically viable.

TRACE Procedure

TRACE 700 is a building and energy modeling software created by Trane. It is used in building design applications to model a building so that correct mechanical equipment can be chosen before construction begins. Facilities and Services here at the University of Illinois use TRACE for its building design projects. John Prince at Facilities and Services suggested we use the program and provided it.

A preliminary TRACE model of the Mechanical Engineering Building had previously been made by Facilities and Services. In this model a great deal of building information had already been provided including rooms, room areas, windows, doors, lighting, roof properties, wall properties, room assignments, air handling unit systems, and utility plants. Some modifications from this model were made. The model given to us and a TRACE tutorial were used to learn the program [11].

The building model was used to evaluate the energy consumption by the building when proposed improvements were implemented. A model of the existing building was created first as a baseline. This model had the existing wall and roof properties as well as spaces being conditioned by the current systems. The results from a blower test were also input as infiltration for the existing building model.

Room Creation

In a TRACE model, rooms of a building are the first element to be defined. Once a new room is created its layout and attributes must be entered. The room area or dimensions were input first and were provided in feet. The total wall space is defined which will be important in the application of outside loads to the space.

The construction of the walls is input depending on what materials were used. TRACE provides thermal resistance values based on a standard. The size and number of windows is defined for each room as well as the type of window. The thermal resistance and emissivity of the window can be changed. The lighting in watts per square foot is input for each room with the type of bulb and what percent of the bulb’s thermal load is given to the conditioned space. The infiltration of air to the room in cubic feet per minute, or CFM, can be defined for each room. Based on the results from the blower test the amount of infiltration was defined as CFM per square foot of wall. The ventilation that must be provided to the room based on the type of room in ASHRAE standards is defined for the room. The existence of a roof for certain rooms is also defined during room creation.

System Creation

Once the rooms of the building have been created, the mechanical systems that service the area can be modeled. This is largely the air handling units, or AHU, in the building. The type of AHU is chosen from a number of previously designed systems including variable air volume ,or VAV, constant volume, and underflow distribution. The system is chosen based on how the room is desired to be conditioned and what type of system will be able to be installed. When existing AHUs are modeled, the horse power and pressure of the fan must be input for energy usage estimation. An economizer is set for each system which will draw one hundred percent outside air when the outside air is 55^0F. The rooms serviced by the AHU are assigned to it and for some systems placed in zones which can be used for future energy analysis of specific spaces.

When the systems have been modeled for the building, the utility plants must be modeled. These plants supply the systems with steam and chilled water. Plants will be created for the purchased chilled water, purchased steam, rooftop chiller, and A/C unit chillers. Energy usages for pumps and compressors must be entered here in kW/ton or COP. The systems will be assigned to the respective plants that they obtain energy from.

For the existing building, a number of the rooms are conditioned by window A/C units. When the building is modeled in TRACE the system type for the window A/C units is constant volume non-mixing packaged terminal air conditioner. The new HVAC system that will be implemented will use a variable volume reheat with a 30% minimum flow.

Model Output Use

Once the building model has been created, its system and energy analysis can be run. There are multiple outputs that can be exported from the model. For our purposes the monthly energy consumption and the Load/Airflow Summary output were exported.

The monthly energy consumption of the building was exported for each iteration of improvements that was run. This output showed us the electricity in kWh, chilled water in therms, and purchased steam in therms that were used by the building conditioning systems. This energy was quantified to dollars and compared for savings and payback.

The Load/Airflow Summary output we obtained from model showed the quantity of air that the space being conditioned by a given air handler required. The data that was important to us was the Space Design Maximum CFM and the Floor Area ft^2. When a new AHU is chosen for installation this information is used to size the air handler and determine a budget for mechanical equipment. When improvements were added to the building the Maximum CFM would change for the new air handler.

Model Accuracy

The models developed for Mechanical Engineering Building took into account every major system and load within the building. Despite the extensive effort that went into modeling these systems, there were still discrepancies in the results from the utility usages in 2009, seen in table 12. In modeling it isn't uncommon for models to need to be modified by some method. We found that since cost analysis would be performed against the TRACE model developed for the existing building and not to actual usages, that the adjustment of the economic data would not be necessary. However, to provide validation of our methods and confirm that the model was behaving similarly to the real building we applied an offset to the data.

Looking at the data we noticed that the model's usage curves and the actual utility usage curves there were similar. Thus, an offset was applied to each utility allowing the modeled data to come into the same magnitude as the actual usage. In all cases the offset was positive. Offsets for each utility can be seen in table 1 below. The result of applying the offset can be seen in figure 1, figure 2, and figure 3. While there is still deviation from the model in the actual utility usage we see that the general trend of usage is behaving appropriately. Electricity usage was the most accurately modeled utility with an average error of less than 1 percent. Steam and chilled water had larger offsets and had average errors of approximately 24 and 15 percent, respectively.

Table 1: Offsets Applied to TRACE Model

Utility	Offset	Unit	Percent of Increase from Model
Electricity	12115	kWh	5%
Steam	11531	Therms	78%
Chilled Water	4864	Therms	73%

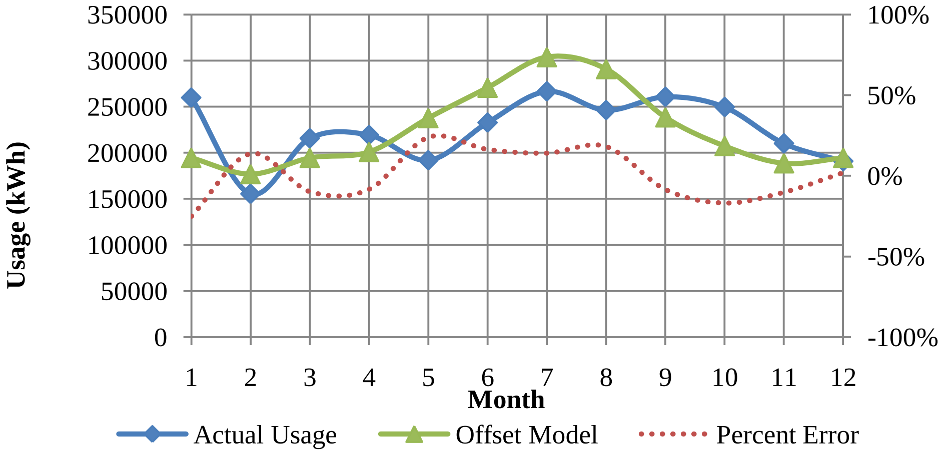

Figure 1: Actual vs. Offset Model Electricity Use

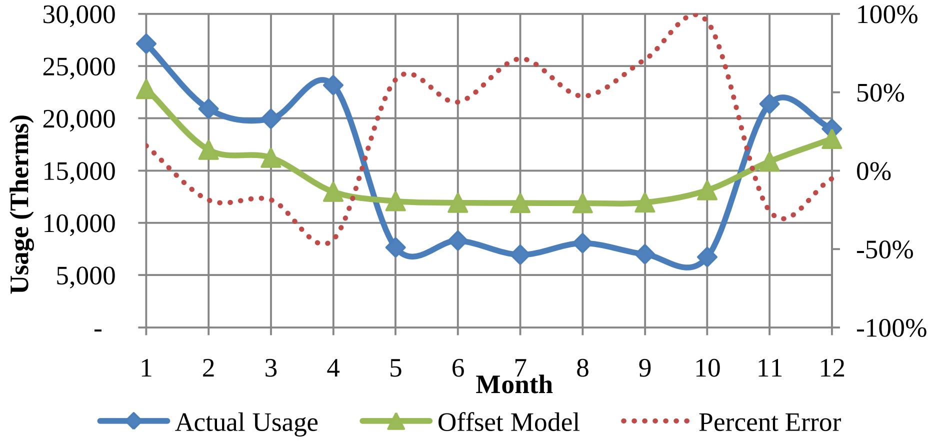

Figure 2: Actual vs. Offset Model Steam Use

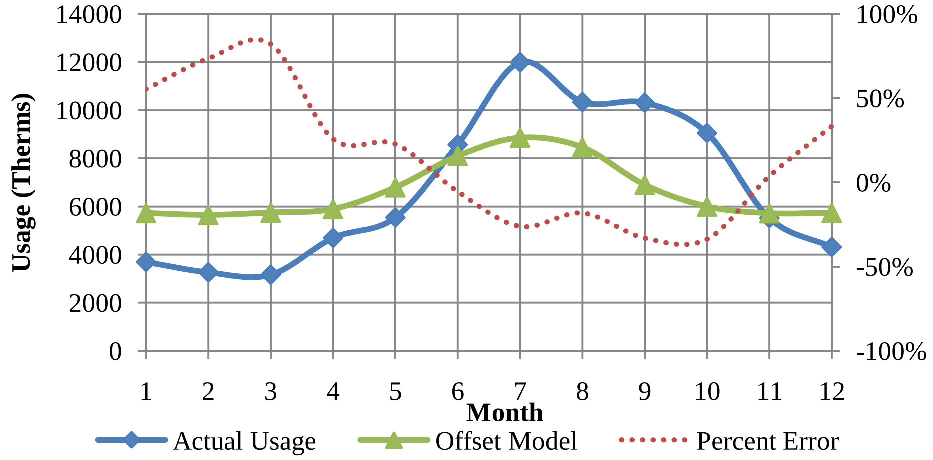

Figure 3: Actual vs. Offset Model Chilled Water Use

The exceptional accuracy with which electricity was modeled suggested an accurate model of the building to us. However, the higher offsets and larger average errors in the steam and chilled water systems also suggested that there are significant inefficiencies in the systems that operate within the building. Such inefficiencies could include but are not limited to leakage in steam pipes, blown through steam traps, and increased flow rates to deter freezing in chilled water pipes during winter. All things considered, obtaining a model within 25 percent average error was acceptable for our purposes.

Building Improvements

Clean Room

Clean rooms require highly controlled environments to effectively operate within desired specifications. Mechanical Engineering Building contains two labs, one Class 100 lab and one Class 1000 lab. The labs occupy about 3000 square feet in the north wing of the building. The labs are serviced by two air handling units, one of which conditions the incoming air and the second which filters and pressurizes the lab space. The lab exhaust is handled by hood vents which vent into chimneys scattered across the roof. In these labs, temperature, humidity, and pressure must be vigilantly controlled within tight tolerances. In talks with the lab specialist, Michael Hansen, it was learned that the current lab control scheme took almost five years to fine tune [5]. From the discussion, it became clear how the clean room is a multi-variable, dynamic system. The consequences of altering one of the parameters are largely unpredictable and cause variance within the established system. Establishing new parameters and scheduling of the room was deemed unachievable in its current condition.

The subject of cultural changes in the lab came up as well. Such improvements would have included powering down computers and turning off lights when the lab was not in use. This simple idea would be easy and free to implement. However, the lack of light in a laboratory space raises safety concerns when hazardous materials are being handled, and thus it could not be pursued.

Finally, we considered possible ways of reclaiming heat from the exhaust of the clean room. The options considered were a heat wheel or heat exchanger. A heat wheel, sometimes called an enthalpy wheel, is a heat and humidity transfer device utilizing a large spinning wheel which crosses between the exhaust and supply ductwork. The transfer of heat and humidity between the flows is facilitated by a gel medium. Complications with this method of heat recovery included the extensive ductwork needed to route the exhaust by the supply stream and the potential of contaminants from the lab crossing over from the exhaust into the supply. The other option, the heat exchanger, carried similar challenges. While the heat exchanger removed the possibility of cross-contamination, it still had the issue of installing extensive duct work to bring together the exhaust and supply.

Upon evaluating these options and taking into consideration the information learned in conversations about the lab, we decided that any alteration of the lab space would be impractical to implement. The disruption to the lab space and cluttering of the already crowded roof space would only limit the function of the laboratory. Therefore, we chose to leave the clean room systems as they are now and focus on other areas of the building to implement energy saving solutions.

Lighting

Currently the Mechanical Engineering Building contains mostly T12 fluorescent lighting fixtures as well as a few T8 fixtures. Since upgrading from T12 lighting generally has a quick payback we performed analyses to find out if that was true in the case of MEB [9]. Also, with the implementation of a new HVAC system in the south section of MEB a new drop ceiling would be installed along with the ductwork and hence new lighting fixtures would be installed as well.

In order to perform analysis on the lights we need to know the cost of the lights, the quantity of fixtures, and the power per area to input into the TRACE model.

To help with this, Bruce Baldwin of Hubbell lighting was kind enough to provide fixture prices as well as supply us with a program called LitePro 2.0 [8]. One of the features of this program is the calculation of the number of a chosen lighting fixture necessary to maintain a chosen luminance in a rectangular room of a specified size.

To find the necessary luminance for each room type we found an EPA document detailing such information [4]. Instead of putting each room in separately into LitePro, we added up the areas of all the rooms requiring the same number of foot-candles and created one square room with that area. Next, a typical recessed ceiling fixture was chosen from www.columbialighting.com capable of handling T5, T8, and T5 high output bulbs. Then the associated LitePro-compatible files were downloaded for each type and input into the program. Information on each fixture type can be found in table 8. The resulting information from Lite-Pro 2.0 is detailed in table 9. T5 2' by 4' and T8 2' by 4' fixtures were the only fixtures with a low price as well as low power per area ratio. Hence, those were the two fixtures chosen to go on to the TRACE model.

The power per area was input into each respective room type. The outcome of the modeling is the clear preference for the T5 2' by 4' fixture. As in table 2, it has a payback of 7.83 years compared with the T8 payback of 25.53 years. This is despite the T5 having a slightly higher initial cost and power per area. This could be due to the increased heating due to the higher power per area that the T5 provides during the winter.

Table 2: Economic Impact of Lighting

Improvement	Capital Cost	Payback	Annual Savings
T5 2'x4'	$125,685.00	7.83	$16,059.00
T8 2'x4'	$112,320.00	25.53	$4,399.00

Wall Panel Insulation

As stated before, the current insulation in MEB is abominable. The calculated R value of the walls is around R-4 as compared to most new buildings which have R-15 [2]. Hence, additional wall insulation was a natural choice for improvement.

We chose to look into exterior wall panel insulation as opposed to interior insulation. Installing wall panels would be much easier than trying to install interior insulation since radiators and other such things would not have to be reseated due to a thicker wall protruding and surrounding it. Also, wall panels are easily snapped together. This would also give the building a more modern and appealing aesthetic since the panels come in a multitude of colors, sizes, and textures to accommodate any desired style. Since the building is not considered historically significant there is no concern about changing the exterior.

Essentially the wall panels are foam with a sheet metal exterior as seen in figure 5 courtesy of www.metlspan.com. While allowing for easy installation this also prevents the infiltration of any outside substances that may degrade the insulation, making them extremely durable. The specific panels we looked at were Metl-Span CF Architecture Insulated Metal Wall

Panels. We also looked into wall panels from Centria but the quoted price was much greater. The panel's insulation was rated at R-7.5 per inch of thickness. We compared the effects of 2", 4", and 6" thick panels which had respective R values of 15, 30 and 45.

The costs quoted by Bob Breen of RCB Architectural Products came in a considerable range [1]. Labor varied the most from $1 to $4 per square foot of paneling. For simplicity's sake the values used in our calculations are the average values without texturing. The whole range of values can be found in table 10. The highlighted values are those that were used.

After adding each panel thickness to the wall construction in TRACE and running the simulation it is evident that 4" are most cost-effective with a payback of 12.62 years. The results show that the 6" panels actually use more energy as seen in table 3. This is most likely due to heat loads in the building causing more of a load on the cooling system since the heat can no longer leak through the building envelope as easily.

Table 3: Economic Impact of Wall Panels

Improvement	Capital Cost	Payback	Annual Savings
2" Wall Panel	$225,400.00	20.29	$11,109.00
4" Wall Panel	$257,600.00	12.62	$20,418.00
6" Wall Panel	$273,700.00	19.12	$14,314.00

Water Fixtures

Although a small expense in the MEB utility budget, reducing potable water use was nonetheless considered. We looked at changing water closets, urinals, and faucets. All pricing data was taken from RSMeans.

The only way to accurately measure bathroom use is to mark every time a person uses each fixture, which is out of the question. Hence, it must be estimated. Facilities and Services contact John Prince gave an outline to this estimation method. To estimate the use of each fixture, a number of assumptions were made.

The first assumption is that the building is filled to half occupancy. Normally, this would be full occupancy, but since MEB is so underused half occupancy is a better guess. Next, we assume that MEB contains half male and half female occupants. This may be slightly little off considering the number of male mechanical engineering students outnumbers female students although the office staff is mostly female. Next, we assumed that each female uses a water closet three times daily and each male uses a urinal twice daily and a water closet once. Both male and female uses a lavatory three times daily. Each sink in MEB can have the flow rate adjusted. Hence, the sink was approximated to have a flow rate of eight gallons per minute. Each person was assumed to run the sink for thirty seconds.

The result of this analysis is shown in table 11. All fixture costs include rough-in, supply, waste, and vent costs. The waterless urinal includes the necessary one quart of trap liquid per urinal. The lavatory includes a faucet with an automatic sensor. The highlighted rows in the table show the recommended fixtures. Each has a relatively short payback. The only catch is that some of the assumptions described above may be off. One of concern is the assumption that MEB is half occupied. MEB is so underused it could easily be a quarter occupied. With the implementation of the package of improvements recommended at the end of this report MEB will surely be more comfortable and hence attract more occupants. The payback periods may shorten to less than what is in table 11 if this is the case.

Windows

Windows can be a significant source of infiltration in a building's exterior envelope. Additionally, windows can allow solar energy to enter a building and allow the interior space to heat up. Having well sealed and solar resistant windows can help improve the stability of the environment within the building. For Mechanical Engineering Building we sought to examine whether modernization of the windows would yield any significant improvements to the building envelope. To evaluate this we first performed a blower test on the existing windows to gain an understanding of how much infiltration was occurring around them.

The blower test essentially allowed for quantification of the leakage that was occurring around and through the windows in Mechanical Engineering Building. We built an airtight frame to place around the window. This frame was constructed out of lumber and sealed with duct tape. Weather-stripping was used to ensure an adequate seal around the interface between the frame and the window. For the evaluation two windows were tested, one with an A/C unit and one standard window. By removing the air from between the frame and the window and measuring the resulting flow rates and pressure, a profile for infiltration of the window could be developed. This relationship is a power law function following the equation, $Q = C\Delta P^{n}$. Where Q is the flow rate, C is a constant, ΔP is the pressure difference and n is the power of the function. Results of the evaluation can be seen in figure 4.

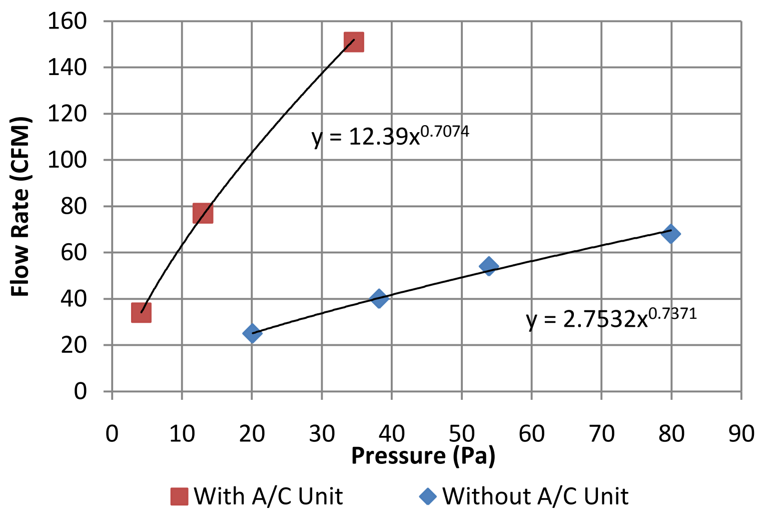

Figure 4: Blower Test Results

There was a noticeable difference in infiltration with respect to the presence of a window A/C unit. Being able to remove these window units would be beneficial to the integrity of the building envelope. Next, we modeled both double and triple paned windows in TRACE and ran simulations of these changes. Their properties are listed in table 4. Results of the simulations can be seen in table 5.

Table 4: Properties of Simulated Windows

Window	R-Value	Shading Coefficient
Single Pane (Original)	1.1	0.95
Double Pane	2.0	0.55
Triple Pane	4.5	0.23

Table 5: Economic Impact of Windows

Improvement	Capital Cost	Payback (yrs.)	Annual Savings
Window-Double Paned	$ 800,000.00	39.96	$ 20,019.40
Windows-Triple Paned	$ 944,000.00	34.35	$ 27,480.56

We can see that the addition of modern windows to the building does provide considerable energy savings per year, but at a very large capital expense. Cost per window was estimated by Marvin Windows at roughly $2500 for double paned windows to $2950 for the triple paned windows [7]. Window estimates were for double and triple paned, aluminum clad, argon filled windows. Payback for this project would be almost 35 or 40 years. For this reason it is hard to justify this improvement on its own as a viable energy savings solution. However, we were aware of the possibility for synergistic effects between improvements, so we included the better of the two options, the triple paned windows, in combination with other measures.

Roofing

Currently the roof on Mechanical Engineering Building consists of built up gravel or painted rubber. On the north wing of the building there are numerous mechanical systems protruding out of the roof, including exhaust chimneys and Carrier chiller units. Since there is relatively little insulating material on the roof, there is an opportunity to improve the current roof of Mechanical Engineering Building by adding insulation and high albedo coatings. We examined three different solutions to the roofing which were similar in profile, but different in properties and cost. These solutions included the application of 2-inch foam board insulation and high albedo coating, 2-inch spray foam insulation with high albedo coating, or panel insulation which consists of foam sandwiched between sheet metal. The properties for each solution can be seen in table 6 and the results of the simulations for each roofing type are shown in table 7.

Table 6: Properties of Simulated Roof Insulations

Roof Insulation Type	R-Value	Solar Absorptivity
Spray Foam	16.9	0.45
Foam Board	11.0	0.45
Pre-fabricated Panel	18.6	0.9

Table 7: Economic Impact of Roofing Insulation

Improvement	Capital Cost	Payback	Annual Savings
Foam Board Insulation	$ 186,667.52	25.19	$ 7,409.87
Spray Foam Insulation	$ 182,035.20	19.97	$ 9,113.28
Pre-fabricated panel Insulation	$ 348,798.72	29.50	$ 11,823.00

The results of the simulations show that there are moderate savings achieved by adding a new roof, but at a considerable cost. Paybacks ranged from 20 to 30 years and saved approximately $7000 to $12000 dollars annually. Most roofs' lifespan are shorter than this payback period and so the application of new roofing alone is not an acceptable solution to energy savings. The best solution though based on these simulations is the spray foam roof. It had the shortest payback period of 20 years with a savings of $9,000 annually. In addition it would be the most efficient to install, since it can form around existing roof features like exhaust chimneys and pipes.

Central HVAC in the South Building

One of the main goals of this project is to implement and model the addition of a central heating ventilation and air conditioning system in the south building [9]. Currently floors one, two, and three are only serviced by window A/C units. Due to the buildings current ventilation condition, the space is most often over heated by the radiators or over cooled by the window A/C units. In addition, when the window A/C units are not being used, the infiltration of outside air is much greater than if a standard window were installed. This effect was seen during the blower test. Both students and instructors do not feel the space is adequately comfortable to learn and teach and believe a change must be made.

Variable Air Volume

For the south building a VAV HVAC system is chosen. A VAV system heats or cools the outside air to 55^0F at the central air handling unit [9]. The result is often less humid supply air. This conditioned air is then blown by a supply fan through the ductwork to zones throughout the building. Each zone has a terminal reheat box. This box has a hot water coil which will heat the incoming air to the desired temperature for that room or decrease the amount of incoming air or CFM by controlling a damper. Depending on the amount of air needed for a room throughout the day, the central air handling unit fan runs faster or slower. The fan will maintain a constant pressure in the ductwork to reduce over pressurization and failure when dampers are closed. A VAV system was chosen for this building because a number of rooms, particularly classrooms, are not being conditioned throughout the day or year. When the rooms are not used, the damper can be closed and the main fan can use less energy to run.

Feasibility

The new HVAC system would only be implemented for floors one two and three in the south building. There are some rooms being conditioned by window A/C units in the basement but the cost to extend ductwork to this area would be too great. Instead it is suggested to use the existing air handling unit in the basement to service these areas and the remainder of the basement. This air handling unit located in the basement currently uses duct space to the roof for outside air that will be needed for the new HVAC system. It is suggested that this outside air ductwork be drawn from the northern end of the building instead. Also, demolition of existing ductwork from original central heating will need to be removed including the rooftop air handling unit.

Sizing of Air Handling Units

The addition of a central HVAC system to a space of this size would require a great deal of new mechanical equipment. The most notable is a new air handling unit. This unit will be placed on the roof of the building where the existing heating air handling unit is located. This location is directly above existing ductwork space to all floors. The new air handling unit will be a custom unit and will not be bought as a packaged unit. The size of the unit will be directly dependent on the maximum CFM needed for the space at peak load [6]. From the TRACE output, it was determined that if a VAV system was implemented without additional improvements, the space would require roughly 80,000 CFM. Two air handling units would be required each running roughly 40,000 CFM at maximum capacity. The CFM when an HVAC system is implemented alone and with other improvements is seen in table 15. Due to the layout of the building, each air handling unit would service either the east or west sides of the building.

Equipment

Extensive new ductwork and piping will have to be installed in the building. The area that will be serviced by the new HVAC system is roughly 40,000 ft^2. This area was used to obtain an estimate for the mechanical equipment. New piping would have to be run to the locations of each zone for the terminal reheat boxes.

Some extensive modifications will be required since such a large modern HVAC system will be installed in an older out of date building. The building is already connected to the campus chilled water loop. A new HVAC system would also connect to this chilled water loop. However, the demand for the building would increase substantially from roughly 22,000 therms to 54,000 therms as estimated by the building model. The building does not currently have a hot water supply and only has purchased steam from the campus loop. Hot water will be required for the air handling unit and the terminal reheat boxes throughout the building. One proposed solution is to preheat the hot water with condensate from the purchased steam already in the building so that a smaller reheat loop will be required. Lastly, the addition of ductwork throughout the building will require a plenum space. A dropped ceiling will be needed to create this space.

Capital Cost

The total cost of a new VAV HVAC system to the south building space will cost roughly $2.5 million. The cost of new mechanical equipment was estimated by Tom Lee at Duct Systems Incorporated [6]. The estimate for a system implemented in a poorly insulated space was $1.5 million. Labor costs were estimated to be 1.5 times the cost of the equipment. Demolition costs of existing equipment were estimated to be $13,000. The installation of a dropped ceiling is estimated to be roughly $0.2 million [10].

Energy Consumption

In the model of the current building, a total of $279,400 annually is used between electricity, chilled water, and steam. If a new HVAC system were to be installed, the TRACE model estimates an annual utility cost of $297,900. This increase in utility cost is expected. The addition of a new large HVAC system will expectedly require a great deal of energy to run. The space is currently not being conditioned for adequate comfort and reaching an expected comfort level will require more energy. The addition of an HVAC system to the building will not make it more energy efficient but it will allow the building to be at what is seen as a necessary level of comfort. Packages of improvements will also be evaluated with the comparison to the assumption of installation of a central HVAC system.

Improvement Packages

Multiple improvements were considered for the building. The effectiveness of these improvements installed together was estimated using TRACE. The implementation of numerous improvements together was shown to drastically reduce the energy consumption of the building as opposed to being implemented alone. Packages were chosen based on their energy savings and payback when a central HVAC system is also implemented.

Best Payback

Improvements

The improvements implemented in a package with feasibility and the shortest payback periods are: VAV HVAC, T8 lighting, 4” wall insulation, and spray roof insulation. These improvements were chosen based on their energy savings and payback periods alone.

Capital Cost

The installation of T8 lighting will cost $112,000. 4” wall insulation will cost $257,000. Spray foam roof will cost $182,000. The installation of a HVAC system will be lower due to these improvements. A smaller air handler and smaller ductwork will be required to condition the space. A VAV system will cost roughly $2,086,000. The total installation of this package is estimated to cost $2,637,000. These cost estimates are seen in table 14.

Energy Savings and Payback

The implementation of these improvements to the building will result in a modeled energy usage of $199,000. From the existing building’s modeled energy usage this is an $80,000 reduction and from an assumed HVAC installation a $99,000 reduction in utility cost. The payback period from all implementations including a HVAC system is estimated to be 32.86 years. The payback period for the improvements when a HVAC system is assumed to be installed is only 1.79 years. These results can be found in table 13.

Best Savings

Improvements

The improvements implemented in a package with feasibility and the greatest energy savings are: VAV HVAC, T8 lighting, 4” wall insulation, spray roof insulation, and triple pane argon gas filled windows. These improvements were chosen based on their energy savings and payback periods alone.

Capital Cost

The installation of T8 lighting will cost $112,000. 4” wall insulation will cost $257,000. Spray foam roof will cost $182,000. Triple pane windows will cost $944,000. The installation of a HVAC system will be lower due to these improvements. A smaller air handler and smaller ductwork will be required to condition the space. A VAV system will cost roughly $1,710,000. The total installation of this package is estimated to cost $3,206,000. These cost estimates are seen in table 14.

Energy Savings and Payback

The implementation of these improvements to the building will result in a modeled energy usage of $163,200. From the existing building's modeled energy usage this is an $116,000 reduction and from an assumed HVAC installation a $135,000 reduction in utility cost. The payback period from all implementations including a HVAC system is estimated to be 27.60 years. The payback period for the improvements when a HVAC system is assumed to be installed is only 5.54 years. The payback period of the improvements to a HVAC system is still reasonable and considered worthwhile. It is also seen that the payback period of all improvements including a new HVAC system decreases as more improvements are added. These results can be found in table 13.

Conclusions and Recommendations

This project can be summarized by several recommendations for future action. We have categorized the two recommended solutions package as shortest payback period and as the greatest quantity of energy saved. Both packages will have VAV HVAC systems included but vary in the additional measures implemented to improve the building. Alternatively, we also suggest a more radical solution which may provide opportunities for additional research. That solution is to rebuild Mechanical Engineering Building. Conservative estimates put construction costs at around $320/ft^2. For a 100,000 square foot building, not much larger than the current building, cost would be in the $32 million range. This sounds like a lot of money, but some of the renovation packages considered in this project cost up to $3.4 million. This is over ten percent the cost of a new building just to bring an aging building up to current standards. That does not include interior renovations or modernization. These revelations about Mechanical Engineering Building make studies on economic and architectural feasibility of such a project a prudent decision, and demonstrate forward-thinking on the part of the Department of Mechanical Engineering.

However, if renovation of Mechanical Engineering Building is found to be the optimum course of action, we recommend the preceding packages of solutions to be implemented depending on the mindset of the University. As just described the “Shortest payback” package is the package with the quickest recovery of investment, while the “Greatest energy savings” package has the greatest annual savings in energy. What choice is made is a matter of resources and intent. Either way, an improvement to Mechanical Engineering Building is necessary and imperative, and the ideas brought forth in this report should be implemented to increase occupant comfort and environmental sustainability.

References

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[5]Hansen, Michael. "Interview on MEB Cleanroom." Personal Interview. 2 Nov. 2010.

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Appendices

Table 8: Lighting Fixture Description

Part Number	Short Name	Power (W)	Lumens	Cost	Install	Total
EPC24-228G-SH-EPU-F5835	T5 2x4	65	5200	$103.50	$85.50	$189.00
EPC24-232G-SH-E104U-PLUS835	T8 2x4	56	5500	$94.50	$85.50	$180.00
EPC24-254G-SH-EU-F5841	T5HO 2x4	114	8900	$108.70	$85.50	$194.20
EPC22-214G-SH-EP	T5 2x2	34	2700	$110.80	$85.50	$196.30
EPC22-217G-SH-E104U-FO735	T8 2x2	35	2750	$94.25	$85.50	$179.75

Table 9: Lighting Fixture Calculations

			T8 2"x4"		T5 2"x4"		T8 2"x2"		T5 2"x2"		T5HO 2"x4"	
Room Type	Luminance (fc)	Area (sq. ft)	Quantity	W/sq.ft	Quantity	W/sq.ft	Quantity	W/sq.ft	Quantity	W/sq.ft	Quantity	W/sq.ft
Hallway	10	21928.35	42	0.107	49	0.145	110	0.176	100	0.155	30	0.156
Mechanical Area	20	6936.59	30	0.242	30	0.281	72	0.363	72	0.353	20	0.329
Classroom, Office, Conference Room, Restroom	30	35958.47	210	0.327	225	0.407	506	0.493	484	0.458	144	0.457
Laboratory	75	23993.47	342	0.798	361	0.978	841	1.227	812	1.151	240	1.140
Total Quantity			624		665		1529		1468		434	
Cost			$180.00		$189.00		$179.75		$196.30		$194.20	
Total Cost			$112,320.00		$125,685.00		$274,837.75		$288,168.40		$84,282.80	

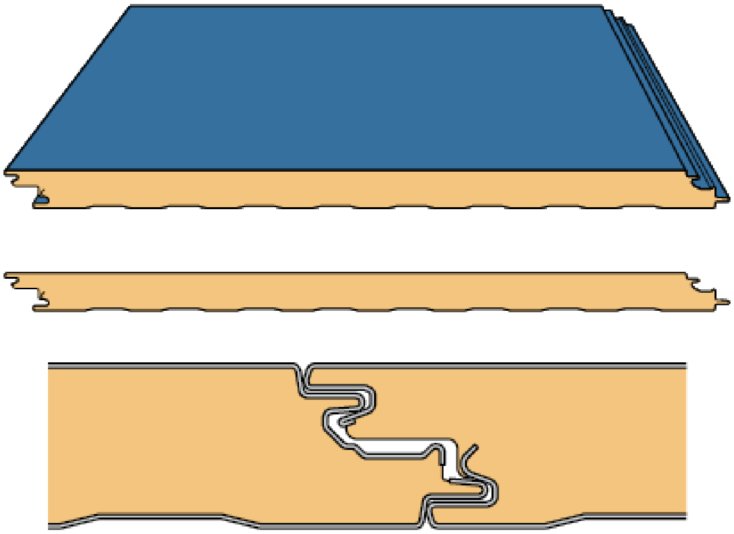

Figure 5: Wall Panel Cross Section

Table 10: Wall Panel Cost Calculations

Thickness		Material		Labor		Texture	Total			Total w/ texture		
		min	max	min	max		min	max	average	min	max	average
2"	per area	$4.00	$5.00	$1.00	$4.00	$0.70	$5.00	$9.00	$7.00	$5.70	$9.70	$7.70
	total	$128,801	$161,001	$32,200	$128,801	$22,540	$161,001	$289,802	$225,402	$183,541	$312,343	$247,942
4"	per area	$5.00	$6.00	$1.00	$4.00	$0.70	$6.00	$10.00	$8.00	$6.70	$10.70	$8.70
	total	$161,001	$193,202	$32,200	$128,801	$22,540	$193,202	$322,003	$257,602	$215,742	$344,543	$280,142
6"	per area	$5.50	$6.50	$1.00	$4.00	$0.70	$6.50	$10.50	$8.50	$7.20	$11.20	$9.20
	total	$177,101	$209,302	$32,200	$128,801	$22,540	$209,302	$338,103	$273,702	$231,842	$360,643	$296,242

Table 11: Water Fixture Analysis

Fixture	Water Use	Unit Cost	Quantity	Total Cost	Water Saved per Use (gal)	Uses per Day	Yearly Savings	Payback (years)
Water Closet	1.28 gpf	$1,620	17	$27,540	2.22	1400	$5,451	5.05
	1.6 gpf	$1,355	17	$23,035	1.90	1400	$4,665	4.94
Urinal	1 gpf	$1,685	12	$20,220	0.50	700	$614	32.94
	0.5 gpf	$2,085	12	$25,020	1.00	700	$1,228	20.38
	0 gpf	$1,306	12	$15,670	1.50	700	$1,841	8.51
Lavatory	5 gpm	$2,085	13	$27,105	1.50	4200	$11,049	2.45

Table 12: Actual Utility Usage for 2009

Month	Utility Usage		
	Electricity (kWh)	Steam (klbs)	Chilled Water (Mbtu)
January	259,714	2,715	369
February	155,454	2,092	326
March	215,674	1,996	316
April	219,214	2,318	469
May	191,860	765	554
June	232,720	830	857
July	266,514	667	1,199
August	246,214	806	1034
September	260,634	700	1031
October	249,534	673	905
November	210,134	2139	552
December	190,874	1900	431
Rate/Unit	**$ 0.07**	**$ 19.75**	**$ 11.67**

Table 13: Recommended Improvement Packages Comparison

	Estimated Installation Cost ($)	Model Estimated Annual Utility Cost ($)	Energy Savings ($)		Payback (years)	
			From Existing	From HVAC	From Existing	From HVAC
Existing Building	-	$279,000.00	-	-	-	-
VAV HVAC	$2,250,000.00	$298,000.00	-	-	-	-
Best Payback	$2,637,000.00	$199,000.00	$80,000.00	$99,000.00	32.86	1.79
Best Energy Savings	$3,206,000.00	$163,000.00	$116,000.00	$135,000.00	27.6	5.54

Table 14: Recommended Improvement Packages Itemized Cost

Short Payback	
Items	Cost ($)
VAV HVAC	$2,085,672
T8 Lighting	$112,320
4" Wall Insulation	$257,600
Spray Foam Roof	$182,035
Total:	$2,636,627

Energy Savings	
Items	Cost ($)
VAV HVAC	$1,709,673
T8 Lighting	$112,320
4" Wall Insulation	$257,600
Spray Foam Roof	$182,035
Triple Pane Windows	$944,000
Total:	$3,205,628

Table 15: Required Load for Proposed Central HVAC System

Package	CFM Required
VAV only	82365
Shortest Payback	52027
Greatest Energy Savings	22907