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2017 Fall ENGR333 Project Final Report (Section A)

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Energy Savings Projects

Engineering 333: Section A

Professor Heun

December 19, 2017

Objective

Calvin College currently spends $836,000 annually on natural gas consumption. The engineering 333-A class was tasked with the question, "What would it take for Calvin College to save $75,000 per year on natural gas costs". The class was split into five groups (Boilers, Dorms and Dining Hall, Academic Buildings, Finance, and PE Complex) to research possible areas of savings. Through the class' research, it was determined that Calvin College has the potential savings of $87,000 a year through the reduction of natural gas usage.

Approach

Projects:

Finance

The finances for each project were analyzed, and this included the cost that the project would have to implement, as well as the potential annual savings of the project. From the financial analysis of each project, it was determined which projects would be recommended to implement, based on the project's return on investment and payback. Calculations were also performed for varying costs of capital, and including the rate of cost escalation for natural gas.

Boilers

The current boilers on Calvin College's campus were examined to determine options to improve the efficiency of the boilers. The projects that were evaluated were: increasing the amount of maintenance that is done on the boilers, installing economizers on the boilers, upgrading the controls system on the boilers, and replacing some of Calvin's older boilers.

Dorms and dining hall

The dorms and dining halls looked into a variety of different projects including: replacing dining hall appliances, adding additional roof insulation, modifying the dormitory radiators, utilizing the heat from the pizza oven, and replacing single pane windows with double pane windows. The ideas which were chosen for further analysis were modifying dorm radiators, adding additional insulation to the dorm rooms, and replacing windows.

Academic Buildings

The academic buildings looked into a variety of ideas includings: replacing windows with more efficient ones, lowering building temperatures, replacing doors on the exterior of the buildings, and adding additional roof insulation. The ideas the team chose to further look into were replacing windows with more efficient ones, and lowering building temperatures.

PE Complex

The PE Complex explored ideas to decrease the natural gas usage in Spoelhof Fieldhouse. These ideas include adding insulation in the fieldhouse,standardizing the temperature across the building, as well as other behavioral changes.

Results and Discussion

From the projects that the class researched and modeled, it is believed that there is the potential to save approximately $87,000 per year, by implementing the six projects that had the highest return on investment. The total annual savings, implementation cost, and years to payback of these five projects can be seen below in Table 1.

Table 1: Final Annual savings, Implementation cost and Payback Time

Total Annual Savings	$87,300
Implementation Costs	$395,000
Payback Time	4.5 years

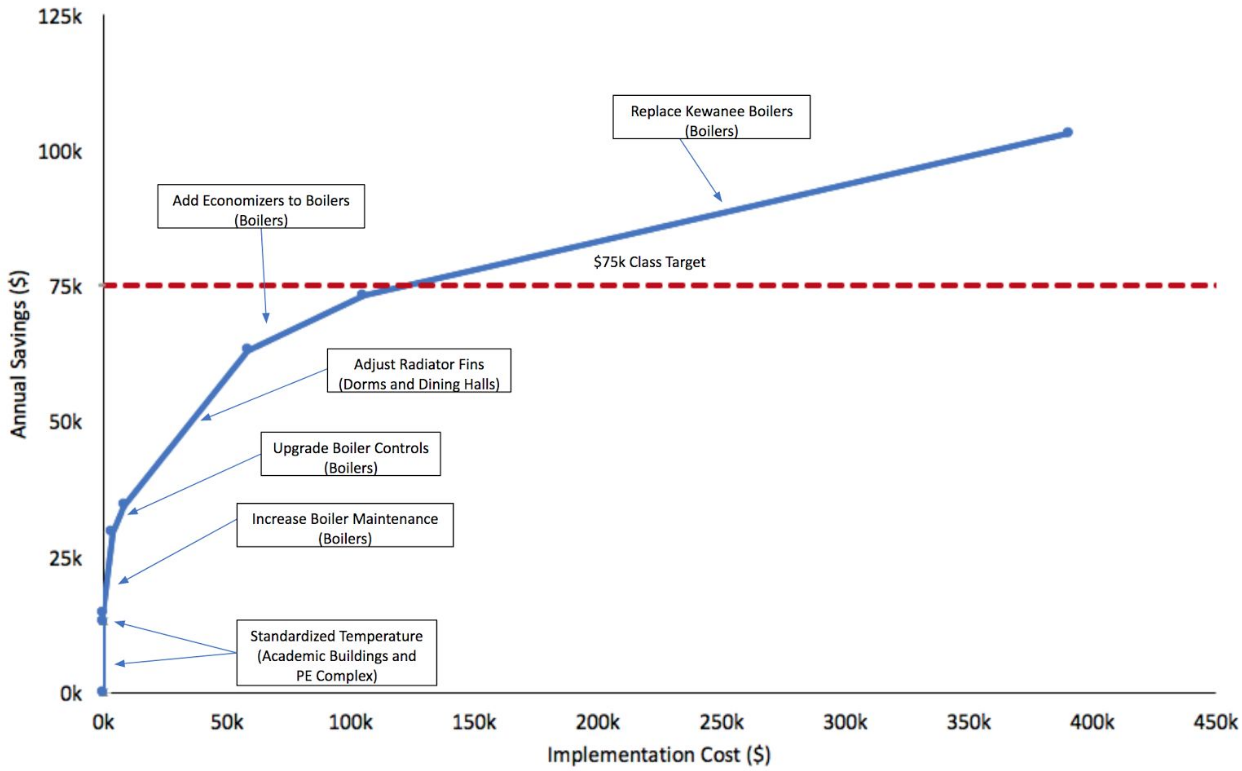

Figure 1: Top Six Projects

Conclusion

The ENGR-333A class has developed a pathway for Calvin to decrease its natural gas spending by $87,000 annually. The top ideas the class would recommend implementing based on their research are: to upgrade the boiler systems, replace the Kewanee brand boilers, adjust the radiator fins in the dorms, and standardize the temperature for all buildings on campus.The team believes that they were successful in finding the top cost savings projects for Calvin College.

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Appendix A: Finances

From Left to Right: Trevor Nyeholt, Francis Kapesa, Justin Thalmayer, and Erik Karlson

Introduction

The finance team was tasked with working with each team throughout the whole project and therefore each member of the team was paired with another team (Boilers, Dorms and Dining Halls, Academic Buildings, and PE Complex) to analyze their finances. The individual teams were tasked to come up with two to three ideas that they believed would decrease the natural gas consumption on Calvin College's campus and save the college money. The goal for the finance team was to work with the teams to determine which projects would be best to save the college $75,000 per year on natural gas costs. Cost models were then developed in order to measure each project's feasibility.

Approach

After looking at Calvin College's natural gas consumption data, provided by the Calvin College Physical Plant, for the year starting July 2016 and ending June 2017, it was calculated Calvin spent $836,830 on natural gas.

Once the natural gas consumption was determined, the next step was to analyze the historical natural gas price trend. While the price fluctuates from year to year, the Sightlines Report, by Sightlines Institute, cited that $5.21 per million BTU was the cost that Calvin College paid for natural gas in 2016. Therefore, the team decided that this price would be the baseline of cost savings calculations for all projects.

With the known gas consumption and price of natural gas, cost models could be created. The cost models included upfront costs, recurring costs, and the related savings. Upfront costs included initial capital investments and labor costs such as installation, while recurring costs consisted of maintenance costs and replacement costs if applicable.

Results

As mentioned above, the finance team received a variety of projects that were potential cost saving options. However, after further analysis, the projects that the group suggests Calvin implement are: increasing maintenance on the boilers, replacing the Kewanee boilers, adding economizers to the Hurst boilers, upgrading the boiler controls, standardizing building temperatures across campus, and adjusting the quantity of fins in the dorm radiator. Table A-1, below, summarizes the projects that were chosen, their implementation costs, gas savings per year, net annual cost savings, return on investment, and years to payback.

Table A-1: Final Projects to Be Pursued

Project	Implementation Cost ($)	Gas Savings (MMBTU/Yr)	Annual Cost Savings ($/Yr)	ROI	Payback (Years)
Increase Maintenance	$0	3000	$11,000	NA	0.00
Replace Kewanee Boilers	$300,000	6000	$30,000	10%	10.00
Add Economizers	$45,000	2000	$10,000	22%	4.50
Upgrade Controls	$5,000	1000	$5,000	100%	1.00
Change Building Temp	$0	2250	$11,800	NA	0.00
Adjusting Radiator Fins	$45,000	3700	$19,500	43%	2.31

Figure A-1 shows the projects, ordered by their return on investment. The steeper the slope of each line the better the ratio of gas savings to implementation cost, and therefore the better the project. From the projects that the class recommends implementing, the goal of saving $75,000 per year on natural gas consumption was exceeded by $12,000, which can be seen in Table A-2. As seen in Figure A-1, replacing the windows in the academic buildings had significant cost savings opportunity of around $10,000. However, its implementation cost was $650,000. At an interest rate of only 3% and $10,000 annual savings, the discounted payback for this project would be infinite and the project would never pay itself back. More precisely, the annual interest rate on the implementation cost would be $19,500 which is almost double the annual savings of $10,000. This shows why window replacement, and some other cost intensive projects were rejected.

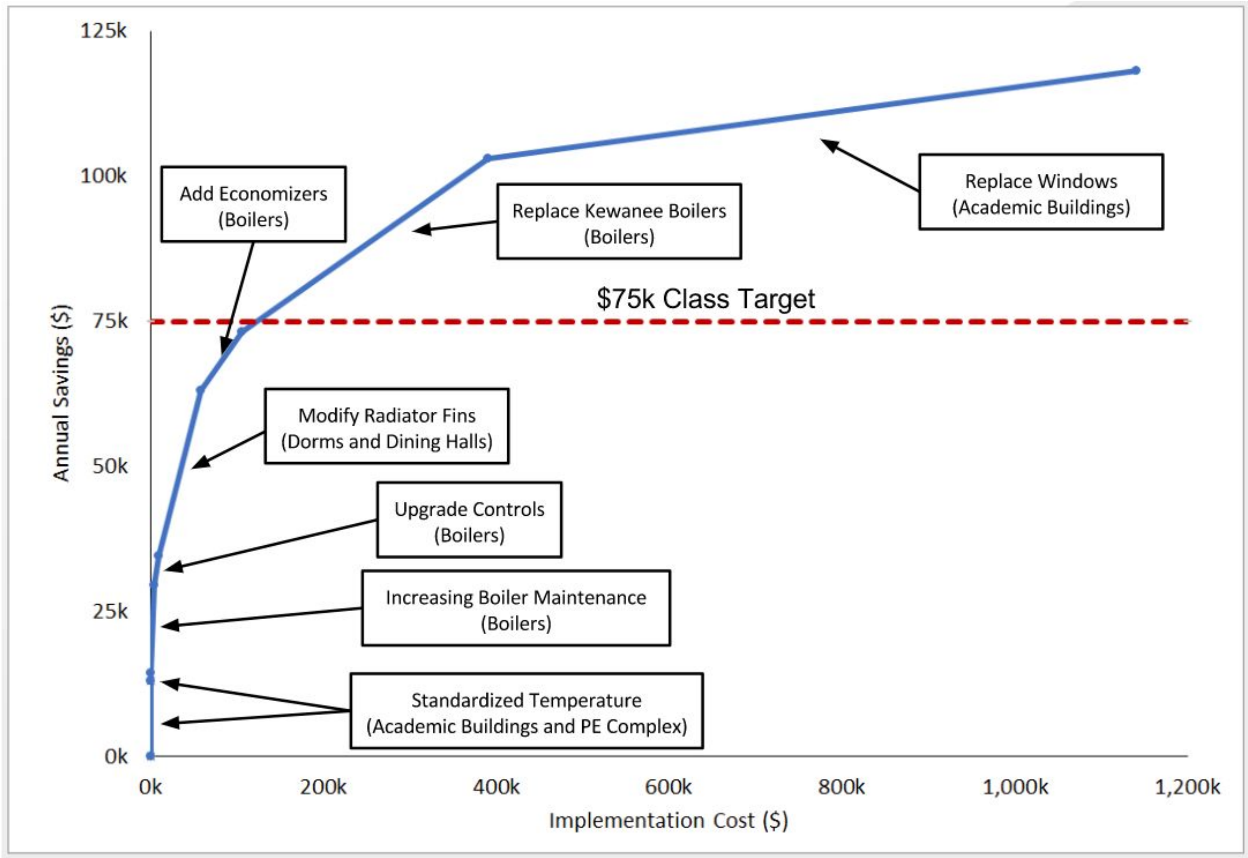


Figure A-1: Incremental Gas Savings and Incremental Implemental Implementation Cost

Table A-2: Summarized Results

Total Annual Savings ($)	$87,300
Implementation Cost ($)	$395,000
Payback (Years)	4.5

Table A-2 above summarizes the final results of the six projects that the class would highly recommend implementing. The team was able to exceed our goal of $75,000 in annual natural gas savings. Moreover, the implementation cost of the chosen projects would be $395,000 with an outstanding payback of 4.5 years.

Discussion

Uncertainties in the estimations and assumptions may arise from the chosen natural gas price and borrowing rate. The first source of uncertainty is the price of natural gas. Natural gas prices are very volatile and therefore difficult to predict. According to the Energy Escalation Rate Calculator (EERC) provided by the Department of Energy, the cost of natural gas is estimated to have an escalation rate of 5.4% over the next 20 years. Assuming a constant natural gas consumption for the next 20 years, the rising cost of natural gas will increase the estimated savings over this period. Figure A-2 below incorporates the increase in natural gas cost for the next 20 years to show its impact on the future estimated savings.

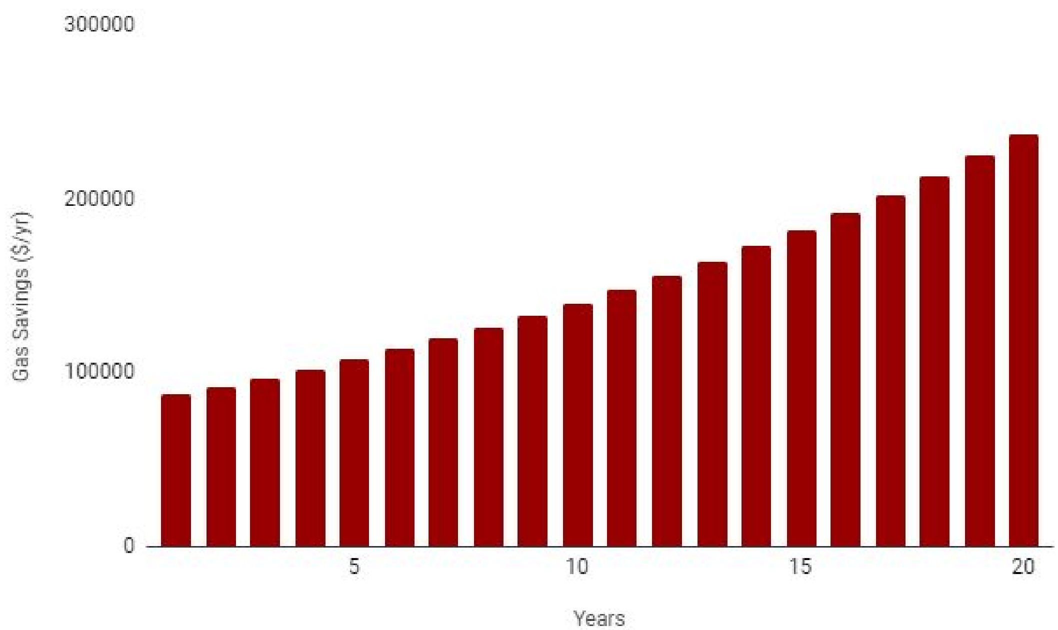


Figure A-2. Future Savings Escalation

Another source of uncertainty is the interest rate. In a previous example, a cost of money of 3% was used, which might be a bit too optimistic. Calvin might not be able to borrow money at such a low rate, so a variety of rates were examined. Table A-3 represents three economic scenarios and the appropriate project payback that was calculated for each scenario. The rates represent good economy (3%), a moderate economy (6%), and a poor economy (12%). As the Table shows, the payoff period for each project increases as the interest rate increases. The only significant change in the projects chosen, was that the Kewanee boiler replacement would never pay itself off with the 12% interest rate.

Table A-3:Discounted Payback by Market

Project	Implementation Cost ($)	Annual Cost Savings ($/Yr)	3% Interest Payback (Years)	6% Interest Payback (Years)	12% Interest Payback (Years)
Increase Maintenance	$0	$11,000	0.00	0.00	0.00
Replace Kewanee Boilers	$300,000	$30,000	12.07	15.73	NA
Add Economizers	$45,000	$10,000	4.91	5.40	6.85
Upgrade Controls	$5,000	$5,000	1.03	1.06	1.13
Change Building Temp	$0	$11,800	0.00	0.00	0.00
Adjusting Radiator Fins	$45,000	$19,500	2.43	2.56	2.86

Conclusion

The recommended mix of savings projects will results in substantial net savings for the college. The expected rise in natural gas costs over the next several decades will also serve to magnify this benefit. As shown in the Sub-Appendix A.1 these savings projects provide the college with positive net present value cash flows for the next twenty years, even with a weighted average cost of capital higher than 15%.

Sub-Appendix A Table of Contents

Sub-Appendix A.1: Finance Graphs

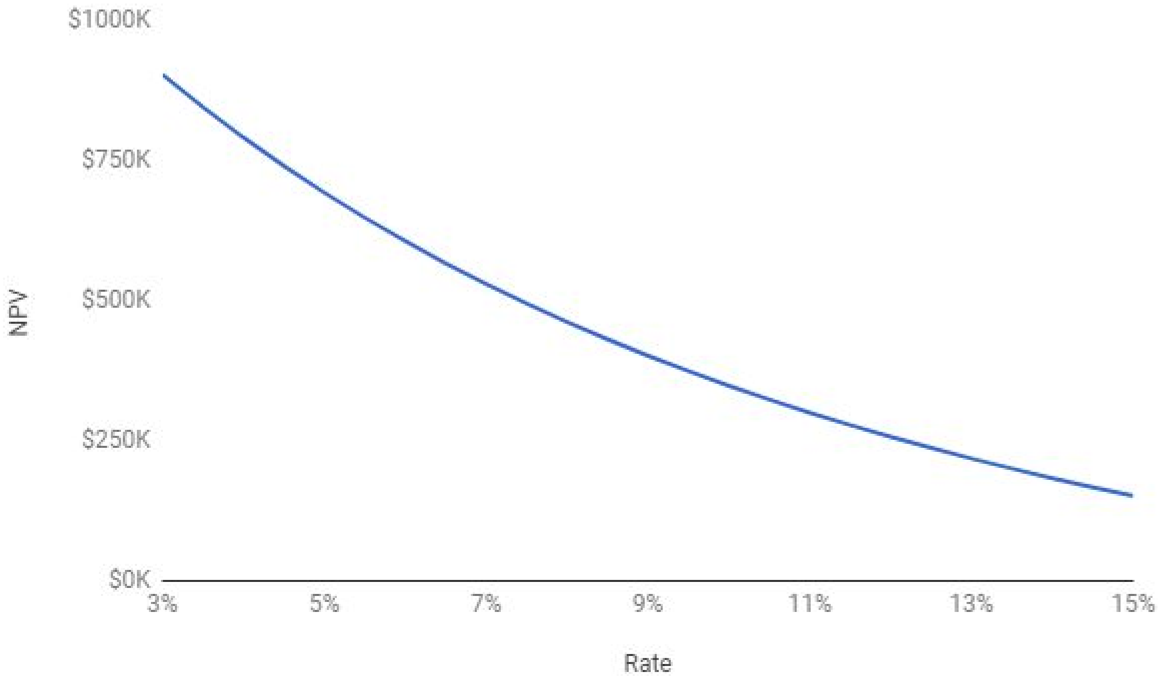


Figure A.1-1:Projects' Value vs WACC

Figure A.1-1 above represents the total net present value of the recommended savings projects for various weighted average costs of capital (WACC). This demonstrates the value of these recommendations for various market conditions, not accounting for fuel escalation rate.

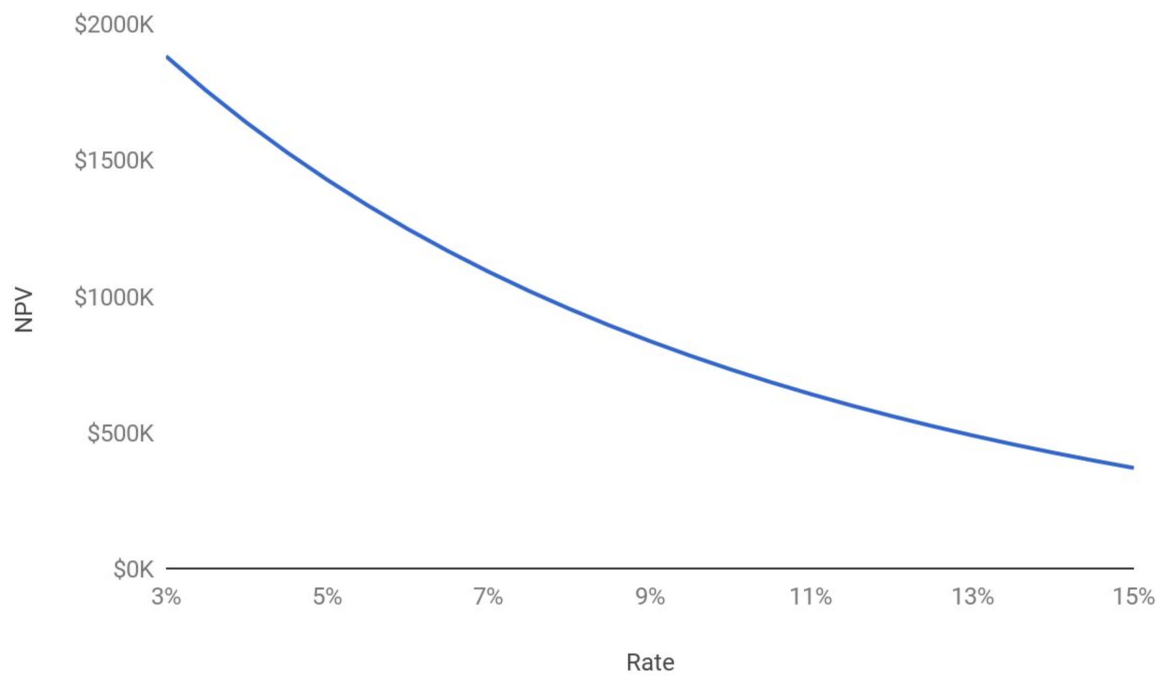


Figure A.1-2:Projects' Value vs WACC (Adjusted)

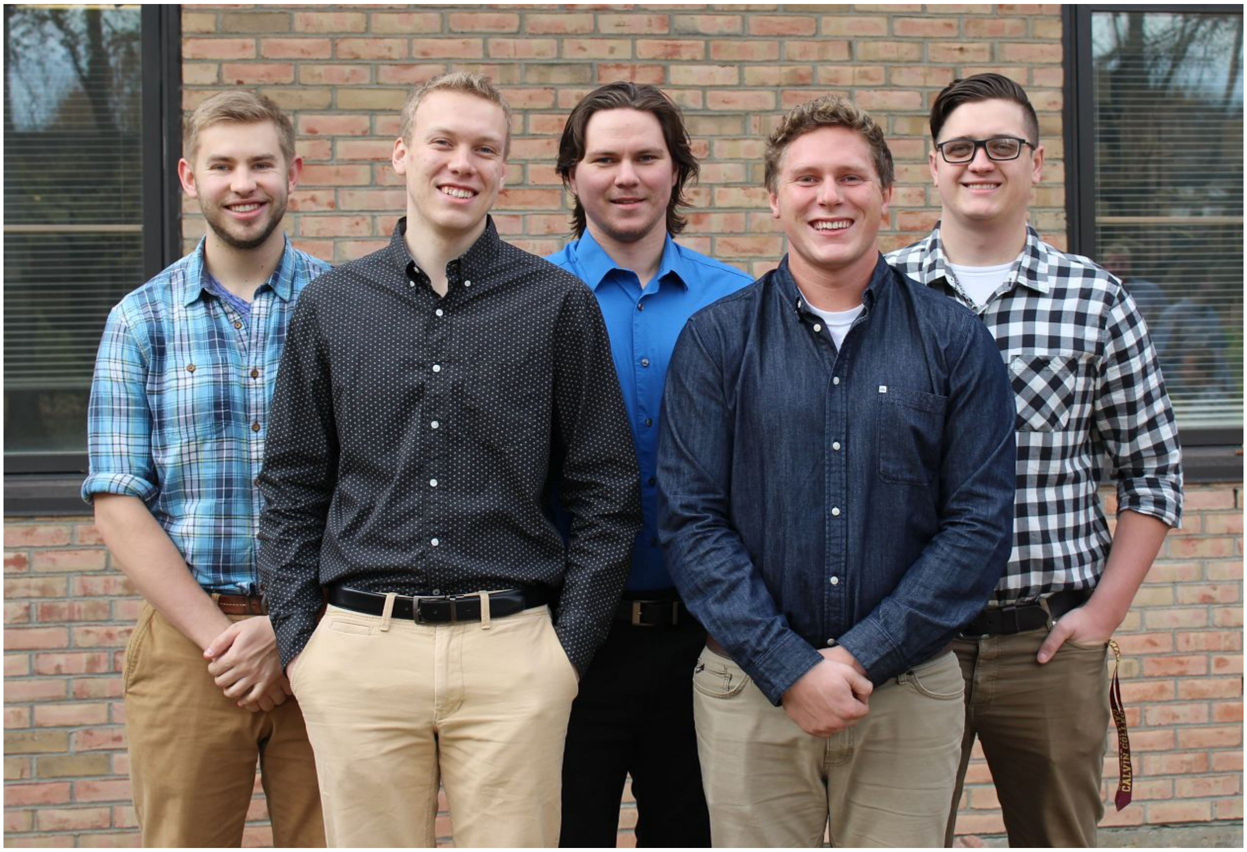
Figure A.1-2 displays the net present value of twenty years worth of savings, similar to the preceding figure. An adjustment is made to account for a 5.4% fuel escalation rate, which was found using the energy escalation rate calculator (EERC).

Sub-Appendix A.2: Work Cited

"Energy Escalation Rate Calculator Download." *Department of Energy*, energy.gov/eere/femp/energy-escalation-rate-calculator-download.

Sitelines- 2017 Utilities PowerPoint, Physical Plant

Appendix B: Boilers



From Left to Right: Kyle van Veen, Kirk Brink, Steven Tarske, Brent Homan, and Nathan de Haan

Introduction

In this project the task was “"What would it take for Calvin College to save $75,000 per year on natural gas costs?" The Boilers group was tasked with analyzing the boiler systems in order to find potential savings projects. Since 80-90% of Calvins natural gas consumption is used to run the six large boilers on campus, the group decided to focus on these devices. The group looked into increasing the boiler efficiencies by adding improvements to the current system and by replacing the old Kewanee boilers. Either method would decrease the amount of natural gas needed to fuel the boilers. The estimated cost savings from each of these projects are listed on the following page, in Table B-2.

The estimated savings in the top row of Table B-2 show the potential savings if each of the boilers’ efficiencies are increased by 2%. The bottom part shows the potential savings if the Kewanee boilers are replaced with new more efficient boilers. The bottom row of the figure shows the savings from replacing the kewanee boilers and increasing the new Hurst boilers by two percent.

These savings estimates are the result of research and analysis on various savings projects. The involved methods of estimation and analysis will be explained further in the following sections.. The team looked into improved maintenance, preheaters/economizers, small boiler replacements, large boiler replacements, and improved integrated controls of boilers.

Approach

For the boiler team, the project started by gathering as much information as possible about the boilers that Calvin College currently owns, and about how boilers function in general. The team found that the Kewanee boilers were purchased in the 1960’s and that the manufacturer went out of business in 2001. This caused difficulty in obtaining information. The information for the other boilers was obtained from the manufacturer's specifications.

By meeting with Phil Beezhold, the recently retired Physical Plant director, the team was able to: collect data for the boilers, obtain boiler model numbers, and receive a copy of the 2016 natural gas usage data for Calvin College. With this information the boiler team developed tables detailing the summation of the natural gas usage by the different boiler locations. This information was used to create a savings sheet based on the efficiency of the boilers. The current natural gas usage was coupled with a new efficiency estimate; to predict the future amount of natural gas needed (less than the initial natural gas usage). The new boiler efficiencies estimates were used to calculate cost savings from the improvement in efficiency.

Results

The team focused on five different ways to increase the efficiency of the boilers: replace the old Kewanee boilers with new large boilers, replace the old Kewanee boilers with new small boilers, add economizers to existing boilers, update the controls on the old Kewanee boilers, and increase the frequency of the maintenance cleaning on the boilers. These annual cost saving measures are described below.

Table B-2: Estimated Cost Savings from Boilers

	Cost	Annual Cost ($/yr)	Efficiency Increase	Savings ($/yr)	Distributor	Model
Large Boilers	$55,000.00		84.00%	$31,103.69	Boiler.com JB Industries	S-Series, 300hp
Large Boilers	$85,000.00		80.00%	$24,974.43	Hurst	S-500-G-300-125
Small boilers	$69,755.00		83.60%	$30,517.16	Cleaver Brooks	CB-8047 4WI-700-100-30 HW, 100 hp
Economizers	$46,809.00		8%	$10,500.00	HeatSponge	B5SS
Controls	$5,000.00		5%	$4,802.81	Ferguson Enterprises	Tekmar Boiler Control 284
Maintenance		$3,800.00	2.00%	$15,000.00	Calvin College Physical Plant	N/A

The boiler team recommends that Calvin College should increases the boiler maintenance, add economizers, update the controls, and replace the Kewanee boilers with new large boilers from Hurst. The details of each of these projects are found below in Sub-Appendices B.1-B.5.

Discussion

The boiler efficiencies utilized in cost calculations were from a combination of sources. A previous ENGR-333 class calculated the approximate efficiency of the Kewanee boilers at 67%. However, since the Kewanee boilers are steam boilers and the school operates a hot water system, the steam produced by the Kewanee boilers is run through a heat exchanger and used to heat the water. This heat exchanger lowers the overall efficiency of the boiler room. By replacing the Kewanee boilers with hot water boilers, this heat exchanger system can be eliminated and further savings can be expected. The manufacturer efficiency value of 78% was used for the Hurst hot water boilers .

The calculations assumed the boilers were running near the peak efficiencies of 67% and 78% for the respective boilers. Boilers reach peak efficiency when operating near peak loading conditions, and efficiency decreases as the load decreases. If the heating load demands more than one boiler to operate at a time, a second boiler must be used at partial capacity. Sequencing controls help regulate this by choosing an optimal set of boiler conditions to consume the smallest amount of fuel. By modeling cost saving around the optimal efficiency, there can be discrepancies if the boilers are running significantly under optimal loading. However, Calvin College has sufficient demand to ensure the boilers will rarely run under small loading conditions.

The Kewanee boilers are fire tube boilers, which means that combustive products are run through piping to heat water in a drum. The Hurst boilers are the reverse of this, water tube boilers, where water runs through the piping and is heated by combustion products in the drum. Water tube boilers are generally more efficient, and have become more affordable in the past decades as technological advancements were made. During boiler operation,combustion particulates make their way into the system's pipes. Here they form an insulating layer, known as fouling, that reduces the amount of heat transfer in the boiler. Regular maintenance is required to keep this layer minimal and improve efficiency. The modern Hurst boilers with fully digital control systems allow for cleaner combustion, and less particulate makes its way into boiler. This is the primary reason why the Kewanee boilers need to be cleaned five times as often.

Conclusion

Savings options include: increases in routine maintenance, adding economizers, updating control systems, and/or replacing the old boilers. In Table B-2 all the saving options are listed. The boiler team recommends that Calvin College implements the maintenance changes to gain some savings without any capital investment, integrate economizers into the Hurst boilers, and update the controls on the old Kewanee boilers. Additionally, the old Kewanee Boilers are at the end of the average boiler life span, so replacing the boilers with new Hurst boilers is also recommended.

Sub-Appendix B

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Sub-Appendix B.1: Maintenance

The most cost effective way to increase the efficiency of the boilers is to increase the frequency of routine maintenance. Cleaning the boilers one additional time per year would increase the efficiency of the boilers by decreasing the buildup of soot and scaling. Currently, the steam Kewanee boilers are cleaned once per year and the hot water Hurst boilers are cleaned only about once every 5 years. The present cost for labor is $44.50/hour.

It takes about two work days (16 hours) to clean each of the Kewanee boilers and about one and a half days (12 hours) to clean each of the Hurst boilers. The total cost for the additional one cleaning per boiler per year is shown in Table B.1-1 below.

Table B.1-1: Maintenance Cost for Cleaning Boilers

	Steam Boiler	Hot Water Boiler
Wages	$44.50/hour	$44.50/hour
Number of Boilers	3	3
Cleaning Time	16 hours	12 hours
Cleaning Cost	$2,136.00	$1,602.00
	Total	$3,738

With this extra cleaning, it is estimated that the efficiency of the boilers could be kept around 2% higher due to the decreased foiling build up in the boilers. For the estimated cost of $4,000 the savings would be roughly $15,000, this means a net annual savings of $11,000.

Sub-Appendix B.2: Large Boiler Replacement

The project that would bring the largest annual cost savings for Calvin College on natural gas was the replacement of the three Kewanee boilers. This project also has the highest implementation cost because of the purchase, shipment, and installation that would be required. The implementation cost may be high, but there are several aspects that make the project worth pursuing. Through the team's research, it was found that large industrial boilers have a lifespan of 50-60 years. This is important because Calvin's Kewanee boilers are currently about 50 years old. This means they must be replaced soon regardless of efficiency or savings. Furthermore, the Kewanee boilers are fire tube boilers which have a much lower efficiency than water tube boilers. The Kewanee boilers also generate steam which is then used to heat water adding to their inefficiency.

By replacing the Kewanee boilers with new boilers, Calvin College can see an increase in efficiency of these boilers by 13%. This replacement can also be seen as a preventative step to replace aging boilers before they irreparably fail. A model was made to calculate the change in cost associated with the annual natural gas usage due to the boilers' efficiency. The results of this model are illustrated in Table B.2-1 below.

Table B.2-1: Replacement of Boilers with New Large Boilers

Boiler Location	Boiler Manufacturer	Efficiency (%)	Replacement Savings ($/yr)	Capital Investment ($)
Commons	Kewanee	0.67	$11,694.46	$110,000.00
Knollcrest	Kewanee	0.67	$18,826.25	$55,000.00
		Total	$30,520.71	$291,923.08

Analyzing these potential saving, the increase in efficiency would save Calvin College about $30,000 dollars a year, based on the natural gas usage in 2016. With these savings, the implementation cost of $300,000 would have a payback of 10 years.

Sub-Appendix B.3: Small Boiler Replacement

An alternative to the large boiler replacement is to replace the three Kewanee boilers with six smaller modular boilers. The idea was suggested by Paul Pennock, a retired Calvin mechanical technician, based on the reasoning that boilers are most efficient when running near maximum firing rate. During the spring and fall, when heating is necessary but minimal, the current boilers must be run inefficiently at low firing rate. Small modular boilers can be turned on or off based on the heating load required. The load of two large boilers running at half capacity is equivalent of four small boilers running near capacity. If managed properly, the heating load could be met at near peak efficiency, even during spring and fall.

The six small modular boilers would be 100 hp boilers that cost around $70,000 each, with a 84% efficiency. The annual net savings would be $30,000 per year. The implementation cost would be much larger than just the purchase cost, because additional infrastructure would be required to house a greater number of boilers. Because the cost of one small boiler is almost equivalent to the cost of a large boiler, but is only able to have a fraction of the production of the large boilers, the small boiler replacement is not a realistic solution.

Sub-Appendix B.4: Upgraded Control Systems

Boiler control systems work to continuously meet a specified outlet temperature. Using sensors they continuously monitor and optimize the fuel flow for all loading conditions. Control systems are crucial for running at the optimal efficiency for the current demand.

The current American Standard controls on the Kewanee boilers are extremely dated and are not sequencing, which means that the boilers run independently of each other. The benefit of the controls is the automatic analysis of load conditions, and the selection of best combination of boilers that will meet that load most efficiently. The lack of sequencing results in losses in system efficiency as the boilers usually will not run to optimally conserve fuel. Additionally, the currently implemented controls depend on simple circuitry alone and do not have a computerized control unit. If the Kewanee boilers are replaced by new boiler units, these controls may be implemented on those units as well.

The selected boiler control system, Tekmar Boiler Control 284, is designed to connect and operate up to four boilers as a way to accurately maintain a target outlet water temperature. These controls should be implemented in both the Commons and Knollcrest boiler rooms for maximum cost savings. Boiler room efficiency increases in excess of 5% can be expected from this change. This translates to approximately $5,000 in annual savings with an initial investment shown below in Table B.4-1.With a one year payback period, it is highly suggested that Calvin College invests in upgraded boiler control systems.

Table B.4-1: Upgraded Controls Implementation Cost

Wages	$44.50/hour
Controls Cost per Unit	$1,852
Number of Units	2
Time of Install	25 hours
Total Cost	$4,900

Sub-Appendix B.5: Preheaters and Economizers

Two ideas proposed to increase the efficiency of the boilers on Calvin's campus were the implementation of preheaters and economizers onto the existing systems. Preheaters use natural gas combustion exhaust in order to heat the inlets of the boilers, so that less energy is required to heat the air. This is estimated to produce an efficiency increase of 1% for every 20°C that the flue gas temperature is decreased. An economizer is a unit that captures the heat from the flue gas in the stack, and then returns it to a water system. While this is an expensive piece of equipment, it has the potential to increase the thermal efficiency of the boilers by between 5% and 15%.

Upon further research on preheaters, we came to the conclusion that they were not feasible to use with existing systems. All of the companies and suppliers said that preheaters are purchased with the boilers, but they are not something that you can add to a boiler at a later time. Therefore, preheaters are something that Calvin can look at including if they decide to replace the Kewanee boilers, but they are not an option as an addition to the existing Hurst boilers.

There are two types of economizers that can be chosen to increase the efficiency of a boiler; non-condensing economizers can increase thermal efficiency by 5%, and condensing economizers can increase thermal efficiency by up to 15%. Assuming the recommended replacement of the Kewanee boilers with new Hurst boilers, the non-condensing economizers should be chosen as they provide the correct application. If however, the Kewanee boilers are not replaced, then the condensing economizers should be chosen and will result in a greater boiler efficiency increase. Quoted from HeatSponge, the cost of installing model B5SS non-condensing economizers to our current system would be approximately $15,000, while yielding an annual savings of $3,500. This equates to a total upfront cost of $45,000, with annual savings of $10,500 due to the increase in efficiency.

Sub-Appendix B.6: Works Cited

AMIC Economiser and Air Preheaters on Steam/Hot Water Boilers Fact Sheet:
http://www.amic.org.au/SiteMedia/W3SVC116/Uploads/Documents/Economisers%20&%20Air%20Preheaters%20on%20Boilers.pdf

Basic Boiler Information:

https://energy.gov/energysaver/furnaces-and-boilers

Boiler Efficiency Calculator:
https://www.hsb.com/efficiencycalculators/boilers.aspx

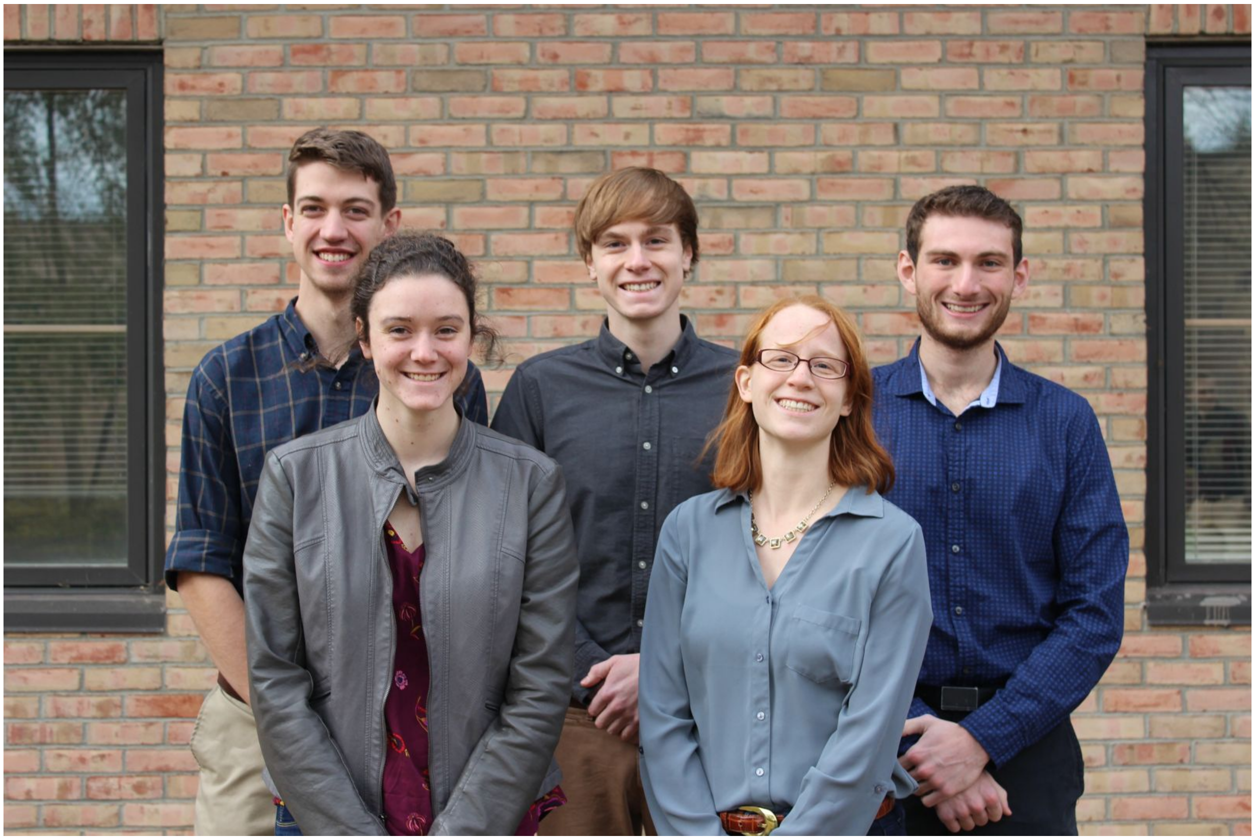
Boiler Soot/Scaling Build-up and Maintenance:
http://ietd.iipnetwork.org/content/boiler-maintenance

Hurst Boiler Water Tube Information:
https://www.hurstboiler.com/boilers/scotch_marine/series_500

Steam Coil Air Preheater Information:
http://www.cdoctorindia.com/steam_coil_air_pre_heaters.htm

Water Tube and Fire Tube Boiler Information:
http://www.nationwideboiler.com/what-boiler-is-best-for-you/watertube-vs-firetube.html

Appendix C: Dorms and Dining Halls



From Left to Right: Paul Bootsma, Megan Anders, Philip Holmes, Melanie Fox, and Noah Pirrotta

Objective

The goal of the Dorms and Dining Halls team, was to determine how to reduce the natural gas usage throughout the dormitories and dining halls at Calvin College.

Research

The team began their work by investigating possibilities for saving natural gas in both the dormitories and dining halls. Ideas included replacing dining hall appliances, adding additional insulation, modifying the dormitory radiators, utilizing the heat from the pizza oven, and replacing single pane windows with double pane windows. Since switching to newer appliances would not significantly improve appliance efficiency, that idea was eliminated from Dorm and Dining Hall analysis. Replacing the dining hall windows was also considered, but discarded due to the large discrepancy between the replacement cost and annual savings.

After eliminating the least financially impactful options for saving money, the group focused on replacing windows, adding insulation, and improving radiator heat distribution in the dormitories. Dormitory floor plans and roof drawings were gathered from the Calvin College Physical Plant and the U.S. Department of Energy recommendations for insulation were also found. The blow-in and rigid insulation information was taken from Green Fiber® and Owen Corning®, respectively. Insulation information for miscellaneous building materials was taken from coloradoenergy.org. To simulate the variety of temperatures experienced over the course of a year, the average temperature was found for each month in 2016, using data from Weather Underground (wunderground.com). The average temperature for each month in 2016 is displayed in Table C-1 and was used in the roof, window, and radiator simulations.

Table C-1: Average Monthly Temperature

Month	Temperature (℉)
October	55
November	46
December	28
January	26
February	30
March	41
April	46
May	61

The Academic Buildings and PE complex teams also chose to analyze windows, so a separate team containing members from these two teams and the Dorms and Dining Halls team was formed to specifically study windows. They determined the properties of the current windows and found window replacement options that would be the most energy and cost efficient.

A radiator model originally used for summer research was modified to suit the purposes of the team. The original model was built by Chris Greaves to study the effect of fans on radiator heat distribution for his project, “Personal Temperature Control based on Corporate Radiant Heating Solutions.” Dimensions for both dormitory rooms and radiators were used to repurpose the model for the analysis. Testimonies from students who had lived in the dormitories described the qualitative properties of the current heating system and highlighted the need for improvements.

Approach

For each proposal two Engineering Equation Solver (EES) models were made, one for the current case and one with the proposed modifications. Each model was of a single dormitory room, but in the case of the radiators, the model included all the dormitory rooms on one side of a hallway. A year's worth of monthly average temperatures was run through each model to determine the annual cost associated with heat transfer rates. The difference in cost needed to heat the current and proposed models was the cost that could be saved. The results of the models were scaled up by the number of rooms or half hallways in a building and by the number of dormitories; yielding a campus-wide savings value. The implementation cost for each proposal was also estimated.

Windows

The smallest dormitory, Beets-Veenstra, was used as the the base case dormitory to avoid savings overestimation. It was estimated that a dormitory pair (male and female sides) has 46 rooms per floor, each with a 4' by 6' window. Windows in the dormitory lobby, stairwells, and additional windows spread throughout the dormitory were also used in this analysis; the dimensions of these windows varied. The number of windows within Beets-Veenstra was multiplied by 7, to account for each set of dormitories. The total area of windows in the dormitories was estimated to be about 29,000 ft^2, which resulted from an estimate of over 1500 windows. Each window analyzed was assumed to have an overall heat transfer coefficient of 0.69 BTU/hr-℉-ft^2. This overall heat transfer value was identified in the specification book for Kalsbeek-Huizenga-vanReken (KHvR) located within the Physical Plant and was assumed to be the current window coefficient for all dormitory windows. Since KHvR is the newest dormitory, using this coefficient lessened the likelihood for overestimating heat transfer rates. An overall heat transfer coefficient for replacement windows was assumed to be 0.30 BTU/hr-℉-ft^2, a value given by Energy Star. To estimate possible savings from replacing the given dormitory windows, heat transfer rates through the variety of windows were calculated using Equation C-1.

$$\dot{Q}_i = U_i A_{wind}(T_{in} - T_{out})$$ **[Equation C-1]**

Where Q_i is the heat transfer rate for either a given old or new group of windows, U_i is the overall heat transfer coefficient for old or new windows, A_{wind} is the area of a given group of windows, T_{in} is the temperature inside the dormitory, assumed to be 73℉, and T_{out} is the average outside temperature for a given month.

Heat transfer rates were multiplied by natural gas price in $/MMBTU to obtain a cost rate due to heat loss in $/hr for both the old and new windows. This was done for the eight months with average temperatures listed in Table C-1. Then, the cost rate for a given month was multiplied by the time in each month to approximate total heat loss cost for both old and new windows. To estimate the cost of each window, the windows group gathered low-end cost estimates from two websites which resulted in an average window cost around $40/ft^2. However, research online for window prices varied greatly, so this value may not be realistic. Due to the vast numbers, locations, and sizes of windows needed to be replaced, the $40/ft^2 estimation was used.

Insulation

The Kalsbeek-Huizenga-vanReken dormitory was used as the base case for the same reasons described earlier. KHvR's current roof insulation consists of rigid R-30 insulation (units hr-℉-ft^2/BTU) and other roof construction materials such as wood and the roof membrane. To account for other roof materials, the rigid insulation was multiplied by a factor of 1.5, producing a total roof insulation R-value of 45 hr-℉-ft^2/BTU. According to the U.S. Department of Energy, R-60 roof insulation is recommended for the climate where Calvin College is located. A design was developed to create an attic space above the 3rd floor of each dormitory room. This attic space would be filled with blow-in insulation which was modeled after Green Fiber® blow-in insulation product. Next, a design which adds insulation to the interior side of the dormitory walls was formulated. For this model, 3 inches of R15 rigid insulation, modeled after Owen Corning®'s rigid insulation product, was added to the interior of the dormitory walls. Figure C-1 displays where the proposed insulation would be added.

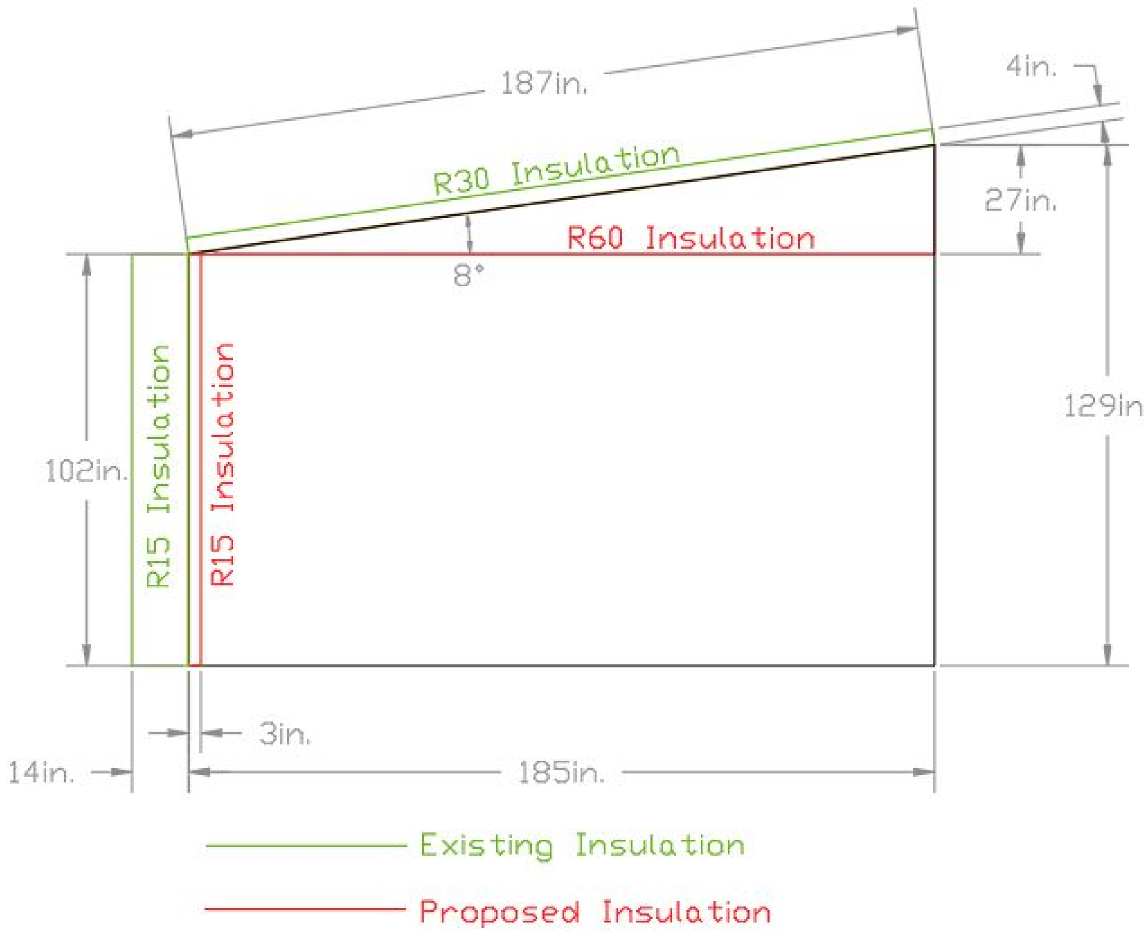


Figure C-1: Dormitory Room Cross Section with Existing and Potential Insulation.

EES was used to calculate both the heat transfer rates through the existing insulation, as well as through the insulation of the proposed design. For the roof, since the blow-in insulation is in the shape of a wedge, the height of one end approaches zero. This means that if the insulation is cut into an infinite number of vertical slices, the heat transfer rate through the wedge will approach infinity. This was found using Equation C-2 and Figure C-2.

$$\dot{Q}_i = \sum_i \frac{kA_i}{\bar{h}_i}\Delta T$$ **[Equation C-2]**

Where Q_i is the heat transfer rate through a given slice, A_i is the cross-sectional area of the bottom portion of a given wedge slice, $\hbar_i$ is half the height of a given wedges slice, k is the thermal conductivity of the insulation, and ΔT is the temperature difference between the top and bottom of the wedge.

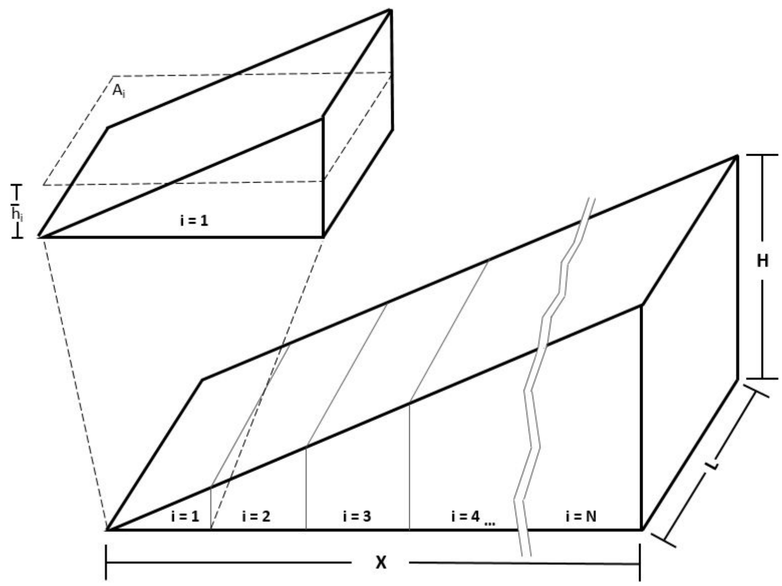


Figure C-2: Model Used to Assess Roof Insulation Wedge

Figure C-3, on the following page, shows that at about 10,000 slices, the heat transfer levels out significantly. So, for the EES calculations, 10,000 slices were accounted for. When calculating the heat transfer for the walls, the process was straightforward, with the constant R-value of the new insulation being simply added to the existing insulation R-value. With both of these heat transfer rates and the natural gas cost in $/BTU provided, the savings stemming from added insulation were calculated.

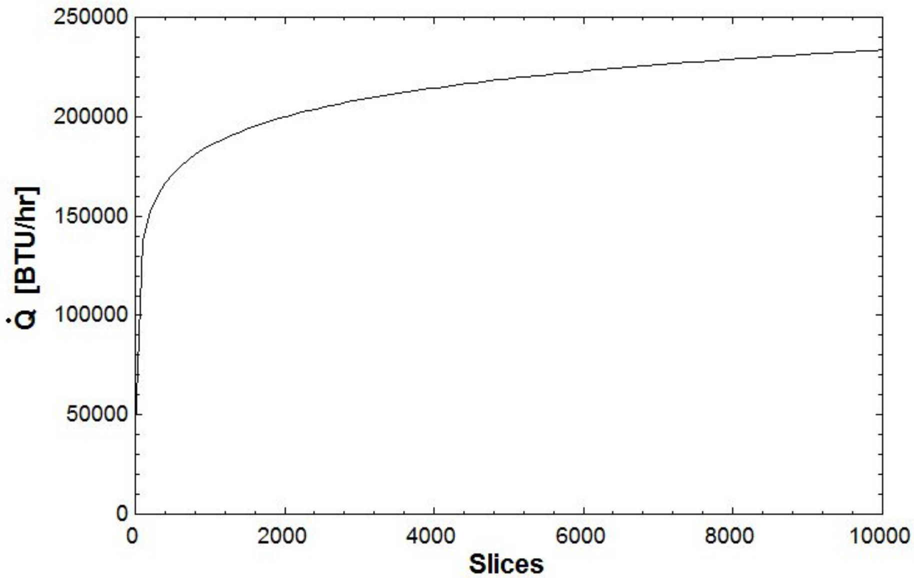


Figure C-3: The Effect of Number of Slices in an Insulation Wedge on Heat Transfer

Radiators

Calvin College's current dormitory heating system is primitive. Hot water enters the building, goes straight through the radiators in each dormitory, then exits and returns to the boiler to be reheated as shown in Figure C-4.

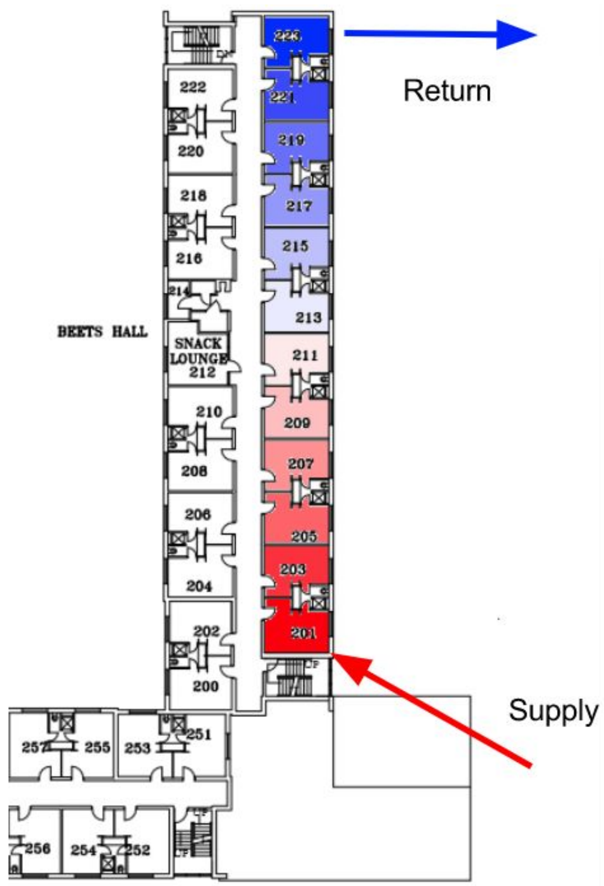


Figure C-4: Dormitory Heat distribution

This system overheats rooms near the inlet end while under heating rooms near the outlet. To compensate, students open their room windows which wastes heat that could be used to warm rooms further down the hall. In order to eliminate this waste, the heat released by each radiator can be balanced by altering the number of active fins.

Two models were created to determine the savings from varying fin quantities, one to calculate the number of fins needed for each radiator, and the other to quantify the heat emitted.

The model to determine the amount of heat emitted through the radiators consisted of EES code simulating a single radiator. The key inputs of the code were mass flow rate, temperature of the room, the number of fins and the inlet stream temperature. The key outputs of the code were the heat emitted and the outlet temperature. A parametric table was used to iterate the system setting the inlet temperature of the radiator to the outlet temperature of the previous radiator. The model was iterated twelve times, once for each room on one side of the hallway. The total heat emitted was then multiplied by twelve sides per dormitory and then by eight dormitories to achieve the total heat usage of the dormitories on campus. Eight dormitories were assumed because both KHvR and Bolt-Heyns-Timmer (BHT) have three wings instead of two. The third wing was removed from each of these dormitories and combined to create an eighth dormitory. This value could then be converted to an overall cost of heating the dormitories. Full EES code for the model including a parametric table for the ideal case can be found in Sub-Appendix C.1.

The model to determine the number of fins needed for each radiator in series consisted of EES code using the duplicate function. This function automatically set the inlet streams equal to the outlet of the previous radiator. In order to determine the amount of fins needed the heat emitted from the radiator was set equal to the heat lost to the outside in each room. The number of fins was then allowed to vary. The key inputs for this model were the room temperature, the outdoor temperature, the mass flow rate and the initial stream temperature. Full EES code can be found in Sub-Appendix C.1.

Two cases were studied, the current case where windows would be opened and an ideal case where the windows would not be opened. Each case was evaluated on a per month basis using the average outdoor temperature of that month from 2016. The outdoor temperature affects the temperature of the inlet stream as well as the amount of heat lost through the walls. Average temperatures were found using Weather Underground.

For the current case, the fin number was held constant at 240, which is the current number of fins in each radiator. The inlet temperature of the flow corresponding to the outdoor temperature was placed in the first temperature input for the parametric table. Following temperatures were determined by running the parametric table with the outlet temperature as an output.

For the ideal case, the fin number was determined using the fin determination model. The corresponding inlet flow temperature and outdoor temperature for each month was set as an input in a parametric table. It was found that the month of January produced the highest amount of fins necessary for the comfortable temperature to be achieved. The model was then run using the month of January to determine the number of fins needed for each room. The results are shown in Table C-2.

Table C-2: Fin Number per Room

Room Number	Number of Fins
201	128
203	129
205	130
207	131
209	132
211	133
213	134
215	135
217	136
219	137
221	138
223	139

By using January values, the model accounts for being able to produce comfortable temperatures even during the coldest month of the year. This means that the radiators will produce more heat than necessary during other months, but fin numbers must be higher to ensure that the dormitories are warm enough year-round. These radiator fin numbers were then used in the heat emitted model to determine the new amount of heat emitted from the radiators. This heat was totaled in the same way as the current case.

The savings for this project were totalled by subtracting the ideal case costs from the current case costs. The ideal case that obtained these radiator fin values used heat transfer resistance coefficients from ASHRAE; it also assumed a window area of 1 m^2. Changing the window area to 4ft x 6ft (2.23 m^2) lowered the savings produced from the model. However, changing the heat transfer resistance coefficients to values used in the insulation and dorm window EES models increased the savings produced from the radiator model. Thus, the results from middle ground were chosen using the original model.

For both cases, it was assumed that each room was kept at a constant temperature of 68 ℉. This was deemed reasonable for the current case, as it was assumed that the windows would only be opened to reduce the temperature of the room to that temperature, after which they would be closed until the temperature rose again. This value was also assumed for the ideal case as it was expected that the windows would not be opened at all if the temperature of the room were kept at 68℉. A consistent mass flow rate of water through the radiators was needed between the cases to accurately compare savings. A flow rate of 0.2 kg/s was deemed a reasonable value given the diameter of pipe running through the radiators.

Results

It was found that approximately $34,000 could be saved on natural gas annually by implementing all the proposed changes. The specific annual savings for insulating the roof, walls, replacing the windows, and modifying the radiators are in Table C-3.

Table C-3: Annual Savings

	Savings	Capital Cost
Roof Insulation	$480/yr	$29,000
Wall Insulation	$1,530/yr	$75,000
Window Replacement	$11,000/yr	$1,200,000
Radiator Insulation	$21,000/yr	$44,800

Discussion

Windows

The estimated annual current window heat-loss cost, replacement window heat-loss cost, and savings from replacing the windows are shown in Figure C-4. Though replacing the windows would save money, the payback period for such an investment is considerably large. It was estimated that it would take around $1.2 million to replace the current windows with new windows. Since this cost could be a low estimate, the payback period for actual window replacement cost may be even greater.

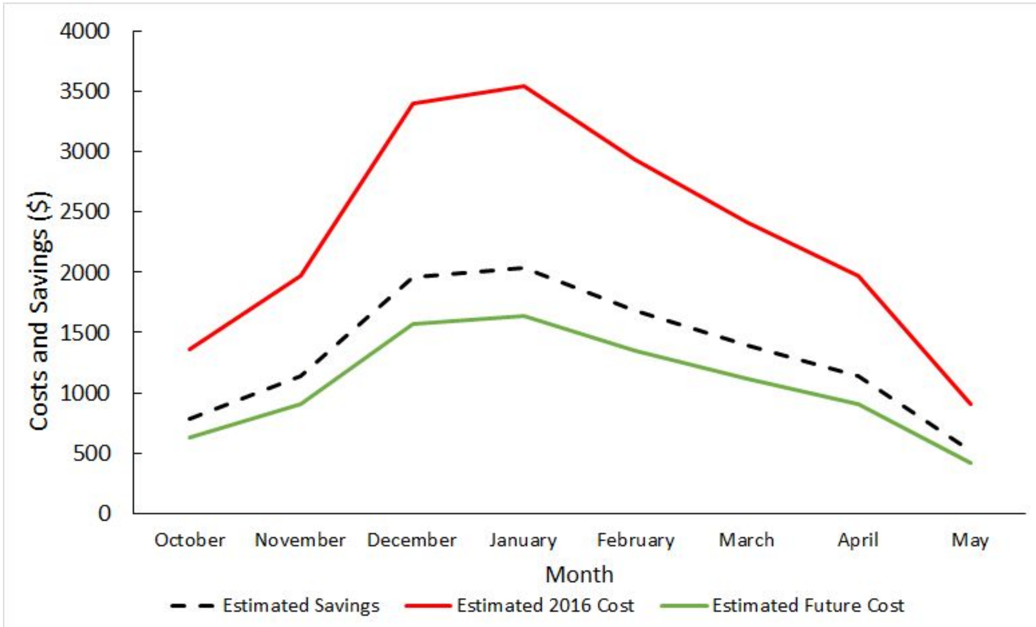


Figure C-4: Total Window Cost and Savings

This puts the estimated payback period at more than a human lifetime. However, it is likely that this opportunity for energy savings could be implemented over time and as the college sees fit. Certain windows may need to be replaced in the near future and doing so would help save the college money each year.

Insulation

The monthly estimated costs due to heat loss through the roof and wall for the current insulation setup and proposed insulation-added setup can be found in Figures C-5 and C-6 for Roof and Wall insulation, respectively.

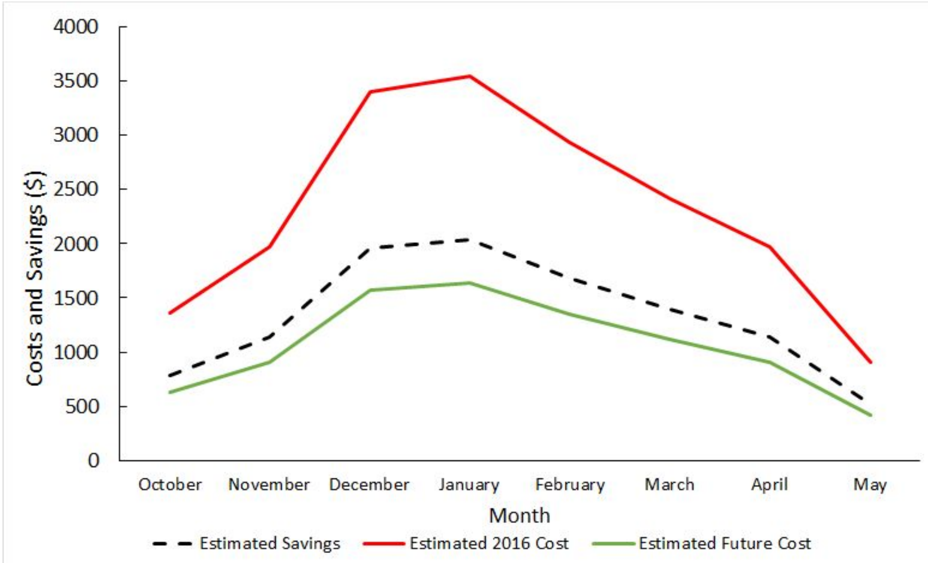


Figure C-5: Roof Insulation Cost and Savings

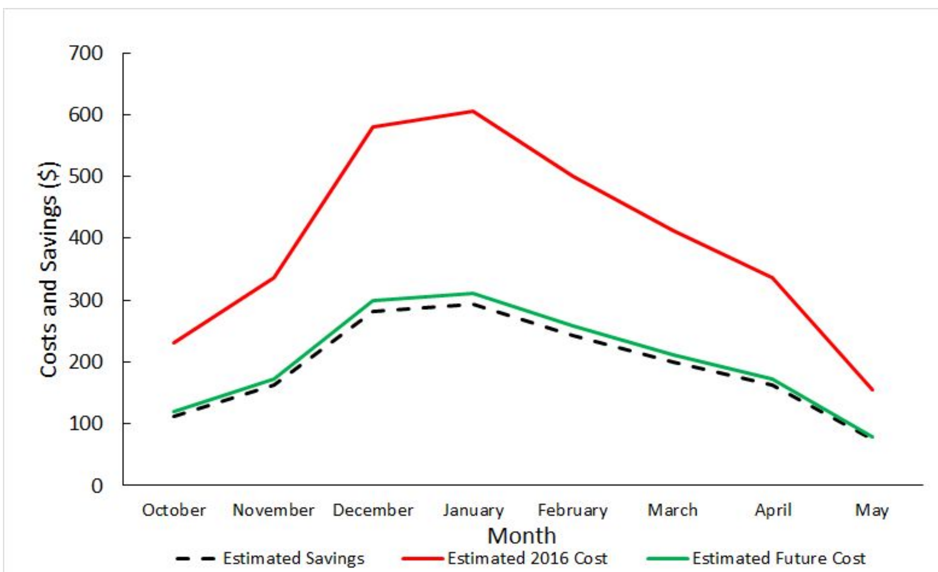


Figure C-6: Wall Insulation Costs and Savings

For the roof, the estimated annual savings from adding insulation was found to be $480 per year. For the walls, the estimated annual savings from adding insulation was found to be $1530 per year. Both opportunities to save money through insulation are hindered by significant implementation costs. The additional roof insulation would cost $29,000 in insulation materials, not including lumber and labor, with a payback period of over 60 years. Insulating the walls would cost $75,000 in insulation materials, not including labor and drywall, with a payback period of over 50 years. The addition of the ceiling insulation would also impact Calvin College's dormitory culture by removing the tall sloped ceilings which are highly coveted by students. This would violate the engineering design norm of cultural appropriateness.

Radiators

Unequal distribution of heat in Calvin College's dormitories has been a common complaint for a number of years. The team determined that modifying the radiators would cost $44,800 in labor, but pay for itself in 2.25 years as shown in Figure C-7.

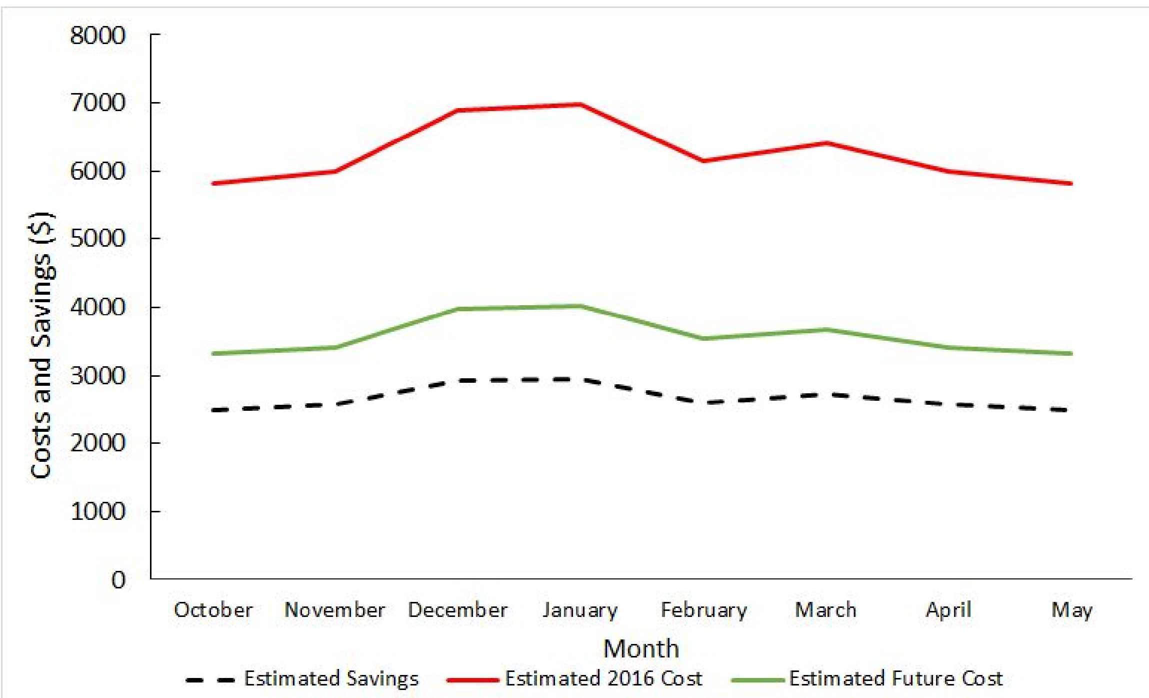


Figure C-7: Radiators Costs and Savings

However, the model used for these calculations could be improved with the addition of dormitory room temperature data. Such data was unavailable to the team because the heat was not turned on during the course of the project.

Even though the models suggest removing fins, actually removing fins from the radiators could damage the piping. Instead, insulation or foam could be used to block heat escaping from certain fins, effectively removing them. Regular cleaning would also increase the radiator efficiency for rooms that do not receive enough heat.

Dining Halls

At the beginning of the analysis it was assumed that the cost to replace the windows in the dining halls would be immense, but this is not the actual case. Physical Plant leaders have previously examined the cost of replacing the windows and found the endeavor to be within reasonable expense. Though this information was received too late to be included in the team's analysis, it is worth future investigation.

Conclusion

The Dorms and Dining Hall team found ways to reduce the natural gas usage in the dormitories and dining halls by analyzing the windows, roof and wall insulation, and radiators in the dormitories. The payback periods of the replacing windows and insulating the dormitory roofs and walls were found to be extensive; therefore, the team does not suggest implementing these projects. The radiator project, producing savings of $21,000 annually and having a payback period of 2.25 years, was found to be a viable option for Calvin College to implement to save money on natural gas.

Sub-Appendix C

Table of Contents

Sub-Appendix C.1: EES Code Radiator Ideal Case

```
"Decision Variables"

m_dot_water = 0.2 [kg/s] //(1135.62/60)

"Temperatures"
T_room = converttemp(C,K,20)
T_outdoor = 269.8//converttemp(C,K,0)
T[1] = converttemp(F,K,185)
T_wall = (T_outdoor+T_room)/2

"Radiator Specs"
D_pipe=0.63*convert(in,m)
L_pipe=39*convert(in,m)
A_pipe=pi*D_pipe*L_pipe
ht_plate=.09 [m]
w_plate=.08 [m]
th_plate=0.0005 [m]
A_plate=ht_plate*w_plate
//plate_density=220 [1/m]
//number_plates[12] = 240

"Room specs"
Vol_room = (((102 [in]+129 [in])/2)*185 [in]*122 [in])*convert(in^3,m^3)
A_wall = 129[in]*122 [in]*convert(in^2,m^2) - A_window
A_window=1 [m^2]//2.3

"Constants"
g = 9.81 [m/s^2]
P_atm = 101.3 [kPa]
rho_w = 1000 [kg/m^3]
rho_w = density(Water, T=T[1], P=P_w)
cp_water = cp(Water, T=T[1], P=P_w)
 beta=1/(T_room)

"Convection"
Lc_fin = ht_plate/2+th_plate/2
```

```
Lc_plate=(ht_plate*w_plate*th_plate)/(2*ht_plate*w_plate+2*w_plate*th_plate+2*ht_plate*th_
plate)
Bi_lumped=.1
k_plate=50 [W/m*K] //Cu is 400, Iron 50-80

"Wall info"

t_bricks=.23
t_blocks=.2
k_bricks=1.33
k_blocks=.2

th_window=.005 [m]
k_window= .92 [W/m*C]

h_window=6
h_outside=34
h_inside=8.3

R_wall= (t_bricks/k_bricks+t_blocks/k_blocks)+1/h_outside+1/h_inside
R_window="1/h_window"th_window/k_window+1/h_outside+1/h_inside  //Single pane or
double pane

Q_wall=A_wall*(T_outdoor-T_room)/R_wall
Q_window=A_window*(T_outdoor-T_room)/R_window
Q_loss=Q_window+Q_wall

Q_loss + Q_radiator_natural = 0

Duplicate i=1,12
"Temperature"
T_plate[i] = (T[i]+T[i+1])/2
T_pipe[i] = T_plate[i]
//T_out = converttemp(C,K,84)


"Radiator"
number_plates[i] = L_pipe*plate_density[i]
```

```
"convection"
T_film[i]=(T_room+T_pipe[i])/2
rho[i]=density(Air,T=T_film[i],P=P_atm)
Pr[i]=prandtl(Air,T=T_film[i])
v[i]=kinematicviscosity(Air,T=T_film[i],P=P_atm)
k[i]=conductivity(Air,T=T_film[i])


Q_radiator_natural =
eta_fin_natural[i]*h_plate_natural[i]*A_plate*number_plates[i]*(T_plate[i]-T_room)
//2*plates???

Ra_tube[i] = g*beta*(T_pipe[i]-T_room)*D_pipe^3*Pr[i]/(v[i]^2)
Nusselt_tube_nat[i] = (.6+ (.387*Ra_tube[i]^(1/6))/(1+(.559/Pr[i])^(9/16))^(8/27))^2
h_tube_natural[i] = Nusselt_tube_nat[i]*k[i]/D_pipe

Ra_plate[i] = g*beta*(T_pipe[i]-T_room)*ht_plate^3*Pr[i]/(v[i]^2)
Nusselt_plate_nat[i] = (.825+(.387*Ra_plate[i]^(1/6))/(1+(.492/Pr[i])^(9/16))^(8/27))^2
h_plate_natural[i] = Nusselt_plate_nat[i]*k[i]/ht_plate

eta_fin_natural[i] = tanh(m_fin_natural[i]*Lc_fin)/(m_fin_natural[i]*Lc_fin)
m_fin_natural[i] = (2*h_plate_natural[i]/(k_plate*th_plate))^(.5)

Q_radiator_natural = (m_dot_water*cp_water*(T[i]-T[i+1]))*convert(kW,W)
End

Q_tot = Q_radiator_natural*12*convert(W,BTU/h)
Q_tot_cost = Q_tot*24*30*5.21/1000000*6*2*7
```

A_{pipe} = 0.0498 [m^2]

A_{plate} = 0.0072 [m^2]

A_{wall} = 9.154 [m^2]

A_{window} = 1 [m^2]

β = 0.003411 [1/K]

Bi_{lumped} = 0.1

cp_{water} = 4.061 [kJ/kg·K]

D_{pipe} = 0.016 [m]

g = 9.81 [m/s^2]

ht_{plate} = 0.09 [m]

h_{inside} = 8.3 [W/m^2*K]

$h_{outside}$ = 34 [W/m^2*K]

h_{window} = 6 [W/m^2*K]

k_{blocks} = 0.2 [W/m*K]

k_{bricks} = 1.33 [W/m*K]

k_{plate} = 50 [W/m*K]

k_{window} = 0.92 [W/m*C]

Lc_{fin} = 0.04525 [m]

Lc_{plate} = 0.0002471 [m]

L_{pipe} = 0.9906 [m]

$\dot{m}_{water}$ = 0.2 [kg/s]

P_{atm} = 101.3 [kPa]

P_w = 76059 [kPa]

Q_{loss} = -311.9 [W]

$Q_{radiator,natural}$ = 311.9 [W]

Q_{tot} = 12771 [BTU/h]

$Q_{tot,cost}$ = 4024 [$]

Q_{wall} = -161.6 [W]

Q_{window} = -150.3 [W]

ρ_w = 1000 [kg/m^3]

R_{wall} = 1.323 [m^2*K/W] {7.511 [ft^2*F*hr/BTU]}

R_{window} = 0.1553 [m^2*K/W] {0.882 [ft^2*F*hr/BTU]}

th_{plate} = 0.0005 [m]

th_{window} = 0.005 [m]

t_{blocks} = 0.2 [m]

t_{bricks} = 0.23 [m]

$T_{outdoor}$ = 269.8 [K]

T_{room} = 293.2 [K]

T_{wall} = 281.5 [K]

Vol_{room} = 42.72 [m^3]

w_{plate} = 0.08 [m]

$\eta_{fin,natural,i}$	$h_{plate,natural,i}$ [W/m2*K]	$h_{tube,natural,i}$ [W/m2*K]	k_i [W/m*K]	$m_{fin,natural,i}$ [1/m]	$number_{plates,i}$	$Nusselt_{plate,nat,i}$	$Nusselt_{tube,nat,i}$	$plate_{density,i}$ [1/m]
0.7351	7.094	8.838	0.02753	23.82	128.2	23.19	5.137	129.4
0.7354	7.083	8.825	0.02752	23.8	129.1	23.17	5.132	130.3
0.7357	7.072	8.812	0.0275	23.79	130	23.14	5.127	131.3
0.736	7.06	8.799	0.02749	23.77	131	23.12	5.123	132.2
0.7363	7.049	8.786	0.02747	23.75	131.9	23.09	5.118	133.2
0.7366	7.038	8.774	0.02746	23.73	132.9	23.07	5.113	134.1
0.7369	7.027	8.76	0.02745	23.71	133.9	23.04	5.108	135.1
0.7371	7.015	8.747	0.02743	23.69	134.9	23.02	5.103	136.1
0.7374	7.004	8.734	0.02742	23.67	135.9	22.99	5.098	137.1
0.7377	6.992	8.721	0.0274	23.65	136.9	22.96	5.093	138.2
0.738	6.981	8.708	0.02739	23.63	137.9	22.94	5.087	139.2
0.7383	6.969	8.694	0.02738	23.61	139	22.91	5.082	140.3

Pr_i	$Ra_{plate,i}$	$Ra_{tube,i}$	ρ_i [kg/m3]	T_i [K]	$T_{film,i}$ [K]	$T_{pipe,i}$ [K]	$T_{plate,i}$ [K]	v_i [m2/s]
0.7216	3.439E+06	19332	1.084	358.2	325.6	358	358	0.00001821
0.7217	3.426E+06	19259	1.085	357.8	325.4	357.6	357.6	0.00001819
0.7217	3.413E+06	19184	1.085	357.4	325.2	357.2	357.2	0.00001818
0.7218	3.400E+06	19110	1.086	357	325	356.8	356.8	0.00001816
0.7218	3.386E+06	19035	1.087	356.6	324.8	356.4	356.4	0.00001814
0.7219	3.373E+06	18959	1.087	356.2	324.6	356	356	0.00001812
0.7219	3.360E+06	18883	1.088	355.8	324.4	355.7	355.7	0.0000181
0.7219	3.346E+06	18807	1.089	355.5	324.2	355.3	355.3	0.00001808
0.722	3.332E+06	18731	1.089	355.1	324	354.9	354.9	0.00001806
0.722	3.319E+06	18654	1.09	354.7	323.8	354.5	354.5	0.00001804
0.7221	3.305E+06	18576	1.09	354.3	323.6	354.1	354.1	0.00001803
0.7221	3.291E+06	18499	1.091	353.9	323.4	353.7	353.7	0.00001801
				353.5				

Sub-Appendix C.2: EES Radiator Code Actual Case

```
" Team A-3
ENGR 333
Professor Heun
Dorm Radiator Model"

"Decision Variables"

m_dot_water = 0.2 [kg/s]

"Temperatures"
T_room = converttemp(C,K,20)
T_outdoor = 300//converttemp(C,K,0)
//T_in = 344//converttemp(C,K,85)
T_wall = converttemp(C,K,10)
T_plate = (T_in+T_out)/2
T_pipe = T_plate
//T_out = converttemp(C,K,84)

"Radiator Specs"
D_pipe=.63*convert(in,m)
L_pipe=39*convert(in,m)
A_pipe=pi*D_pipe*L_pipe
ht_plate=.09 [m]
w_plate=.08 [m]
th_plate=.0005 [m]
A_plate=ht_plate*w_plate
plate_density=number_plates/L_pipe
//number_plates=240

"Room specs"
Vol_room = (((102 [in]+129 [in])/2)*185 [in]*122 [in])*convert(in^3,m^3)
A_wall = 129[in]*122 [in]*convert(in^2,m^2) - A_window
A_window=1 [m^2]//2.3

"Constants"
g = 9.81 [m/s^2]
P_atm = 101.3 [kPa]
rho_w = 1000 [kg/m^3]
```

```
rho_w = density(Water, T=T_in, P=P_w)
cp_water = cp(Water, T=T_in, P=P_w)

"! Convection Calculations"
T_film=(T_room+T_pipe)/2
rho=density(Air,T=T_film,P=P_atm)
Pr=prandtl(Air,T=T_film)
v=kinematicviscosity(Air,T=T_film,P=P_atm)
k=conductivity(Air,T=T_film)
beta=1/(T_room)


Q_radiator_natural =
eta_fin_natural*h_plate_natural*A_plate*number_plates*(T_plate-T_room) //2*plates???

Ra_tube = g*beta*(T_pipe-T_room)*D_pipe^3*Pr/(v^2)
Nusselt_tube_nat = (.6+ (.387*Ra_tube^(1/6))/(1+(.559/Pr)^(9/16))^(8/27))^2
h_tube_natural = Nusselt_tube_nat*k/D_pipe

Ra_plate = g*beta*(T_pipe-T_room)*ht_plate^3*Pr/(v^2)
Nusselt_plate_nat = (.825+(.387*Ra_plate^(1/6))/(1+(.492/Pr)^(9/16))^(8/27))^2
h_plate_natural = Nusselt_plate_nat*k/ht_plate

eta_fin_natural = tanh(m_fin_natural*Lc_fin)/(m_fin_natural*Lc_fin)
m_fin_natural = (2*h_plate_natural/(k_plate*th_plate))^(.5)
Lc_fin = ht_plate/2+th_plate/2

Lc_plate=(ht_plate*w_plate*th_plate)/(2*ht_plate*w_plate+2*w_plate*th_plate+2*ht_plate*th_
plate)
Bi_lumped=.1
k_plate=50 [W/m*K] //Cu is 400, Iron 50-80

"! Heat through the Wall"

t_bricks=.23
t_blocks=.2
k_bricks=1.33
k_blocks=.2
```

```
th_window=.005 [m]
k_window= .92 [W/m*C]

h_window=6
h_outside=34
h_inside=8.3

R_wall=(t_bricks/k_bricks+t_blocks/k_blocks)+1/h_outside+1/h_inside
R_window="1/h_window"th_window/k_window+1/h_outside+1/h_inside  //Single pane or
double pane

Q_wall=A_wall*(T_outdoor-T_room)/R_wall
Q_window=A_window*(T_outdoor-T_room)/R_window
Q_loss=Q_window+Q_wall

Q_radiator_natural = (m_dot_water*cp_water*(T_in-T_out))*convert(kW,W)

Q_tot = 6495.6*convert(W,BTU/h)
Q_tot_cost = Q_tot*24*243*6*2*7*5.21/1000000
```

A_{pipe} = 0.0498 [m^2]	A_{plate} = 0.0072 [m^2]	A_{wall} = 9.154 [m^2]
A_{window} = 1 [m^2]	β = 0.003411 [1/K]	Bi_{lumped} = 0.1
cp_{water} = 1 [kJ/kg·K]	D_{pipe} = 0.016 [m]	$\eta_{fin,natural}$ = 1
g = 9.81 [m/s^2]	ht_{plate} = 0.09 [m]	h_{inside} = 8.3 [$W/m^2 \cdot K$]
$h_{outside}$ = 34 [$W/m^2 \cdot K$]	$h_{plate,natural}$ = 1 [$W/m^2 \cdot K$]	$h_{tube,natural}$ = 1 [$W/m^2 \cdot K$]
h_{window} = 6 [$W/m^2 \cdot K$]	k = 1 [W/m*K]	k_{blocks} = 0.2 [W/m*K]
k_{bricks} = 1.33 [W/m*K]	k_{plate} = 50 [W/m*K]	k_{window} = 0.92 [W/m*C]
Lc_{fin} = 0.04525 [m]	Lc_{plate} = 0.0002471 [m]	L_{pipe} = 0.9906 [m]
$\dot{m}_{water}$ = 0.2 [kg/s]	$m_{fin,natural}$ = 1 [1/m]	$number_{plates}$ = 1
$Nusselt_{plate,nat}$ = 1	$Nusselt_{tube,nat}$ = 1	$plate_{density}$ = 1 [1/m]
Pr = 1	P_{atm} = 101.3 [kPa]	P_w = 1 [kPa]
Q_{loss} = 91.5 [W]	$Q_{radiator,natural}$ = 1 [W]	Q_{tot} = 22164 [BTU/h]
$Q_{tot,cost}$ = 56569	Q_{wall} = 47.4 [W]	Q_{window} = 44.1 [W]
Ra_{plate} = 1	Ra_{tube} = 1	ρ = 1 [kg/m^3]
ρ_w = 1000 [kg/m^3]	R_{wall} = 1.323 [m^2*K/W]	R_{window} = 0.1553 [m^2*K/W]
th_{plate} = 0.0005 [m]	th_{window} = 0.005 [m]	t_{blocks} = 0.2 [m]
t_{bricks} = 0.23 [m]	T_{film} = 280 [K]	T_{in} = 345.4 [K]
T_{out} = 293.2 [K]	$T_{outdoor}$ = 300 [K]	T_{pipe} = 293.2 [K]
T_{plate} = 293.2 [K]	T_{room} = 293.2 [K]	T_{wall} = 283.2 [K]
v = 1 [m^2/s]	Vol_{room} = 42.72 [m^3]	w_{plate} = 0.08 [m]

$number_{plates}$	T_{in} [K]	T_{out} [K]	$Q_{radiator,natural}$ [W]
128	345.4	345.1	239.7
129	345.1	344.8	239.9
130	344.8	344.5	240.1
131	344.5	344.2	240.3
132	344.2	343.9	240.4
133	343.9	343.6	240.5
134	343.6	343.3	240.6
135	343.3	343	240.7
136	343	342.7	240.7
137	342.7	342.4	240.7
138	342.4	342.1	240.7
139	342.1	341.8	240.7

Sub-Appendix C.3:*EES Code Windows Analysis*

```
"Team A-3
Professor Heun
ENGR 333-A
Project - Windows
Start Date: 10/28/2017"



"!Overall Window Specifications/Assumptions"

"Heat Transfer Specifications"
U_old = 0.69 [BTU/hr-ft^2-F]          "Assume Wind Speed of 15 mph always"
U_new = 0.30 [BTU/hr-ft^2-F]


"Cost Information"
Price_BTU = (5.21 [$]/ 1 [MBTU])/1000000[BTU/MBTU]
Cost_windowarea = 40 [$/ft^2]

"Inside Temperature Specification"
T_inside = 73 [F]

 "Temperature Difference"
DELTAT = T_inside - T_outside



 "!Analysis"


"!Dorm Room Specifications"

"Dorm Room Information"
N_floors = 3
N_roomsperfloor = 46
N_dorms = 7
```

N_rooms = N_roomsperfloor * N_floors
N_rooms_total = N_rooms* N_dorms

"Dorm Room Window Dimensions"
L_room_window = 6 [ft]
h_room_window = 4 [ft]
A_room_window = L_room_window * h_room_window

"Total Dorm Room Window Areas"
A_tot_room = A_room_window * N_rooms_total

"!Dorm Room Heat Transfer Calculations"

"Dorm Room Heat Transfer"
Q_dot_roomold = U_old * DELTAT * A_room_window
Q_dot_roomnew = U_new * DELTAT * A_room_window
Q_dot_roomsavings = Q_dot_roomold - Q_dot_roomnew

"Dorm Room Money results"
Hours_month = dayspermonth*24[hr/day]
Savings_totalroom_month = Q_dot_roomsavings * N_rooms_total * Price_BTU * Hours_month
Cost_totalroom_monthOLD = Q_dot_roomold * N_rooms_total * Price_BTU*Hours_month
Cost_totalroom_monthNEW = Q_dot_roomnew * N_rooms_total * Price_BTU*Hours_month

"!Dorm Lobby Specifications"

"Dorm Lobby Information"
N_windowpair_lobby = 8 "The lobby has pairs of windows. Each pair has one tall and one short window."
N_lobbies = 7

"Dorm Lobby Window Dimensions"
L_lobby_window = (28.5 [in]) * convert(in,ft)
h_lobby_tallwindow = (77.5 [in]) * convert(in,ft)

h_lobby_shortwindow = (11.5 [in]) * convert(in,ft)
A_lobby_windowpair = L_lobby_window * (h_lobby_tallwindow + h_lobby_shortwindow)
"This is the area of a single pair of windows"

"Total Dorm Lobby Window Areas"
A_tot_lobby = A_lobby_windowpair * N_lobbies * N_windowpair_lobby

"!Dorm Lobby Heat Transfer Calculations"

"Dorm Lobby Heat Transfer"
Q_dot_lobbyold = U_old * DELTAT * A_lobby_windowpair * N_windowpair_lobby "Heat Transfer Rates for a single dorm lobby"
Q_dot_lobbynew = U_new * DELTAT * A_lobby_windowpair * N_windowpair_lobby
Q_dot_lobbysavings = Q_dot_lobbyold - Q_dot_lobbynew

"Dorm Lobby Money results"
Savings_totallobby_month = Q_dot_lobbysavings * N_lobbies * Price_BTU * Hours_month
Cost_totallobby_monthOLD = Q_dot_lobbyold * N_lobbies * Price_BTU * Hours_month
Cost_totallobby_monthNEW = Q_dot_lobbynew * N_lobbies * Price_BTU * Hours_month

"!Dorm Stairwell Specifications"

"Dorm Stairwell Information"
N_stairwells_perdorm = 4 "Each dorm has 4 stairwells"

"Dorm Stairwell Window Dimensions"
"There are 6 different sizes of windows in the stairwells. There are a total of 17 windows"
"L = left, M = middle, R = right, TL = top left, TM = top middle, TR = top right"

N_Lwindow_stairwell = 4
N_Mwindow_stairwell = 3
N_Rwindow_stairwell = 4

N_TLwindow_stairwell = 1
N_TMwindow_stairwell = 1

N_TRwindow_stairwell = 1

"Dorm Stairwell Dimensions"
L_L_stairwell = (29 [in]) * convert(in,ft)
L_M_stairwell = (35 [in]) * convert(in,ft)
L_R_stairwell = L_L_stairwell
L_TL_stairwell = L_L_stairwell
L_TM_stairwell = L_M_stairwell
L_TR_stairwell = L_R_stairwell

h_L_stairwell = (48 [in]) * convert(in,ft)
h_M_stairwell = h_L_stairwell
h_R_stairwell = h_L_stairwell
h_TL_stairwell = (28 [in]) * convert(in,ft)
h_TM_stairwell = h_TL_stairwell
h_TR_stairwell = h_TL_stairwell

A_Lwindow_stairwell = L_L_stairwell * h_L_stairwell
A_Mwindow_stairwell = L_M_stairwell * h_M_stairwell
A_Rwindow_stairwell = L_R_stairwell * h_R_stairwell

A_TLwindow_stairwell = L_TL_stairwell * h_TL_stairwell
A_TMwindow_stairwell = L_TM_stairwell * h_TM_stairwell
A_TRwindow_stairwell = L_TR_stairwell * h_TR_stairwell

A_totalwindow_stairwell = A_Lwindow_stairwell*N_Lwindow_stairwell + A_Mwindow_stairwell*N_Mwindow_stairwell + A_Rwindow_stairwell*N_Rwindow_stairwell + A_TLwindow_stairwell*N_TLwindow_stairwell + A_TMwindow_stairwell*N_TMwindow_stairwell + A_TRwindow_stairwell*N_TRwindow_stairwell

"Total Dorm Stairwell Window Areas"
A_tot_stairwell = A_totalwindow_stairwell * N_stairwells_perdorm * N_dorms

"!Dorm Stairwell Heat Transfer Calculations"

"Dorm Stairwell Heat Transfer"

Q_dot_stairwellold = U_old * DELTAT * A_totalwindow_stairwell * N_stairwells_perdorm
"Stairwell Heat Transfer Rates for a single dorm"
Q_dot_stairwellnew = U_new * DELTAT * A_totalwindow_stairwell * N_stairwells_perdorm
Q_dot_stairwellsavings = Q_dot_stairwellold - Q_dot_stairwellnew

"Dorm Lobby Money results"
Savings_totalstairwell_month = Q_dot_stairwellsavings * N_dorms * Price_BTU * Hours_month
Cost_totalstairwell_monthOLD = Q_dot_stairwellold * N_dorms * Price_BTU * Hours_month
Cost_totalstairwell_monthNEW = Q_dot_stairwellnew * N_dorms * Price_BTU * Hours_month

"!Dorm Additional Windows Specifications"

"Dorm Additional Window Information"
N_Add1_perside = 1 "Sliver of window on third floor"
N_Add2_perside = 3
N_sunroof_perside = 3
N_sides = 2

"Dorm Additional Window Dimensions"
L_Add1_top = (23 [in]) * convert(in,ft)
L_Add1_bot = (26 [in]) * convert(in,ft)
L_Add2_top = (9.5 [in]) * convert(in,ft)
L_Add2_bot = (12 [in]) * convert(in,ft)
L_sunroof = (27 [in]) * convert(in,ft)

h_Add1_top = (45 [in]) * convert(in,ft)
h_Add1_bot = (48 [in]) * convert(in,ft)
h_Add2_top = (45 [in]) * convert(in,ft)
h_Add2_bot = (48 [in]) * convert(in,ft)
h_sunroof = (53 [in]) * convert(in,ft)

A_Add1 = L_Add1_top * h_Add1_top + L_Add1_bot * h_Add1_bot
A_Add2 = L_Add2_top * h_Add2_top + L_Add2_bot * h_Add2_bot
A_sunroof = L_sunroof * h_sunroof
A_additional_totalperside = A_Add1 * N_Add1_perside + A_Add2 * N_Add2_perside + A_sunroof * N_sunroof_perside

"Total Dorm Additional Window Areas"
A_tot_additional = A_additional_totalperside * N_sides * N_dorms

"Dorm Additional Window Heat Transfer"
Q_dot_Additonalold = U_old * DELTAT * A_additional_totalperside * N_sides "All additional windows in a single dorm"
Q_dot_Additonalnew = U_new * DELTAT * A_additional_totalperside * N_sides
Q_dot_Additonalsavings = Q_dot_Additonalold - Q_dot_Additonalnew

"Dorm Lobby Money results"
Savings_Additonal_month = Q_dot_Additonalsavings * N_dorms * Price_BTU * Hours_month
Cost_Additonal_monthOLD = Q_dot_Additonalold * N_dorms * Price_BTU * Hours_month
Cost_Additonal_monthNEW = Q_dot_Additonalnew * N_dorms * Price_BTU * Hours_month

"Total Window Area"
A_tot = A_tot_room + A_tot_lobby + A_tot_stairwell + A_tot_additional

"Total Window Heat Transfer"
Q_dot_totold= U_old * DELTAT * A_tot "All windows"
Q_dot_totnew = U_new * DELTAT * A_tot "All windows"
Q_dot_totsavings = Q_dot_totold - Q_dot_totnew

"Total Savings"
Savings_tot = Q_dot_totsavings * Price_BTU * Hours_month

"Estimated Installed Window Cost"
Cost_install_tot = A_tot * Cost_windowarea

Unit Settings: Eng F psia mass deg

(Table 1, Run 8)

$A_{Add1} = 15.85$ [ft^2]
$A_{Add2} = 6.969$ [ft^2]
$A_{additional,totalperside} = 66.57$ [ft^2]
$A_{room,window} = 24$ [ft^2]
$A_{Rwindow,stairwell} = 9.667$ [ft^2]
$A_{sunroof} = 9.938$ [ft^2]
$A_{totalwindow,stairwell} = 130.4$ [ft^2]
$A_{tot,additional} = 932$ [ft^2]
$A_{tot,lobby} = 986.4$ [ft^2]
$Cost_{Additonal,monthNEW} = 13.01$ [\$]
$Cost_{Additonal,monthOLD} = 29.91$ [\$]
$Cost_{install,tot} = 1.150E+06$ [\$]
$Cost_{totalroom,monthOLD} = 744.1$ [\$]
$Cost_{totalstairwell,monthNEW} = 50.96$ [\$]
$Cost_{totalstairwell,monthOLD} = 117.2$ [\$]
$Hours_{month} = 744$ [hr]
$h_{Add1,bot} = 4$ [ft]
$h_{Add1,top} = 3.75$ [ft]
$h_{lobby,tallwindow} = 6.458$ [ft]
$h_{L,stairwell} = 4$ [ft]
$h_{M,stairwell} = 4$ [ft]
$h_{TL,stairwell} = 2.333$ [ft]
$h_{TM,stairwell} = 2.333$ [ft]
$h_{TR,stairwell} = 2.333$ [ft]
$L_{Add2,top} = 0.7917$ [ft]
$L_{lobby,window} = 2.375$ [ft]
$L_{L,stairwell} = 2.417$ [ft]
$L_{sunroof} = 2.25$ [ft]
$L_{TL,stairwell} = 2.417$ [ft]
$L_{TM,stairwell} = 2.917$ [ft]
$N_{dorms} = 7$
$N_{floors} = 3$
$N_{lobbies} = 7$
$N_{roomsperfloor} = 46$
$N_{rooms,total} = 966$
$N_{Rwindow,stairwell} = 4$
$N_{TLwindow,stairwell} = 1$
$N_{TMwindow,stairwell} = 1$
$N_{TRwindow,stairwell} = 1$
$\dot{Q}_{Additonalold} = 1102$ [BTU/hr]
$\dot{Q}_{Additonalsavings} = 623.1$ [BTU/hr]
$\dot{Q}_{lobbynew} = 507.3$ [BTU/hr]
$\dot{Q}_{roomold} = 198.7$ [BTU/hr]
$\dot{Q}_{roomsavings} = 112.3$ [BTU/hr]
$\dot{Q}_{stairwellnew} = 1878$ [BTU/hr]
$\dot{Q}_{totold} = 238084$ [BTU/hr]
$\dot{Q}_{totsavings} = 134569$ [BTU/hr]
$Savings_{Additonal,month} = 16.91$ [\$]
$Savings_{totalstairwell,month} = 66.24$ [\$]
$T_{inside} = 73$ [F]
$T_{outside} = 61$ [F]

$A_{lobby,windowpair} = 17.61$ [ft^2]
$A_{Lwindow,stairwell} = 9.667$ [ft^2]
$A_{Mwindow,stairwell} = 11.67$ [ft^2]
$A_{TLwindow,stairwell} = 5.639$ [ft^2]
$A_{TMwindow,stairwell} = 6.806$ [ft^2]
$A_{tot} = 28754$ [ft^2]
$A_{tot,room} = 23184$ [ft^2]
$A_{tot,stairwell} = 3652$ [ft^2]
$A_{TRwindow,stairwell} = 5.639$ [ft^2]
$Cost_{totallobby,monthNEW} = 13.76$ [\$]
$Cost_{totallobby,monthOLD} = 31.66$ [\$]
$Cost_{totalroom,monthNEW} = 323.5$ [\$]
$Cost_{windowarea} = 40$ [\$/ft^2]
$dayspermonth = 31$ [days]
$\Delta T = 12$ [F]
$h_{Add2,bot} = 4$ [ft]
$h_{Add2,top} = 3.75$ [ft]
$h_{lobby,shortwindow} = 0.9583$ [ft]
$h_{room,window} = 4$ [ft]
$h_{R,stairwell} = 4$ [ft]
$h_{sunroof} = 4.417$ [ft]
$L_{Add1,bot} = 2.167$ [ft]
$L_{Add1,top} = 1.917$ [ft]
$L_{Add2,bot} = 1$ [ft]
$L_{M,stairwell} = 2.917$ [ft]
$L_{room,window} = 6$ [ft]
$L_{R,stairwell} = 2.417$ [ft]
$L_{TR,stairwell} = 2.417$ [ft]
$N_{Add1,perside} = 1$
$N_{Add2,perside} = 3$
$N_{Lwindow,stairwell} = 4$
$N_{Mwindow,stairwell} = 3$
$N_{rooms} = 138$
$N_{sides} = 2$
$N_{stairwells,perdorm} = 4$
$N_{sunroof,perside} = 3$
$N_{windowpair,lobby} = 8$
$Price_{BTU} = 0.00000521$ [\$/BTU]
$\dot{Q}_{Additonalnew} = 479.3$ [BTU/hr]
$\dot{Q}_{lobbyold} = 1167$ [BTU/hr]
$\dot{Q}_{lobbysavings} = 659.5$ [BTU/hr]
$\dot{Q}_{roomnew} = 86.4$ [BTU/hr]
$\dot{Q}_{stairwellold} = 4319$ [BTU/hr]
$\dot{Q}_{stairwellsavings} = 2441$ [BTU/hr]
$\dot{Q}_{totnew} = 103515$ [BTU/hr]
$Savings_{tot} = 521.6$ [\$]
$Savings_{totallobby,month} = 17.89$ [\$]
$Savings_{totalroom,month} = 420.6$ [\$]
$U_{new} = 0.3$ [Btu/hr-ft^2-F]
$U_{old} = 0.69$ [Btu/hr-ft^2-F]

1..8	$T_{outside}$ [F]	dayspermonth [days]	$Cost_{totalroom,mo}$ [$]	$Cost_{totalroom,mo}$ [$]	$Savings_{totalroom}$ [$]	$Cost_{totallobby,mo}$ [$]	$Cost_{totallobby,r}$ [$]
Run 1	55	31	1116	485.3	630.9	47.49	20.65
Run 2	46	30	1620	704.4	915.8	68.94	29.97
Run 3	28	31	2790	1213	1577	118.7	51.62
Run 4	26	31	2914	1267	1647	124	53.91
Run 5	30	28	2408	1047	1361	102.5	44.55
Run 6	41	31	1984	862.7	1122	84.42	36.71
Run 7	46	30	1620	704.4	915.8	68.94	29.97
Run 8	61	31	744.1	323.5	420.6	31.66	13.76

$Savings_{totallobby}$ [$]	$Cost_{totalstairwell}$ [$]	$Cost_{totalstairwell}$ [$]	$Savings_{totalstair}$ [$]	$Cost_{Additonal,mo}$ [$]	$Cost_{Additonal,mo}$ [$]	$Savings_{Additona}$ [$]	$Savings_{tot}$ [$]
26.84	175.8	76.44	99.37	19.51	44.87	25.36	782.4
38.96	255.2	111	144.2	28.32	65.13	36.81	1136
67.1	439.5	191.1	248.4	48.77	112.2	63.4	1956
70.09	459	199.6	259.5	50.94	117.2	66.22	2043
57.92	379.3	164.9	214.4	42.09	96.82	54.72	1688
47.72	312.5	135.9	176.7	34.68	79.77	45.09	1391
38.96	255.2	111	144.2	28.32	65.13	36.81	1136
17.89	117.2	50.96	66.24	13.01	29.91	16.91	521.6

Sub-Appendix C.4: EES Code Roof Analysis

```
"!General info"
N_rooms = 46
N_dorms = 7
N_rooms_total = N_rooms* N_dorms
N_days = 30
Hours_month = N_days*24[hr/day]
H = 27*convert(in,ft)
X_old = 187*convert(in,ft)
X_new = 185*convert(in,ft)
L = 122*convert(in,ft)
t_roof_insulation = 4*convert(in,ft)
k_additional = 1.5[ft]/60[(F*(ft^2)*hr)/BTU]
k_roof_old = t_roof_insulation/R_roof_old

"!Temperature Specifications"
T_room = 73[F]
T_outside = 30[F]

"Money"
Price_BTU = (5.21 [$/MBTU])/1000000[BTU/MBTU]
Vol_bag = 14.26 [ft^3]
Price_bag = 7.25[$]
Price_insulation = Price_bag/Vol_bag

"!Insulation Specifications"
"Old Insulation"
insulationfactor = 1.5
R_insulation_old = 30[(F*hr*ft^2)/BTU]
R_roof_old = R_insulation_old*insulationfactor
"Additional Insulation"
N = 10000

"!Area of Roof"
A_roof_room_old = (X_old*L)
A_roof_room_new = (X_new*L)
A_i = (X_new*L)/N
```

```
"!Heat Transfer Calculations"
"Temperature Difference"
T_delta = T_room - T_outside
"Heat Transfer"
Q_dot_old = sum(((k_roof_old*A_i)/t_roof_insulation)*T_delta,i=1,N)
Q_dot_new=sum((T_delta*A_i)/((((((i*H)/N)+(((i-1)*H)/N))/2)/k_additional)+(t_roof_insulatio
n/k_roof_old)),i=1,N)
Q_dot_savings = Q_dot_old - Q_dot_new

"!Money results"
Savings_room = Q_dot_savings* Price_BTU
Savings_dorm = n_rooms*Q_dot_savings* Price_BTU
Savings_dorms_total = n_rooms_total*Q_dot_savings* Price_BTU
Lost_roof_old = Q_dot_old*n_rooms_total*Hours_month*Price_btu
Lost_roof_new = Q_dot_new*n_rooms_total*Hours_month*Price_btu

 Savings_Campus_month = Savings_dorms_total*Hours_month

"!Installation cost"
Vol_insulation = ((X_new*L*H)/2)*n_rooms_total
Cost_insulation = Vol_insulation*Price_insulation
```

Unit Settings: Eng F psia mass deg

A_i = 0.01567 [ft^2]

$A_{roof,room,new}$ = 156.7 [ft^2]

$A_{roof,room,old}$ = 158.4 [ft^2]

$Cost_{insulation}$ = 28867 [$]

H = 2.25 [ft]

$Hours_{month}$ = 720 [hr]

insulationfactor = 1.5

$k_{additional}$ = 0.025 [BTU/(F*ft*hr)]

$k_{roof,old}$ = 0.007407 [BTU/(F*ft*hr)]

L = 10.17 [ft]

$Lost_{roof,new}$ = 99.37 [$]

$Lost_{roof,old}$ = 180.9 [$]

N = 10000

N_{days} = 30 [day]

N_{dorms} = 7

N_{rooms} = 46

$N_{rooms,total}$ = 322

$Price_{bag}$ = 7.25 [$]

$Price_{BTU}$ = 0.00000521 [$/BTU]

$Price_{insulation}$ = 0.5084 [$/ft^3]

$\dot{Q}_{new}$ = 82.27 [BTU/hr]

$\dot{Q}_{old}$ = 149.8 [BTU/hr]

$\dot{Q}_{savings}$ = 67.5 [BTU/hr]

$R_{insulation,old}$ = 30 [(F*hr*ft^2)/BTU]

$R_{roof,old}$ = 45 [(F*hr*ft^2)/BTU]

$Savings_{Campus,month}$ = 81.53 [$]

$Savings_{dorm}$ = 0.01618 [$/hr]

$Savings_{dorms,total}$ = 0.1132 [$/hr]

$Savings_{room}$ = 0.0003517 [$/hr]

T_δ = 43 [F]

$T_{outside}$ = 30 [F]

$t_{roof,insulation}$ = 0.3333 [ft]

T_{room} = 73 [F]

Vol_{bag} = 14.26 [ft^3]

$Vol_{insulation}$ = 56778 [ft^3]

X_{new} = 15.42 [ft]

X_{old} = 15.58 [ft]

No unit problems were detected.

Calculation time = 1.94 s

1..8	1 N_{days} [day]	2 $T_{outside}$ [F]	3 $Savings_{Campus,}$ [$]
Run 1	31	55	35.27
Run 2	30	46	51.2
Run 3	31	28	88.17
Run 4	31	26	92.09
Run 5	28	30	76.1
Run 6	31	41	62.7
Run 7	30	46	51.2
Run 8	31	61	23.51

1..8	N_{days} [day]	$T_{outside}$ [F]	$Lost_{roof,old}$ [$]	$Lost_{roof,new}$ [$]
Run 1	31	55	78.25	42.98
Run 2	30	46	113.6	62.4
Run 3	31	28	195.6	107.5
Run 4	31	26	204.3	112.2
Run 5	28	30	168.8	92.75
Run 6	31	41	139.1	76.42
Run 7	30	46	113.6	62.4
Run 8	31	61	52.17	28.66

Sub-Appendix C.5: EES Code Wall Analysis

```
"!General info"
N_rooms = 46*3
N_dorms = 7
N_rooms_total = N_rooms* N_dorms
N_days = 30
Hours_month = N_days*24[hr/day]

"!Temperature Specifications"
T_room = 73[F]
T_outside = 30[F]

"Money"
Price_BTU = (5.21 [$/MBTU])/1000000[BTU/MBTU]
Price_insulation = 45[$]/32[ft^2]

"!Insulation Specifications"
insulationfactor = 1.1
R_cinder = 5.5[(F*hr*ft^2)/BTU]
R_rigidinsulation = 10[(F*hr*ft^2)/BTU]
R_brick = 0.44
R_old = R_cinder + R_rigidinsulation + R_brick
R_additinal = 15 [(F*hr*ft^2)/BTU]
R_new = R_old + R_additinal
"!Area of Roof"
A_window = 4[ft]*6[ft]
A_radiator = (26[in]*42[in])*convert(in^2,ft^2)
A_wall_room = ((102[in]*122[in])*convert(in^2,ft^2)) - A_window - A_radiator

"!Heat Transfer Calculations"
"Temperature Difference"
T_delta = T_room - T_outside
"Heat Transfer"
Q_dot_old = (T_delta*A_wall_room)/R_old
Q_dot_new = (T_delta*A_wall_room)/R_new
Q_dot_savings = Q_dot_old - Q_dot_new
```

"Money results"
Savings_room = Q_dot_savings* Price_BTU
Savings_dorm = n_rooms*Q_dot_savings* Price_BTU
Savings_dorms_total = n_rooms_total*Q_dot_savings* Price_BTU

Lost_walls_old = Q_dot_old*n_rooms_total*Price_BTU*Hours_month
Lost_walls_new = Q_dot_new*n_rooms_total*Price_BTU*Hours_month

Savings_Campus_month = Savings_dorms_total*Hours_month

"!Installation cost"
A_insulation = (A_wall_room)*n_rooms_total
Cost_insulation = A_insulation*Price_insulation

Unit Settings: Eng F psia mass deg

$A_{insulation}$ = 52969 [ft^2]
$A_{radiator}$ = 7.583 [ft^2]
$A_{wall,room}$ = 54.83 [ft^2]
A_{window} = 24 [ft^2]
$Cost_{insulation}$ = 74488 [$]
$Hours_{month}$ = 720 [hr]
insulationfactor = 1.1
$Lost_{walls,new}$ = 276.1 [$]
$Lost_{walls,old}$ = 536 [$]
N_{days} = 30 [day]
N_{dorms} = 7
N_{rooms} = 138
$N_{rooms,total}$ = 966
$Price_{BTU}$ = 0.00000521 [$/BTU]
$Price_{insulation}$ = 1.406 [$/ft^2$]
$\dot{Q}_{new}$ = 76.21 [BTU/hr]
$\dot{Q}_{old}$ = 147.9 [BTU/hr]
$\dot{Q}_{savings}$ = 71.71 [BTU/hr]
$R_{additinal}$ = 15 [(F*hr*ft^2)/BTU]
R_{brick} = 0.44 [(F*hr*ft^2)/BTU]
R_{cinder} = 5.5 [(F*hr*ft^2)/BTU]
R_{new} = 30.94 [(F*hr*ft^2)/BTU]
R_{old} = 15.94 [(F*hr*ft^2)/BTU]
$R_{rigidinsulation}$ = 10 [(F*hr*ft^2)/BTU]
$Savings_{Campus,month}$ = 259.9 [$]
$Savings_{dorm}$ = 0.05156 [$/hr]
$Savings_{dorms,total}$ = 0.3609 [$/hr]
$Savings_{room}$ = 0.0003736 [$/hr]
T_{δ} = 43 [F]
$T_{outside}$ = 30 [F]
T_{room} = 73 [F]

No unit problems were detected.

Calculation time = 78 ms

1..8	N_{days} [day]	$T_{outside}$ [F]	$Savings_{Campus,}$ [$]
Run 1	31	55	112.4
Run 2	30	46	163.2
Run 3	31	28	281
Run 4	31	26	293.5
Run 5	28	30	242.5
Run 6	31	41	199.8
Run 7	30	46	163.2
Run 8	31	61	74.94

1..8	N_{days} [day]	$T_{outside}$ [F]	$Lost_{walls,old}$ [$]	$Lost_{walls,new}$ [$]
Run 1	31	55	231.9	119.4
Run 2	30	46	336.6	173.4
Run 3	31	28	579.6	298.6
Run 4	31	26	605.4	311.9
Run 5	28	30	500.3	257.7
Run 6	31	41	412.2	212.4
Run 7	30	46	336.6	173.4
Run 8	31	61	154.6	79.63

Sub-Appendix C.6: Works Cited

Energy Star:

https://www.energystar.gov/products/building_products/residential_windows_doors_and_skylights/key_product_criteria

Weather Underground:

https://www.wunderground.com/history/airport/KGRR/2016/4/30/MonthlyHistory.html?req_city=&req_state=&req_statename=&reqdb.zip=&reqdb.magic=&reqdb.wmo=

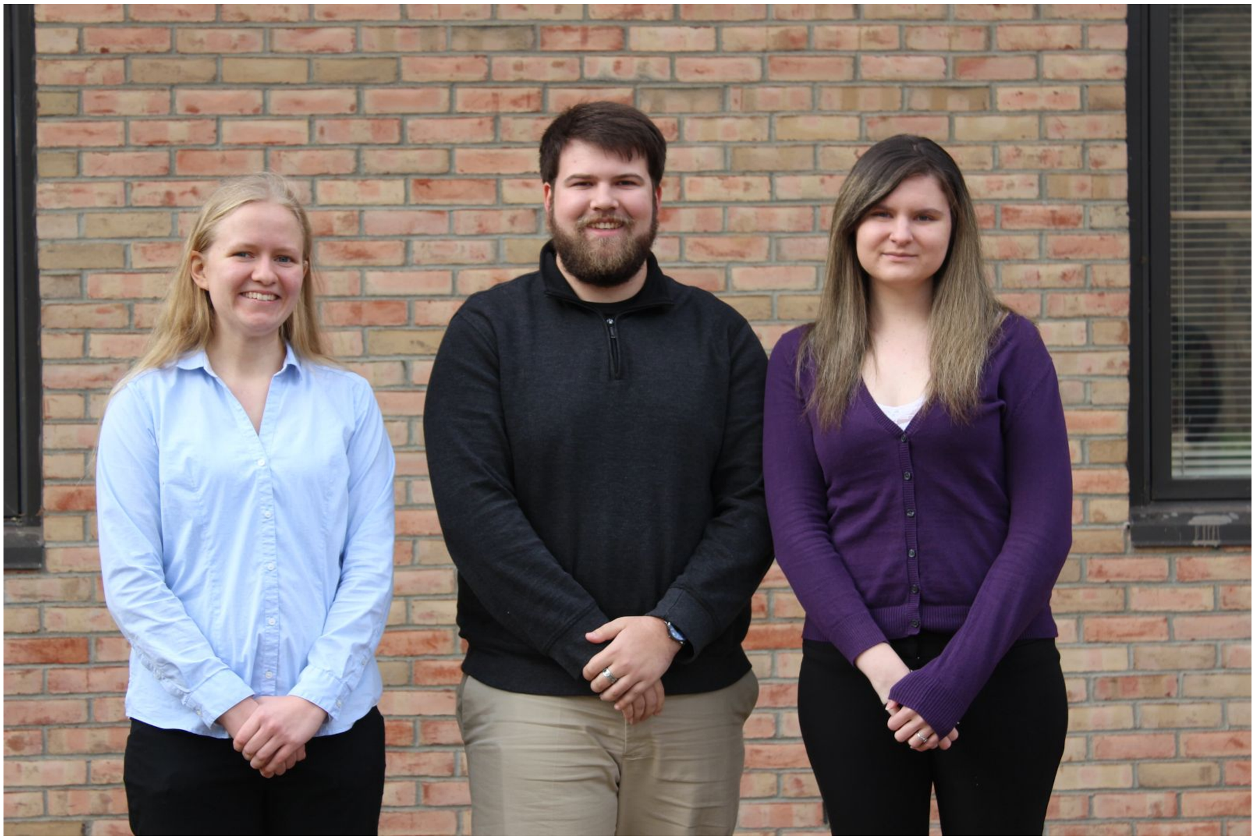
Insulation:

https://www.greenfiber.com/products/541-blow-in-low-dust-insulation

http://www.foamular.com/assets/0/144/172/174/1b241d3e-6d7f-4c14-88db-ab256a190e08.pdf

http://www.coloradoenergy.org/procorner/stuff/r-values.htm

Appendix D: Academic Buildings



From Left to Right: Abigail Berkompas, Ben Wellman, and Halley Press

Not Pictured: Christopher Greaves

Introduction

The Academic Buildings team had the task of reducing natural gas usage in the Science Building, Devries Hall, North Hall, the Spoelhof Center, Hiemenga Hall, the Hekman Library, the Covenant Fine Arts Center, the Prince Engineering Building, and the DeVos Communication Center. After considering several approaches, the team focused on the two options with the greatest potential for savings: replacing windows with more efficient ones, and lowering building temperatures. Both options reduce heat waste in the buildings while reducing the natural gas demand.

Table D-1: Summary of Results

Academic Buildings Savings	Replacing Single-Pane Windows	Lowering Indoor Temperature
Implementation Cost	$650,000	$0
Annual Savings	$6,500	$11,000

Approach

The Academic Buildings portion of the project was divided into two main categories: window replacement and temperature control. While the former was not selected as one of the recommended projects to reach $75,000 of annual savings, it was still beneficial to be looked into because windows will need to be replaced in the future the analysis will still be beneficial to the Physical Plant. The latter project was selected due to the nonexistent implementation cost.

Window Modeling

To tackle the modeling of heat loss through the windows, the team first went to each academic building and took measurements of the windows with a tape measure. For windows not accessible by reach, the team measured the height of bricks and then counted how many bricks were adjacent to those windows. These window measurements were given a larger uncertainty due to the method used in obtaining the data. All data was recorded on paper and later transferred to Google Sheets.

The group then analyzed the windows for each building to determine the percentage of single pane versus double-pane windows. Due to time limitations, all varying quality and thicknesses of double-pane windows were assumed to be of negligible difference and therefore all calculated as the same heat loss rate. Once ratios were collected, the data was transferred to Google Sheets.

Temperature Control Modeling

For this portion of the project, the group noted that Calvin College does not have a set temperature range for the winter. Instead, Physical Plant works towards varying temperatures based on requests from students and professors. Due to this, the team investigated temperature policies from other colleges in similar climate zones. From the research, Grand Valley State University's policy was selected as an outline for Calvin College's.

Using the research from Grand Valley State University's policy, the group decided to lower the set temperature from roughly 73 °F to a standard of 68 °F. To prepare for faculty and student reactions, the team would suggest copying Grand Valley State University in also creating a written policy that states each faculty member and student should dress appropriately for the temperature. In addition, Calvin College's Physical Plant could lower the temperature gradually to lessen possible negative reaction from faculty and students due to realized temperature drops.

The method used to approximate heat loss savings was based off the estimated window heat loss. Using the calculations for window heat loss, total heat loss was scaled up according to common magnitudes of heat loss from buildings. This is not as accurate as measuring the total exterior wall surface and roof areas and performing heat loss calculations for each. However, due to the time constraints on the project that method would not have been feasible.

Results

Window Replacement in Academic Buildings

The academic buildings that had significant amounts of single-pane windows were: the Spoelhof Center (50% of window area is single-pane), Science Building (75% of window area is single-pane), Hiemenga Hall (85% of window area is single-pane), and the Hekman Library (70% of window area is single-pane). By replacing the single-pane windows in these buildings with higher-efficiency double-pane windows, the heat loss will be reduced and lead to financial savings. The heat loss through windows in the academic buildings is expected to decrease from 2500 MMBTU to 1200 MMBTU per year, returning an annual savings of $6,500. The total cost of installing those replacement windows is estimated to be near $650,000.

A significant part of this analysis was the measurement of windows in the academic buildings. Recall that the measurement process was summarized in the Approach. Table D-2 shows the numerical results of these measurements. The estimated accuracy of these results are within 10% for the window area, and within 10% for the percent double pane.

Table D-2: Window Overview of Academic Buildings

Building	*Window Area [sq ft]*	*% Double-Pane*
DeVos Comm. Center	8100	100%
Spoelhof Center	6400	50%
Engineering Building	1100	100%
North Hall	1900	100%
Science Building	3900	25%
DeVries Hall	2000	75%
Hiemenga Hall	6200	15%
Hekman Library	4300	30%
CFAC	3200	100%

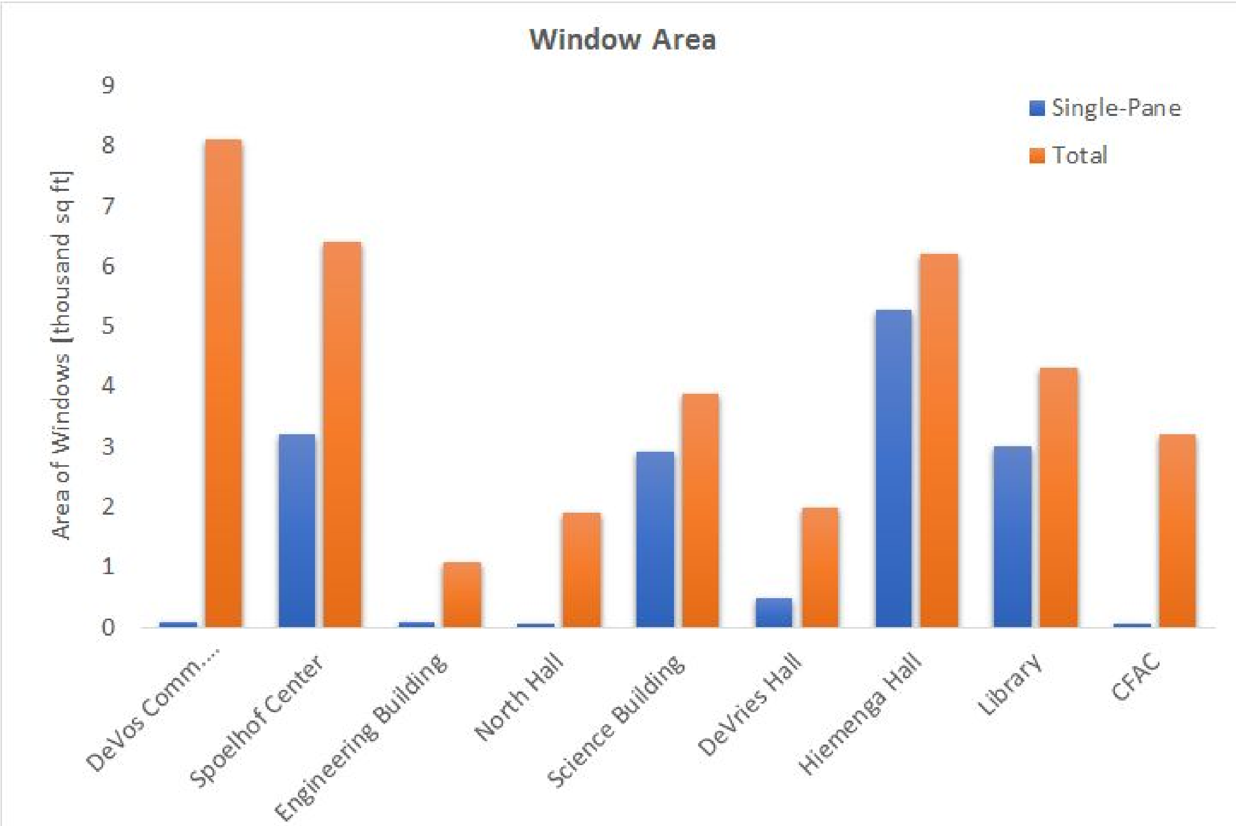


Figure D-1: Window Overview of Academic Buildings

Lowering the Temperature in Academic Buildings in Winter

Reducing the indoor heating temperature in the academic buildings from 73 °F to 68 °F would save Calvin $11,000 per year. Due to the method of approach for this calculation, there is significant uncertainty in this value. However, as a baseline, the decrease in temperature would reduce heat loss through the windows alone by 510 MMBTU per year, which represents a savings of $2,700 annually. A more thorough and time-intensive analysis of the wall and roof insulation throughout the academic buildings would result in more accurate total savings, however the $11,000 annual savings is estimated to be on the low end.

Discussion

Alternative Projects

Possibilities brainstormed at the beginning of the semester included: Working to limit unnecessary use of handicap doors, and surveying students to determine their comfort with building temperatures. Limiting the misuse of handicap doors was eliminated as it was difficult to define a good method to accomplish this, and the few seconds of improved insulation from a closed door offered little benefit compared to other projects. The survey was started, but was ultimately disregarded, due to varying feedback on standardizing temperature. It was decided that a better approach would be to define a maximum allowable temperature, and inform students that they were responsible for their own comfort by dressing appropriately.

Analysis of Results

The payback period of the replacement of windows with higher efficiency windows was calculated to be approximately 100 years. Therefore, immediate replacement of the windows would not be financially advisable at this time. However, if windows need to be replaced in the future due to wear or damage, Calvin ought to consider higher efficiency windows. These windows will probably cost more than other windows, but the increased cost could be made up for in energy savings.

Since lowering building temperatures has no capital investment associated with it, the payback is immediate. Therefore, it would be practical for Calvin to institute a temperature policy similar to the one studied in this project.

It is important to note that the two projects investigated by the Academic Buildings team cannot be combined for a total savings equal to the sum of the savings of each project. Replacement of windows would reduce the amount of total heat loss, cutting back the amount that could be saved by lowering the temperature, and similarly, lowering the temperature will reduce heat loss through the windows, lowering the potential for savings from energy efficient windows.

Conclusion

Upon the completion of the group's analysis, the financial team considered the savings values and deemed that lowering the temperature was a project worth pursuing. This was because the implementation cost was zero and the saving cost was non-negligible. The other option, the window analysis, was taken into consideration. However, due to the high cost to implement the new windows, the idea was not chosen for this project. But, it is recommended that Calvin College looks into slowly replacing the single pane windows in the academic buildings with double pane windows. Also, it should be noted that the savings from changing temperature and changing windows that the savings are not additive, due to a change in window resistance.

Sub-Appendix D

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Sub-Appendix D.1: Responsibilities

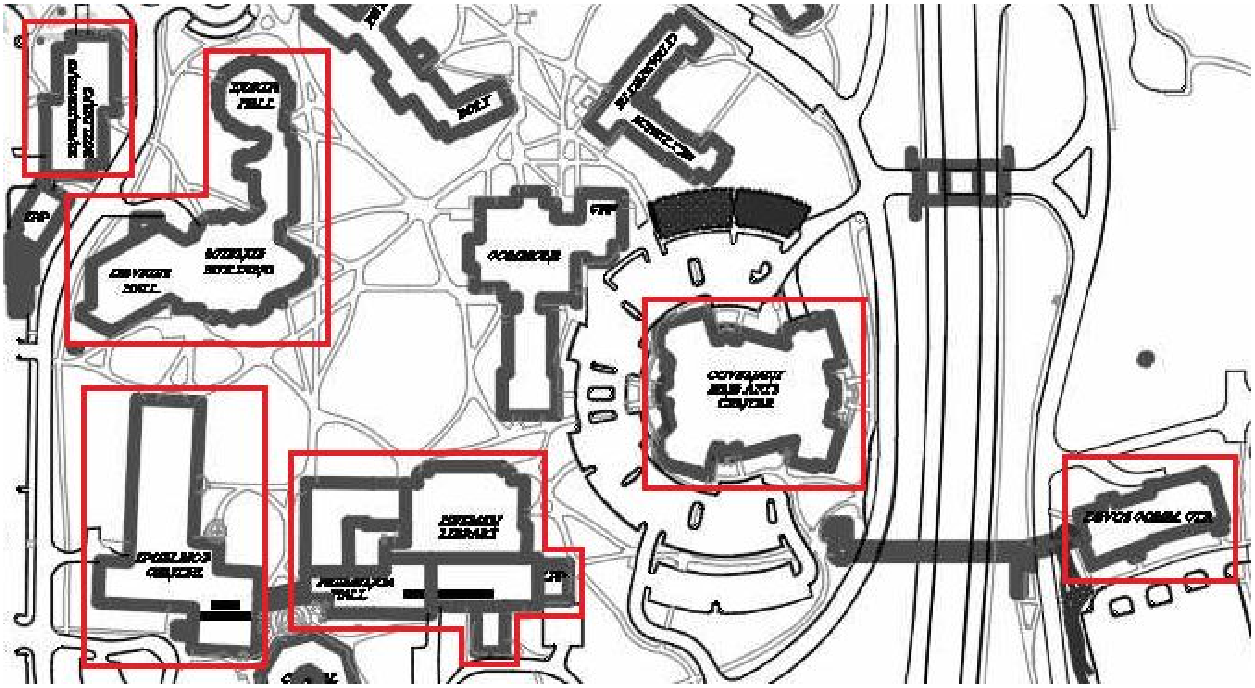

Figure D.1: Academic Building Researched Area

Sub-Appendix D.2: Work Cited

Grand Valley State University Policy

The Policy:
https://www.gvsu.edu/policies/policy.htm?policyId=E677FA8A-E5C3-832D-894D4C2F57EBE2D7&search=#statement

Appendix E: PE Complex

From Left to Right: Josh Templeman and Tim Bosch

Not Pictured: Jake Zandstra and Hendrik Vermeulen

Objective

Team A5, the PE Complex team, investigated the best methods to save on natural gas costs within the Spoelhof Fieldhouse Complex by means of thermodynamic models. In finding savings, the team adhered to all building requirements as defined by NCAA competition rulings, as well as ensured that the proposed solutions may be feasibly implemented.

Introduction

The Spoelhof Fieldhouse Complex is a 362,000 square-foot athletic facility located on the North end of the Calvin College Campus. The complex was originally comprised only of the Hoogenboom Center and functioned as a gymnasium and workout facility for the Calvin campus. Additional buildings were added to the Hoogenboom center in 2009 to create the Fieldhouse Complex which stands today. The additional buildings include the Venema Aquatics Center, Van Noord Arena, Morren Fitness Center, and the Huizenga Tennis and Track Center. These additional buildings provide the complex with an olympic-size swimming pool, 4,500 seat basketball and volleyball arena, an indoor track, and an indoor tennis practice facility. The newly-added facilities in the complex were designed with efficiency in mind, and the Spoelhof Fieldhouse Complex has been recognized for receiving several Lean efficiency awards.

Approach

The team began investigating the complex by conducting building tours, meeting with Physical Plant staff, and reviewing architectural drawings of the complex. When looking at ways to save money on natural gas, the group looked at behavioral, insulation, and temperature changes.

Behavioral Changes

Behavioral changes were focused on keeping the large garage doors in the Tennis and Track center (T&T) closed. These doors are on either side of storage lockers around the perimeter of the building and are often left open. Normally the air within the storage locker acts as insulation, however, when one of the doors are left open the only insulation between inside and outside is the material of the door.

This was modeled using a "bottom-up" heat transfer model. Both storage lockers within the T&T were assumed to be the same size and have their doors left open the same amount of time. It was assumed that the indoor air temperature is 73 ℉ and the outdoor air temperature is 28 ℉ during the winter. The doors were assumed to be open 4 hours a day for 5 days a week during 5 months of winter.

Door properties and were found using technical drawings provided by the company that built the doors (Cross Aluminum) and material properties were found using *Matweb.com*. The door dimensions were used along with material properties to calculate thermal resistance. These values were used to calculate heat loss through the storage lockers when the a garage door is left open versus when it is shut.

Roof Insulation

When the team looked at the roof insulation as a possibility for savings. Phil Beezhold, who was the head of Physical Plant at Calvin College, recommended that the team look at the Hoogenboom roof insulation. The reason for this was due to the fact that Physical Plant is already planning on replacing the roof due to old age and deterioration.

In order to find the savings of replacing the Hoogenboom roof, a bottom-up heat transfer model was created. In the model, the indoor air temperature is assumed to be 73 ℉, while the outdoor air temperature is assumed to be 28 ℉. Using these assumptions and insulation values found in the Physical Plant records, the savings per year was calculated and is shown in Table E-1 below. Convective heat transfer was modeled in EES to give a more accurate understanding of the savings potential.

Standardized Temperature

A temperature standardization of the complex was also investigated. The proposed standardized temperature would lower the internal temperature of the complex to 68 ℉. Although there is no data available for what the current building temperature is, the team used 73℉ as a base-case temperature. The staff at Physical Plant agreed that this temperature is an accurate estimate of internal building temperature. With the nominal internal temperature known, the team used seasonal weather reports to determine exterior conditions for the various months during which the building is heated.

The next step in constructing the bottom-up heat transfer model for the fieldhouse was to determine the dimensions and properties of all exterior surfaces. To achieve this, the architectural drawings and building specification documents produced by GMB Architects and Engineers were thoroughly reviewed. With these drawings and specification documents, it is determined that the fieldhouse consists of about 220,000 square feet of roofing, about 90,000 square feet of exterior wall area, and about 9,000 square feet of exterior window area. Note that these values do not include the entire fieldhouse complex since the Venema Aquatic Center is not included in the bottom-up heat transfer model. This exclusion is a result of NCAA competition rules which, as described by Physical Plant staff, dictate the temperature and humidity of a competition pool room. This means that there is no potential for savings in Venema for a temperature standardization, as the internal temperature of this facility may not be altered.

Equation E-1 shown below was used to calculate the heat transfer model in EES.

$$Q_{anual}(T_{inside}) = \sum_{s} \sum_{i} t_s A_i R_i^{-1} (T_{inside} - T_{outside}) \qquad \textbf{(Equation E-1)}$$

Where A refers to surface area, T refers to temperature, R refers to thermal resistivity, and t refers to time. Summing the expression for all components of the buildings exterior surface and for each season provides the cumulative energy loss for the fieldhouse (excluding Venema) for the year. Assuming the aforementioned natural gas cost of \$5.21E-06/BTU, the annual cost of heating the fieldhouse was found to be around \$20,000 per year. Furthermore, taking the difference of $Q_{anual}(73°F)$ and $Q_{anual}(68°F)$, the fieldhouse may save upwards to \$2,500 annually on natural gas. Hence, this behavioral change appears to have the highest savings potential. For more information regarding the thermodynamic modeling implemented in the fieldhouse, refer to Appendix E.6 where the EES code and solutions window may be viewed.

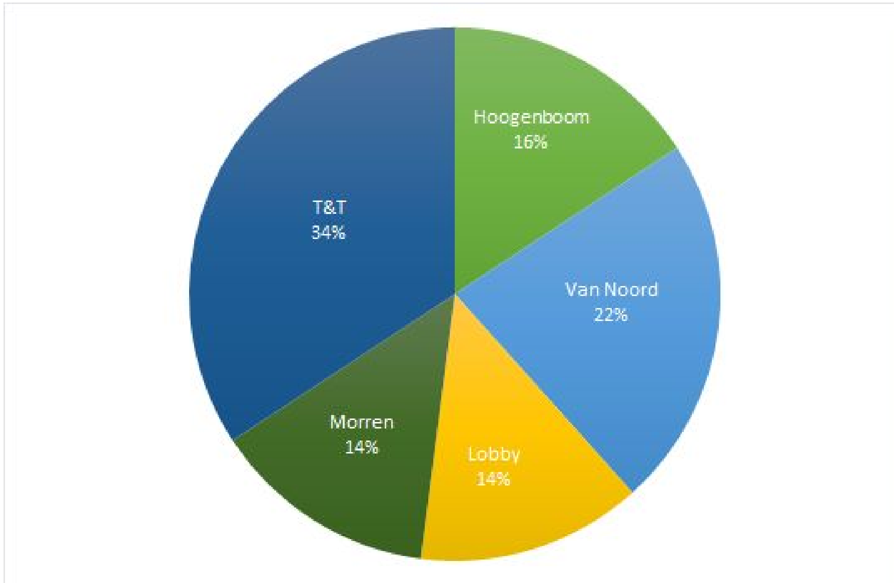

Figure E-1: Savings Distributing of PE Complex

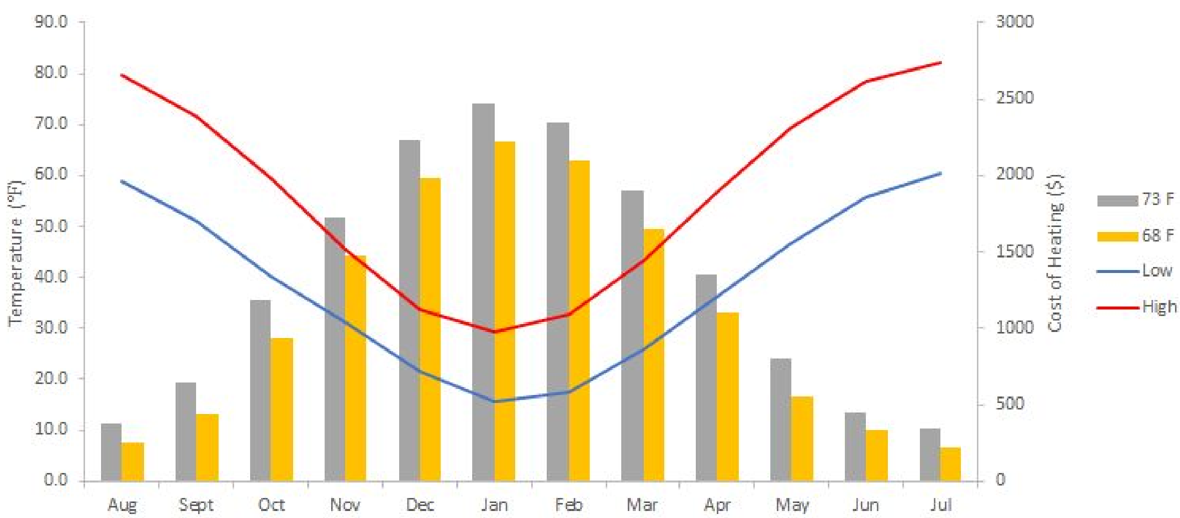

Figure E-2: Average Monthly Temperature and Heating Costs

Results

After looking at many possible projects that would save Calvin natural gas and in turn save them money. The group settled on taking an in-depth look at the the following three projects shown in Table E-1.

Table E-1: Summary of PE Complex Savings

Project	Savings ($/yr)	Implementation Cost ($)	Payoff (years)
Double Hoogenboom Roof Insulation*	308	500,000 **	1,623
PE Temperature Change	2,000	0.00	0
TNT Behavioral Change	3.81	0.00	0
Total Savings	≈2,300	500,000	248

*Physical plant is already planning on replacing roof due to old age and deterioration.

Capital investment

Capital investment has not been definitively determined as of December 19. The only project which requires capital investment is that of changing roof insulation. A quote for this project has not yet been obtained. A contact from GMB has agreed to provide the team with a roofing replacement quote for the building, but has not yet shared said information with the team.

Discussion

Throughout this project the group had looked at many ideas to save Calvin money by reducing natural gas usage in the PE complex. Many of these projects were not pursued though because of how efficient the PE complex is with its natural gas usage. Some of these projects researched and later dropped or discontinued were replacing windows, doubling the roof insulation for the entire PE complex, adding a green roof, and adding a pool cover.

The reason that replacing the windows in the PE complex was not a viable option was because all of the windows in the PE complex are all very new and are very efficient. This meant that there would be little to no payback. Expounding on the topic of windows, a group member from the PE Complex team worked alongside team members from Dorms and Dining Halls and Academic Buildings to investigate window modeling and replacement across campus. The work of this "windows team" was successful in the fact that thermal properties were found for existing campus windows and window heat transfer models were successfully developed. However, the work of the windows team proved window replacement in the fieldhouse infeasible as all alternative window selections surveyed by the various teams boasted thermal properties which were equal to or worse than the thermal properties of the windows already installed in the fieldhouse. The fieldhouse windows currently installed provide adequate thermal resistance with a heat transfer coefficient of 0.29 Btu/hr-ft^{2}F.

Similar to replacing the windows in the PE complex, doubling the roof insulation for the entire PE complex was not pursued. This was due to the fact that the PE complex roof insulation is very efficient, excluding the Hoogenboom roof insulation. Even if the insulation was doubled the savings would be little to none, and a financial loss when considering the implementation cost.

The group also investigated Green roofs, which would act as another insulation for the roof. When looking at this possibility the group talked to Professor Sykes who had done a summer research project on green roofs. After talking with Professor Sykes, it was found that a green roof on the PE complex would not be feasible due to the fact that the PE complex roof has a slope.

The group also looked at adding a pool cover, to the pool, to save on natural gas. It was discovered, when talking to Phil Beezhold, that Physical Plant uses the heat lost by to pool to heat the room. So by adding a pool cover, Physical Plant would have to additionally heat the Venema Aquatic Center, which would require natural gas. Furthermore, the heat dump from a condenser is used to provide heat to the pool. Natural gas is only burned periodically when the pool temperature drops too low. Therefore, the investigations to pool heating were discontinued as the team focused on less-refined areas in the complex.

Addressing the $20,000 per year annual heating cost for the fieldhouse, this estimate appears reasonable considering that this estimate does not account for heat loss through the Venema Aquatic Center, and considering that this estimate does not account for heat loss through open doors, insulation cracks, and insulation holes. Should the team have elected to pursue alternative methods for calculating the savings potential for this change, the number arrived at could have been a march larger sum. Based on a recent sightlines report, the average Btu/GSF at Calvin is approximately 60,000 annually. Applying this average to the fieldhouse, it is discovered that the annual natural gas cost delivered to the building is closer to $100,000. The reason we can not use this number, however, is because there are too many broad assumptions at play which would undoubtedly inflate the savings estimate.

The figure provided by sightlines incorporates all natural gas usage, meaning that laundry services, cooking services, and all other auxiliary forms of natural gas consumption are incorporated. Furthermore, the average figure given incorporates some of the far less-efficient buildings on campus. Since the Fieldhouse is new, and the thermal properties advertised in GMB specification documents are favorable, it must be assumed that the true heat loss through the surfaces of the Fieldhouse is far lower than what may be found by using the average Btu/GSF value found in the sightlines report. For this reason, the team deemed the estimates from the Sightlines report inappropriate for savings calculations as the reported values would be skewed to make savings appear larger than what will actually be saved. Hence, the PE Complex team commissioned the bottom-up heat transfer model of the complex to perform the analysis.

The Venema Aquatic Center was studied for natural gas cost savings. A few potential ideas came from the locker rooms in the P.E. Complex. One in particular that was explored early in the semester was the installation of low-flow nozzles on the showers in the locker rooms. However, it was soon discovered that there were already similar products installed in these showers. The possibility of installing a device that limited the time that the showers ran was also looked into. However, it was recommended by Phil Beezhold that these should not be pursued. Phil had already had problems with Calvin College in trying to modify showers, both in temperature and technology, and recommended that these ideas be neglected.

Conclusion

Throughout the semester the team studied the PE complex for ways to make it more efficient with its natural gas usage. It was found that the PE complex is very efficient with natural gas usage. This is shown through the fact that the biggest natural gas savings come from a behavioral change which is lowering the overall temperature in the complex. This was an important realization because it showed that the PE complex was built with natural gas efficiency in mind.

Sub-Appendix E

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Sub-Appendix E.1: Responsibilities

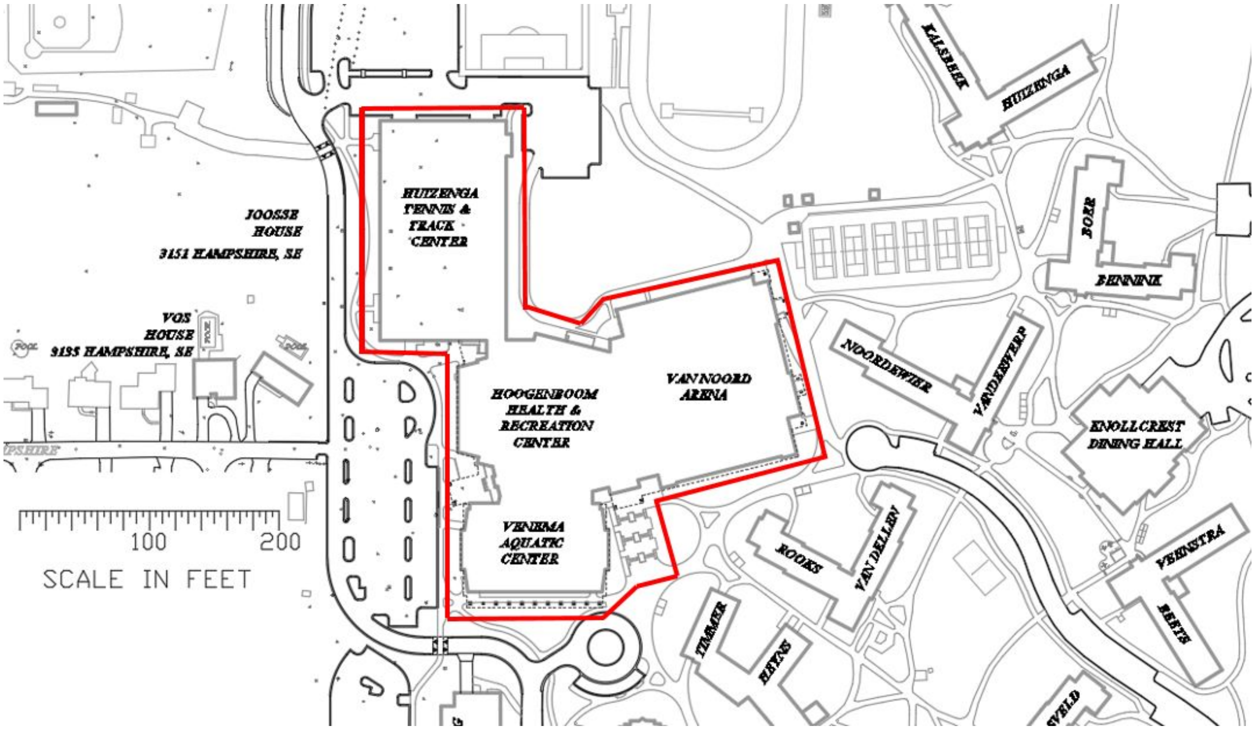

Figure E.1-1: PE Complex Researched Area

Sub-Appendix E.2: Gantt Chart

		Sep 12	Sep 19	Sep 26	Oct 3	Oct 10	Oct 17	Oct 23	Oct 31	Nov 7	Nov 15	Nov 20	Nov 27	Dec 4	Dec 7	Dec 19
	Task	**Week1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week7**	**Week 8**	**Week 9**	**Week 10**	**Week 11**	**Week 12**	**Week 13**	**Week 14**	**Week 15**
1	Determine tasks															
2	Preliminary building complex tour															
3	Identify all major potential sources of energy loss															
4	Identify favoriable solutions, eliminate infeasible ones															
5	Consult with finance to analyze remaining ideas															
6	Read energy audit analyis															
7	Schedule meeting with Phil and go on a tour															
8	Find building heating and cooling settings															
9	Find energy (and its cost) used by the complex															
10	Develop ideas to cut energy costs & calculate savings															
11	Find peak energy hours of the day/week															
12	Find peak energy days of the year															
13	Search Physical Plant for data & measurements															
14	Calculate energy savings in PE complex															
15	Write final report															
16																

Key	
Completed	
In Progress	
Withdrawn	

Sub-Appendix E.3: PE Complex Savings

Table E.3-1: Money Saved Breakdown for the PE Complex

Project	Savings ($/yr)	Implementation Cost ($)	Payoff (years)
Double Hoogenboom Roof Insulation*	308	500,000 **	1,623
PE Temperature Change	1500	0.00	0
TNT Behavioral Change	3.81	0.00	0
Total Savings	≈1800	500,000	248

*Change is already anticipated. Calculated savings does not include current heat leak
**Source: http://roofslope.com/2016/08/11/average-cost-commercial-roof-replacement/

Sub-Appendix E.4: Work Cited

"Air Properties." *The Engineering ToolBox*, www.engineeringtoolbox.com/air-properties-d_156.html.

ASM Material Data Sheet, asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6063T6.

"Average Cost of Commercial Roof Replacement." *Roofing Calculator*, http://roofslope.com/2016/08/11/average-cost-commercial-roof-replacement/

"FL-400 Doors." *Cross Aluminum: Commercial Entry Doors*, www.crossaluminum.com/fl400images.html.

"FL-400-Series Maximum Security Aluminum Flush Door Entrances." *FL-400-Series Maximum Security Aluminum Flush Door Entrances*, Cross Aluminum, www.crossaluminum.com/architecturals/Arch_FL-400FlushDoors.pdf.

Sub-Appendix E.5: EES Code-Bottom Up Model

```
"////////////////////////////////////////////////////////////////////////////////////////////////////////

ENGR 333A; Team A-5
Bottom-up Modeling of Fieldhouse

Fall Semester, 2017

ASSUMPTIONS/CLAIMS
------------------------------------
-Heat loss through cracks/holes in insulation not accounted for
-Heat flow only directly through exterior surfaces
-Venema Aquatic Center not accounted for in final savings
-Seasonal heating during

////////////////////////////////////////////////////////////////////////////////////////////////////////"

"Resistance Info Info"
R11=11 [(hour*ft*ft*F)/BTU]
R19=19 [(hour*ft*ft*F)/BTU]
R38=38 [(hour*ft*ft*F)/BTU]
U_window=0.29 [BTU/(hour*ft*ft*F)]
T_o.w = 20 [F]
```

```
T_o.s = 55 [F]
T_i = 73 [F]
boiler.efficiency_PE = 0.62 [ ]

"-------------------------Thermal Properties---------------------------"
k_plaster = 0.411 [BTU/(hour*ft*F)]
l_plaster = (1/12) [ft]
r_plaster= l_plaster /k_plaster

"***************************************************************************
*******************************
                              WALL THERMAL PROPERTIES
****************************************************************************
******************************"
 "-------------------------------TNT----------------------------------------------"

"Thermal Resistance of Top Section of TNT Wall"
R_insulation = 19 [(hour*ft*ft*F)/BTU]
R_sheet.metal = 0.61 [(hour*ft*ft*F)/BTU]
R_top.TNT = R_insulation + R_sheet.metal

"Thermal Resistance of Bottom Section of TNT Wall"
k_brick.inside = 0.6 [W/(m*K)] * convert(W/(m*K),BTU/(hour*ft*F))
k_brick.outside = 0.15 [W/(m*K)] * convert(W/(m*K),BTU/(hour*ft*F))
l_brick.inside = 7.625 [in] * convert(in,ft)
l_brick.outside = 3.375 [in] * convert(in,ft)
R_brick.inside = l_brick.inside / k_brick.inside
R_brick.outside = l_brick.outside / k_brick.outside
R_bottom.TNT = R_brick.inside + R_brick.outside
```

```
"TNT Wall Thermal Resistance"
Percent.Top.Wall = 0.65 [ ]
Percent.Bottom.Wall = 0.35 [ ]
R_TNT = Percent.Bottom.Wall * R_bottom.TNT + Percent.Top.Wall * R_Top.TNT
Q_dot_Wall_TNT=(A_wall_TNT*(T_i-T_o.w)/R_TNT)*24[hour/day]*(3*31)[day/year] +
(A_wall_TNT*(T_i-T_o.s)/R_TNT)*24[hour/day]*(5*31)[day/year]

"--------------------------Van Noord_----------------------------------------"
R_VN=R_brick.outside + r_brick.inside+r38+r_plaster
Q_dot_Wall_VN=(A_wall_VN*(T_i-T_o.w)/R38)*24[hour/day]*(3*31)[day/year]
+(A_wall_VN*(T_i-T_o.s)/R38)*24[hour/day]*(5*31)[day/year]

"------------------------Hogenboom------------------------------------------"
Q_dot_Wall_HB=(A_HT_W_HB*(T_i-T_o.w)/R19)*24[hour/day]*(3*31)[day/year]
+(A_HT_W_HB*(T_i-T_o.s)/R19)*24[hour/day]*(5*31)[day/year]

"----------------------Lobby Area--------------------------------------------"
Q_dot_Wall_LA=(A_HT_W_LA*(T_i-T_o.w)/R19)*24[hour/day]*(3*31)[day/year]
+(A_HT_W_LA*(T_i-T_o.s)/R19)*24[hour/day]*(5*31)[day/year]


"*******************************************************************************
********************************
WALL DIMENSIONS
********************************************************************************
*******************************"

"--------------------------------Venema----------------------------------"
```

```
L_V=223
W_V=98+47
slope_V=0.3
H_wall_V_min=20
H_mid_V=7*8
A_wall1_V=h_wall_V_min*L_V
A_wall_2_V=H_mid_V*W_V
A_Wall_V=A_wall1_V+2*A_wall_2_V

"-------------------------------Lobby Areas------------------------------------"
 A_wall_LA=2*(40*30+30*30)+(100*15+60*15)



"-------------------------------VanNord-------------------------------"
W_VN=253 [ft]
L_VN=200 [ft]
slope_VN=4[ft]/12[ft]
H_min_VN=5*7
h_mid_VN=h_min_VN+1/4*W_VN*slope_VN

A_wall1_VN=(H_min_VN-H_FG_max)*L_VN
A_wall2_VN=(h_mid_VN-H_FG_max)*W_VN
A_wall3_VN=H_min_VN*L_VN
A_wall4_VN=h_mid_VN*W_VN

A_Wall_VN=A_wall1_VN+A_wall2_VN+A_wall3_VN+A_wall4_VN
```

```
"------------------------------TNT-------------------------------------"
W_TNT=195
L_TNT=338
h_mid_TNT=24
slope_TNT=1/6
h_low_TNT=h_mid_TNT-(1/4)*W_TNT*slope_TNT

W_roof_TNT=W_TNT*1.038
L_roof_TNT=L_TNT

A_wall1_TNT=h_low_TNT*L_TNT
A_wall2_TNT=h_mid_TNT*W_TNT
A_Wall_TNT=2*A_wall1_TNT+A_wall2_TNT+(114/195)*A_wall2_TNT

"----------------------------Hogenboom------------------------------"

Slope_HB=1/3
H_mid_HB=8*6
H_min_HB=H_mid_HB-(28[ft])*slope_HB

A_wall_HB=H_min_HB*140[ft]+2*(36+39+20.25+10.81+10.65+19.71*8)[ft^2]+(36*12+8.38*
2*4+2*60*5)*2 [ft^2]

"------------------------------Front Gym------------------------------"
H_FG_min=5.5*3
H_FG_Max=6*3.5
L_FG=216
W_FG=40
A_wall_FG=L_FG*H_FG_min
```

```
A_wall_TOTAL=A_wall_VN+A_Wall_V+A_wall_TNT+A_wall_LA+A_wall_HB+A_wall_F
G

"****************************************************************************************************
******************************************
                              ROOF DIMENSIONS
*****************************************************************************************************
******************************************"



"Roofing"


R_roof=31.1


"-------------------TNT-----------------------------------"
A_Roof_TNT=1.038*L_TNT*W_TNT


"-------------------VAN NORD-----------------------------------"
 A_Roof_VN=1.038*L_VN*W_VN


"-------------------VENMA-----------------------------------"
 A_ROOF_V=1.038*L_V*W_V


"-------------------HB-----------------------------------"
 A_roof_HB=1.038*2*71*136+1.038*200*60


"-------------------FRONT GYM-----------------------------------"
```

A_roof_FG=1.038*L_FG*W_FG

"-------------------------------Lobby Areas------------------------------------"

A_roof_LA=245*40+20*110+200*44

A_Roof_total=A_roof_TNT+A_roof_VN+A_roof_V+A_roof_HB+A_roof_FG+A_roof_LA

"***
****

WINDOW DIMENSIONS

****
******************************"

"Front Glass-wall"

A_W_FGW=(16*5*(4+8/12)+6.33*4.66+25*10+5.5*9+7*22.5+7*10+15.5*7+25*10) [ft^2]

chw=((6*4)^2+6*6.5*12^2*2)[ft^2] {To check alternative method with GMB provided dims}

"----------------Venma----------------------"

A_W_V=(22*3.33)[ft]*H_wall_V_min+(9*4*4*4)[ft^2]

A_HT_W_V=A_Wall_V-A_W_V

"---------------------TNT----------------------"

A_W_TNT=8*4.666^2

A_HT_W_TNT=A_Wall_TNT-A_W_TNT

"-----------------Hogenboom------------------"

```
A_W_HB=7*4+25*10
A_HT_W_HB=A_Wall_HB-A_W_HB


"-------------------Front Gym--------------------"
A_W_FG=A_Wall_FG
A_HT_W_FG=A_W_FG-A_Wall_FG

"-------------------Lobby Area---------------------"
A_W_LA=2*10*25+8*4*4+8*25*4
A_HT_W_LA=A_Wall_LA-A_W_LA-A_W_FGW

"---------------VAN NORD AREA--------------"
A_W_VN=8*10*2
A_W_total=A_W_FGW+A_W_V+A_W_VN+A_W_LA+A_W_HB+A_W_TNT+A_W_FG



"***************************************************************************
*******************************
                        HT THROUGH ROOF AND WINDOW
***************************************************************************
*******************************"
Q_dot_Wall_TNT_TLOW=(A_wall_TNT*(68[f]-T_o.w)/R_TNT)*24[hour/day]*(3*31)[day/ye
ar] + (A_wall_TNT*(68[f]-T_o.s)/R_TNT)*24[hour/day]*(5*31)[day/year]
Q_dot_Wall_VN_TLOW=(A_wall_VN*(68[f]-T_o.w)/R38)*24[hour/day]*(3*31)[day/year]
+(A_wall_VN*(68[f]-T_o.s)/R38)*24[hour/day]*(5*31)[day/year]
```

Q_dot_Wall_HB_Tlow=(A_HT_W_HB*(68[f]-T_o.w)/R19)*24[hour/day]*(3*31)[day/year] +(A_HT_W_HB*(68[f]-T_o.s)/R19)*24[hour/day]*(5*31)[day/year]

Q_dot_Wall_LA_TLOW=(A_HT_W_LA*(68[f]-T_o.w)/R19)*24[hour/day]*(3*31)[day/year] +(A_HT_W_LA*(68[f]-T_o.s)/R19)*24[hour/day]*(5*31)[day/year]

Q_dot_Roof=((1/R_roof)*(T_i-T_o.w)*A_roof_Total)*24[hour/day]*(3*31)[day/year] + ((1/R_roof)*(T_i-T_o.s)*A_roof_Total)*24[hour/day]*(5*31)[day/year]

Q_dot_Windows=U_window*(T_i-T_o.w)*A_W_total*24[hour/day]*(3*31)[day/year]+U_window*(T_i-T_o.s)*A_W_total*24[hour/day]*(5*31)[day/year]

Q_dot_wall=Q_dot_Wall_LA +Q_dot_Wall_TNT +Q_dot_Wall_VN +Q_dot_Wall_HB

Q_dot_total=Q_dot_roof+Q_dot_Windows+Q_dot_wall +q_roof.year1

Q_dot_roof_Tlow=(1/R_roof*(68[F]-T_o.w)*A_roof_Total)*24[hour/day]*(3*31)[day/year] + (1/R_roof*(68[f]-T_o.s)*A_roof_Total)*24[hour/day]*(5*31)[day/year]

Q_dot_windows_Tlow=U_window*(68[f]-T_o.w)*A_W_total*24[hour/day]*(3*31)[day/year]+ U_window*(68[f]-T_o.s)*A_W_total*24[hour/day]*(5*31)[day/year]

Q_dot_wall_TLow=Q_dot_Wall_LA_TLOW +Q_dot_Wall_TNT_TLOW +Q_dot_Wall_VN_TLOW +Q_dot_Wall_HB_TLOW

costBTU=5.21 [$]/1000000 [BTU]

Cost_roof=Q_dot_roof*costBTU / boiler.efficiency_PE

Cost_wall=Q_dot_wall*costBTU / boiler.efficiency_PE

Cost_window=Q_dot_windows*costBTU / boiler.efficiency_PE

cost_heating=(Q_dot_total)*costBTU / boiler.efficiency_PE

Q_dot_total_TLOW=Q_dot_roof_TLOW+Q_dot_Windows_TLOW+Q_dot_wall_TLOW + q_roof.year2

savings=costBTU*(Q_dot_total-Q_dot_total_TLOW)

AnnualBTU=1610000000000 [BTU]

"Reduction=100 * (1 - (AnnualBTU-(Q_dot_total-Q_dot_total_Tlow)) / AnnualBTU)"

"Convection"

Q_roof.year1 = 234500000 [BTU/year]

Q_roof.year2 = 203400000 [BTU/year]

AnnualBTU = 1.610E+12 [Btu]	$A_{HT,W,FG}$ = 0 [ft^2]	$A_{HT,W,HB}$ = 7882 [ft^2]	$A_{HT,W,LA}$ = 3884 [ft^2]	$A_{HT,W,TNT}$ = 17973 [ft^2]
$A_{HT,W,V}$ = 18659 [ft^2]	$A_{roof,FG}$ = 8968 [ft^2]	$A_{roof,HB}$ = 32502 [ft^2]	$A_{roof,LA}$ = 20800 [ft^2]	$A_{Roof,TNT}$ = 68415 [ft^2]
$A_{Roof,total}$ = 216771 [ft^2]	$A_{ROOF,V}$ = 33564 [ft^2]	$A_{Roof,VN}$ = 52523 [ft^2]	$A_{wall1,TNT}$ = 5366 [ft^2]	$A_{wall1,V}$ = 4460 [ft^2]
$A_{wall1,VN}$ = 2800 [ft^2]	$A_{wall2,TNT}$ = 4680 [ft^2]	$A_{wall2,VN}$ = 8876 [ft^2]	$A_{wall3,VN}$ = 7000 [ft^2]	$A_{wall4,VN}$ = 14189 [ft^2]
$A_{wall,2,V}$ = 8120 [ft^2]	$A_{wall,FG}$ = 3564 [ft^2]	$A_{wall,HB}$ = 8160 [ft^2]	$A_{wall,LA}$ = 6600 [ft^2]	$A_{wall,TNT}$ = 18148 [ft^2]
$A_{wall,TOTAL}$ = 90037 [ft^2]	$A_{Wall,V}$ = 20700 [ft^2]	$A_{wall,VN}$ = 32865 [ft^2]	$A_{W,FG}$ = 3564 [ft^2]	$A_{W,FGW}$ = 1288 [ft^2]
$A_{W,HB}$ = 278 [ft^2]	$A_{W,LA}$ = 1428 [ft^2]	$A_{W,TNT}$ = 174.2 [ft^2]	$A_{W,total}$ = 8934 [ft^2]	$A_{W,V}$ = 2041 [ft^2]
$A_{W,VN}$ = 160 [ft^2]	boiler.efficiency$_{PE}$ = 0.62 [-]	chw = 11808 [ft^2]	costBTU = 0.00000521 [$/BTU]	$cost_{heating}$ = 21110 [$/year]
$Cost_{roof}$ = 10851 [$/year]	$Cost_{wall}$ = 4256 [$/year]	$Cost_{window}$ = 4033 [$/year]	$H_{FG,max}$ = 21 [ft]	$H_{FG,min}$ = 16.5 [ft]
$h_{low,TNT}$ = 15.88 [ft]	$H_{mid,HB}$ = 48 [ft]	$h_{mid,TNT}$ = 24 [ft]	$H_{mid,V}$ = 56 [ft]	$h_{mid,VN}$ = 56.08 [ft]
$H_{min,HB}$ = 38.67 [ft]	$H_{min,VN}$ = 35 [ft]	$H_{wall,V,min}$ = 20 [ft]	$k_{brick.inside}$ = 0.3467 [BTU/(hour*ft*F)]	$k_{brick.outside}$ = 0.08667 [BTU/(hour*ft*F)]
$k_{plaster}$ = 0.411 [BTU/(hour*ft*F)]	$l_{brick.inside}$ = 0.6354 [ft]	$l_{brick.outside}$ = 0.2813 [ft]	L_{FG} = 216 [ft]	$l_{plaster}$ = 0.08333 [ft]
$L_{roof,TNT}$ = 338 [ft]	L_{TNT} = 338 [ft]	L_V = 223 [ft]	L_{VN} = 200 [ft]	Percent.Bottom.Wall = 0.35 [-]
Percent.Top.Wall = 0.65 [-]	$\dot{Q}_{Roof}$ = 1.291E+09 [BTU/year]	$\dot{Q}_{roof\ Tlow}$ = 1.084E+09 [BTU/year]	$\dot{Q}_{total}$ = 2.512E+09 [BTU/year]	$\dot{Q}_{total\ TLOW}$ = 2.115E+09 [BTU/year]
$\dot{Q}_{wall}$ = 5.064E+08 [BTU/year]	$\dot{Q}_{Wall,HB}$ = 7.685E+07 [BTU/year]	$\dot{Q}_{Wall,HB\ Tlow}$ = 6.451E+07 [BTU/year]	$\dot{Q}_{Wall,LA}$ = 3.787E+07 [BTU/year]	$\dot{Q}_{Wall,LA\ TLOW}$ = 3.178E+07 [BTU/year]
$\dot{Q}_{wall\ TLow}$ = 4.251E+08 [BTU/year]	$\dot{Q}_{Wall\ TNT}$ = 2.315E+08 [BTU/year]	$\dot{Q}_{Wall\ TNT\ TLOW}$ = 1.943E+08 [BTU/year]	$\dot{Q}_{Wall,VN}$ = 1.602E+08 [BTU/year]	$\dot{Q}_{Wall,VN\ TLOW}$ = 1.345E+08 [BTU/year]
$\dot{Q}_{Windows}$ = 4.800E+08 [BTU/year]	$\dot{Q}_{windows\ Tlow}$ = 4.029E+08 [BTU/year]	$q_{roof.year1}$ = 2.345E+08 [BTU/year]	$q_{roof.year2}$ = 2.034E+08 [BTU/year]	R11 = 11 [(hour*ft*ft*F)/BTU]
R19 = 19 [(hour*ft*ft*F)/BTU]	R38 = 38 [(hour*ft*ft*F)/BTU]	$R_{bottom.TNT}$ = 5.078 [(hour*ft*ft*F)/BTU]	$R_{brick.inside}$ = 1.833 [(hour*ft*ft*F)/BTU]	$R_{brick.outside}$ = 3.245 [(hour*ft*ft*F)/BTU]
$R_{insulation}$ = 19 [(hour*ft*ft*F)/BTU]	$r_{plaster}$ = 0.2028 [(hour*ft*ft*F)/BTU]	R_{roof} = 31.1 [(hour*ft*ft*F)/BTU]	$R_{sheet.metal}$ = 0.61 [(hour*ft*ft*F)/BTU]	R_{TNT} = 14.52 [(hour*ft*ft*F)/BTU]
$R_{top.TNT}$ = 19.61 [(hour*ft*ft*F)/BTU]	R_{VN} = 43.28 [(hour*ft*ft*F)/BTU]	savings = 2068 [$/year]	$Slope_{HB}$ = 0.3333	$slope_{TNT}$ = 0.1667
$slope_V$ = 0.3	$slope_{VN}$ = 0.3333	T_i = 73 [F]	$T_{o.s}$ = 55 [F]	$T_{o.w}$ = 20 [F]
U_{window} = 0.29 [BTU/(hour*ft*ft*F)]	W_{FG} = 40 [ft]	$W_{roof,TNT}$ = 202.4 [ft]	W_{TNT} = 195 [ft]	W_V = 145 [ft]
W_{VN} = 253 [ft]				

No unit problems were detected.

Calculation time = 78 ms

Sub-Appendix E.6: EES Code Hoogenboom Roof Insulation Model

```
"!Temperature Specifications"
T_room = 72[F]
T_outside = 28[F]

"Money"
Price_BTU = (5.21 [$]/ 1 [MBTU])/1000000[BTU/MBTU]

"!Insultation Specifications"
R_old = 31.1 [(F*hr*ft^2)/BTU]
R_old_Hoogenboom= 30 [(F*hr*ft^2)/BTU]
R_additinal = 31.1 [(F*hr*ft^2)/BTU]
R_new = R_old + R_additinal
R_new_Hoogenboom =  R_additinal*2

"!Area of Roof"
A_roof_TNT = 6080*convert(M^2,ft^2)
A_roof_Hoogenboom = 3353*convert(M^2,ft^2)
A_roof_VanNoord = 8827*convert(M^2,ft^2)
A_roof_Venama = 4171*convert(M^2,ft^2)


"!Heat Transfer Calculations"
"Temperature Difference"
T_delta = T_room - T_outside

"Heat Transfer"
Q_dot_old_TNT = (T_delta*A_roof_TNT)/R_old
Q_dot_new_TNT = (T_delta*A_roof_TNT)/R_new
```

Q_dot_savings_TNT = Q_dot_old_TNT - Q_dot_new_TNT

Q_dot_old_Hoogenboom = (T_delta*A_roof_Hoogenboom)/R_old_Hoogenboom

Q_dot_new_Hoogenboom = (T_delta*A_roof_Hoogenboom)/R_new_Hoogenboom

Q_dot_savings_Hoogenboom = Q_dot_old_Hoogenboom - Q_dot_new_Hoogenboom

Q_dot_old_VanNoord = (T_delta*A_roof_VanNoord)/R_old

Q_dot_new_VanNoord = (T_delta*A_roof_VanNoord)/R_new

Q_dot_savings_VanNoord = Q_dot_old_VanNoord - Q_dot_new_VanNoord

Q_dot_old_Venama = (T_delta*A_roof_Venama)/R_old

Q_dot_new_Venama = (T_delta*A_roof_Venama)/R_new

Q_dot_savings_Venama = Q_dot_old_Venama - Q_dot_new_Venama

"Money results"

Savings_TNT = Q_dot_savings_TNT* Price_BTU

Savings_Hoogenboom = Q_dot_savings_Hoogenboom* Price_BTU

Savings_VanNoord = Q_dot_savings_VanNoord* Price_BTU

Savings_Venama = Q_dot_savings_VanNoord* Price_BTU

Savings_total =Savings_TNT+Savings_Hoogenboom+Savings_VanNoord+Savings_Venama

Hours_month = 30[day]*24[hr/day]

Savings_total_month = Savings_total*Hours_month

Savings_total_year=(Savings_total_month*12)/4

Savings_Hoogenboom_month = Savings_Hoogenboom*Hours_month

Savings_Hoogenboom_year=(Savings_Hoogenboom_month*12)/4

$A_{roof,Hoogenboom}$ = 36091 [ft^2]	$A_{roof,TNT}$ = 65445 [ft^2]	$A_{roof,VanNoord}$ = 95013 [ft^2]	$A_{roof,Venama}$ = 44896 [ft^2]	$Hours_{month}$ = 720 [hr]	$Price_{BTU}$ = 0.00000521 [$/BTU]
$\dot{Q}_{new,Hoogenboom}$ = 25531 [BTU/hr]	$\dot{Q}_{new\ TNT}$ = 46295 [BTU/hr]	$\dot{Q}_{new,VanNoord}$ = 67212 [BTU/hr]	$\dot{Q}_{new,Venama}$ = 31759 [BTU/hr]	$\dot{Q}_{old,Hoogenboom}$ = 52934 [BTU/hr]	$\dot{Q}_{old\ TNT}$ = 92590 [BTU/hr]
$\dot{Q}_{old,VanNoord}$ = 134424 [BTU/hr]	$\dot{Q}_{old,Venama}$ = 63519 [BTU/hr]	$\dot{Q}_{savings,Hoogenboom}$ = 27403 [BTU/hr]	$\dot{Q}_{savings\ TNT}$ = 46295 [BTU/hr]	$\dot{Q}_{savings,VanNoord}$ = 67212 [BTU/hr]	$\dot{Q}_{savings,Venama}$ = 31759 [BTU/h
$R_{additinal}$ = 31.1 [(F*hr*ft^2)/BTU]	R_{new} = 62.2 [(F*hr*ft^2)/BTU]	$R_{new,Hoogenboom}$ = 62.2 [(F*hr*ft^2)/BTU]	R_{old} = 31.1 [(F*hr*ft^2)/BTU]	$R_{old,Hoogenboom}$ = 30 [(F*hr*ft^2)/BTU]	$Savings_{Hoogenboom}$ = 0.1428 [$/h
$Savings_{Hoogenboom,month}$ = 102.8 [$]	$Savings_{Hoogenboom,year}$ = 308.4 [$]	$Savings_{TNT}$ = 0.2412 [$/hr]	$Savings_{total}$ = 1.084 [$/hr]	$Savings_{total,month}$ = 780.7 [$]	$Savings_{total,year}$ = 2342 [$]
$Savings_{VanNoord}$ = 0.3502 [$/hr]	$Savings_{Venama}$ = 0.3502 [$/hr]	T_{δ} = 44 [F]	$T_{outside}$ = 28 [F]	T_{room} = 72 [F]	

No unit problems were detected.

Calculation time = 31 ms