Building Operational Efficiency Project

ENGR-333

To: Professor Heun
By: 2015 ENGR-333 Class
09/15/2015 – 12/18/2015

Objective

The ENGR-333 class was tasked with answering the question: “What would it take for Calvin College to save $600,000/year on campus operations?” The class choose five buildings as study samples, and invested the saving potential on three aspects: energy efficiency, operational and behavioral changes. The five buildings chose by the class were the: Covenant Fine Arts Center, Kalsbeek Huizinga vanReken, Science Building Complex, Shultze Eldersveld, and Spoelhof Fieldhouse Complex.

Approach

Common projects:

Lighting

This project consists two part de-lamping and lighting restrictions. De-lamping means replaces fluorescent light bulbs with LED bulbs, and also reduces the overall number of bulbs in the studied building. Because LED bulbs are twice as bright as the currently installed bulbs, it is possible to reduce the number of bulbs installed. Lighting restrictions means turn off the lights when they are not necessary.

Window-Reflective Coating

This project adds low-E (low-emissivity) coatings onto every window of studied building. The addition of the film reduces the amount of heat loss through the windows during the year. This will increase savings in air conditioning. Cost savings were obtained using the windows model (see Appendix B.4).

Heat Recovery Ventilator

This project installs heat recovery ventilators in replace of existing exhaust fans. Heat recovery ventilators are multipurpose fans that transfer heat from the stale air (exhaust) to the fresh air (intake). This saves energy in heating air during the winter and cooling air during the summer. It also helps buildings meet ventilation requirements. Cost savings were determined by using the CFM (cubic feet per minute) of each exhaust fan with the heat recovery model (see Appendix B.3).

Temperature change

This project only apply to building that are air-conditioned. This project is simply change the temperatures from 70°F to 69°F in the winter, and from 72°F to 75°F in the summer. The size of the building requires a great deal of energy required for heating and air conditioning, which is one of the biggest reasons for the high savings potential from this initiative. And this project allows a big saving potential with no initial cost.

Results

The amount of saving from different projects are presented table below.

Table 1. Major Project Savings

	Temperature Change	LED Conversion	Heat Recovery Ventilator	Window Reflective Coatings
Savings $\left[\frac{\$}{\mathrm{yr}}\right]$	57239	92277	58703	26005

Table 2. Breakdown of Savings by Project Type

	HVAC	Lighting	Extra Buildings	Operational	Behavioral	Overall
Savings $\left[\frac{\$}{\mathrm{yr}}\right]$	104031	56176	81677	73728	8280	323892

Conclusions

Through large amounts of time and effort spent, the ENGR 333 class was finally able to answer the initial question posed to us: "What would it take for Calvin College to save $600,000/year on campus operations?" Calvin College can achieve this through the implementation of the projects mentioned above, as well as keeping an open eye out for potential projects in the future. Through the extrapolation from the buildings analyzed to the entire campus, Calvin College could save $604,485 a year with these projects. These projects vary from operational or behavioral changes to even as simple as something as cutting your shower usage by a couple minutes. This change is possible through the cooperation of everyone at Calvin, not just the operational staff. Calvin College has the opportunity to join a community of organizations around the world that promote a more sustainable and cleaner earth, and these projects are some of the way that this can happen.

Figures

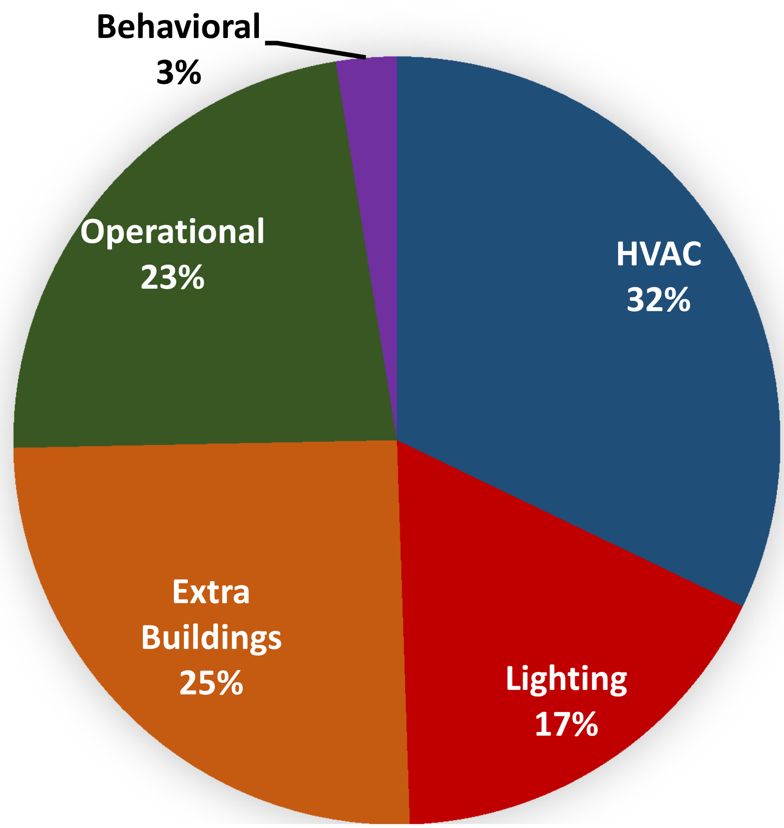


Figure 1. Breakdown of Savings by Project Type

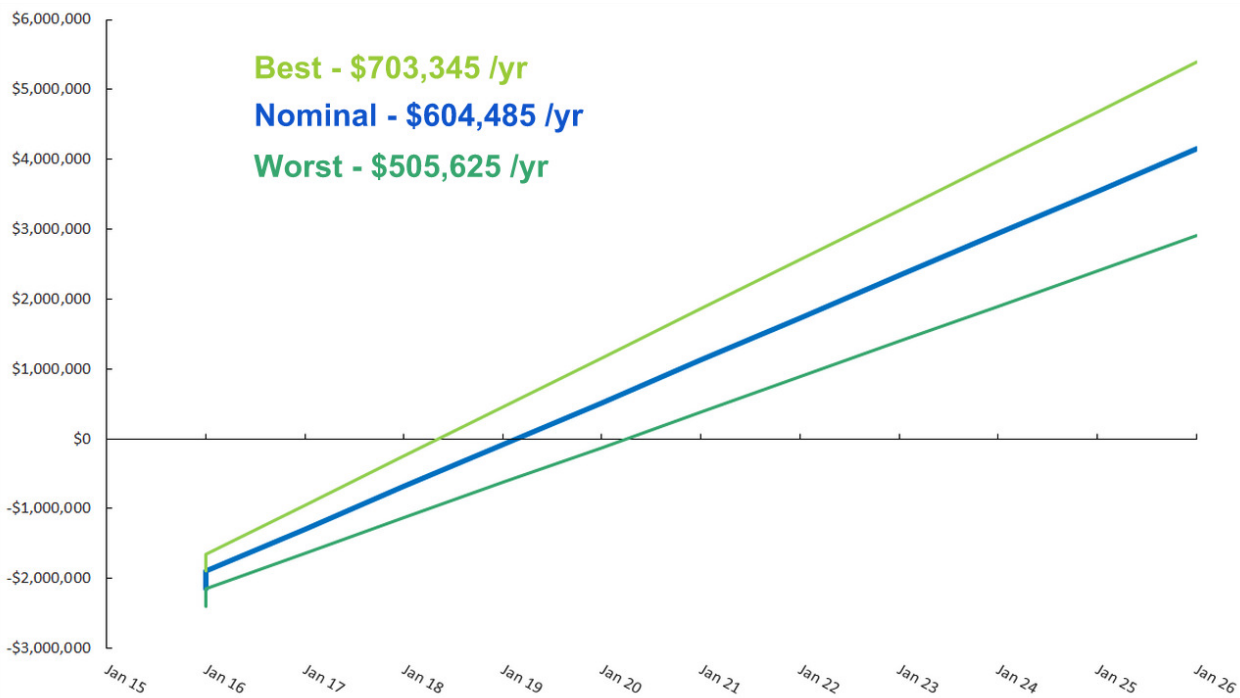
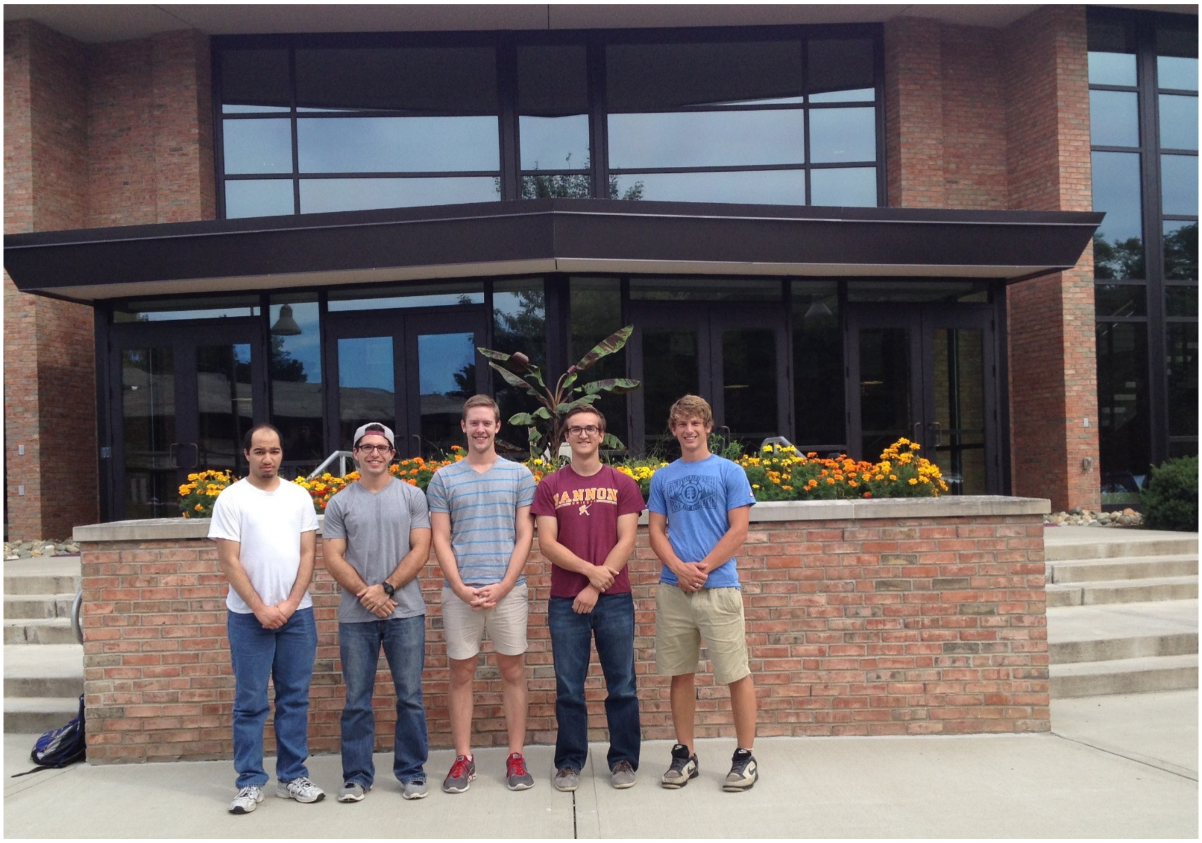


Figure 2. Total Savings Potential of Recommended Projects over a 10 Year Period

Appendix A.1 Team 1
Covenant Fine Arts Center



From Left to Right:

Zach Carney, Vincent Rovedatti, Caleb Meindertsma, Daniel DeVries, and Tobin Tarantowski

Introduction

The Covenant Fine Arts Center (CFAC) serves as a variety of venues for Calvin College. The CFAC contains offices, classrooms, practice and performance spaces, as well as large gathering spaces such as lobbies. The variety of operations performed by the building, as well as the large size of some of the spaces made it especially interesting from an energy efficiency standpoint.

Approach

Team 1 approached the building efficiency project from a variety of areas. Lighting, heating, ventilation and cooling all played roles in the savings opportunities. Another area that was explored for savings potential was replacement of the lighting systems within the auditorium. The last area that Team 1 explored was behavior changes in the practice rooms.

Results

The projects recommended for implementation in the CFAC along with the financial data associated with each are summarized in Table 3 and shown totaled graphically in Figure 3. See Appendix B for more information about the projects and the cost models utilized.

Table 3. Summary of Energy Savings Potential for Each Recommended Project

Project	*Initial cost ($)*	*Rebate ($)*	*Annual Savings ($)*	*Payback (yrs)*
Lighting	54,037.50	5,035.20	7,233.30	6.77
Reflective coating	6,354.00	1,200.00	2,488.00	2.11
Heat exchanger	103,522.00	0.00	20,997.00	4.93
Temp. Change	0.00	0.00	9,483.00	0
Totals	**163,913.50**	**6,235.20**	**40,201.30**	**3.92**

Discussion

As summarized in Table 3 the Calvin College would save around $40,000 annually by implementing all recommended projects in the CFAC. The cost of the initial investment would pay itself back in roughly 4 years. All the savings come from equipment changes since Team 1 considered multiple behavioral changes for the CFAC but ultimately found the savings to be negligible. Included in the lighting savings number is an operational change of reducing the time the hallway lights are on. The current system turns on at 5:40 am and stays on until 1:30 am. The proposed change would reduce this usage to 7 am to 12 am. The savings only adds up to a few hundred dollars annually so the savings are included in the total lighting number. There are no significant rebound effects anticipated as a result of this operational change.

Regarding measurement and verification, additional studies would increase the accuracy of the savings dollars expressed. Lighting sensors could be installed to obtain further data, however within our project, sufficient lighting data was obtained. Temperatures inside and outside of windows would allow the calculation to estimate heat flux and therefore improve the accuracy of the window model utilized. Taking temperature and airflow rates through the HVAC system would allow a more accurate cost savings to be generated from the heat exchanger model as well.

Several obstacles were encountered during the analysis of the CFAC. First, the CFAC underwent a major renovation in 2009 that updated most of the building's lights, HVAC systems, windows and mechanical equipment. This renovation was great for the building but meant that the energy savings were somewhat lower than they might have been previous to the renovation.
Second, the lighting in the auditorium was not included in the lighting calculations due to the extreme complexity associated with converting the 'starry night' light system to LEDs as well as the large upfront cost of switching the stage lights over to LED. The relatively low usage of the auditorium along with the lack of feasible technology available made the auditorium not worth looking into. As technology continues to advance, LED changeovers in the auditorium could become feasible in the future.

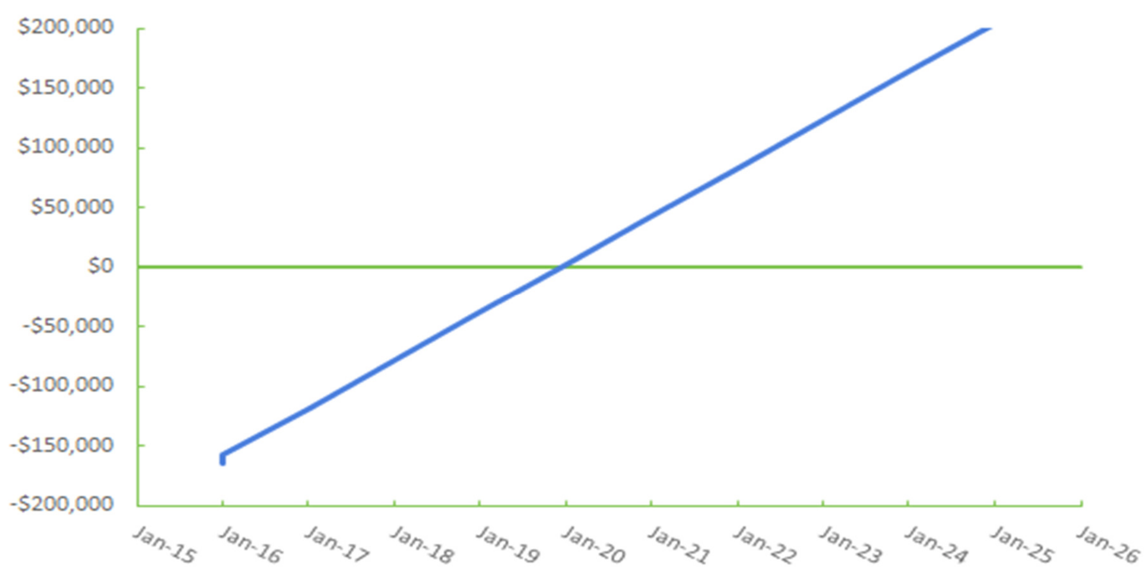


Figure 3. Total Savings Potential of Recommended Projects over a 10 Year Period

Conclusions

Given the age of the building with respect to others analyzed and considering recent updates to the building, the team was satisfied with the calculated annual savings of $40,000. These savings potentials largely came from updates to the HVAC system, but lighting and operational changes also contributed to the overall savings.

Appendix A.2
Kalsbeek-Huizenga-Van Reken (KHvR)

From Left to Right:
Hanfei Niu, Kemal Talen, Ayo Ayoola, and Dalton Veurink

Introduction

Kalsbeek-Huizenga-vanReken (KHvR) is the newest residence hall on campus. The Kalsbeek and Huizenga wings were built in 1988, while the vanReken wings were built in 2008. KHvR was designed with bigger bathrooms and more public areas than any of the other residence halls. As a result, there are lots of energy saving potentials through energy efficiency, operational and behavior changes.

Approach

The six projects that the team focused on this semester were: (1) lighting-delamping, (2) window-reflective coating, (3) heat recovery, (4) appliance reduction, (5) washing machine usage, and an (6) electricity usage website. The team did not recommend any operational projects.

Energy Efficiency Projects

Lighting-Delamping) This project replaces fluorescent light bulbs with LED bulbs, and also reduces the overall number of bulbs in KHvR. Because LED bulbs are twice as bright as the currently installed bulbs, it is possible to reduce the number of bulbs installed. The change to LED bulbs could reduce the bulb count by almost 50 percent in KHvR, thus reducing the energy usage by almost 75%. Energy cost savings were found using the light model (see Lighting Model Appendix B.1).

Window-Reflective Coating) This project adds low-E (low-emissivity) coatings onto every window of KHvR. The addition of the film reduces the amount of heat loss through the windows during the year. vanReken sees even more cost savings from this project because of savings in air conditioning energy during the summer months. Cost savings were obtained using the windows model (see Appendix B.4).

Heat Recovery) This project installs heat recovery ventilators in replace of existing exhaust fans. Heat recovery ventilators are multi-purpose fans that transfer heat from the stale air (exhaust) to the fresh air (intake). This saves energy in heating air during the winter and cooling air during the summer (for Van Reken). It also helps buildings meet ventilation requirements. Each wing of KHvR has two exhaust fans (6 total for KHvR). Cost savings were determined by using the CFM (cubic feet per minute) of each exhaust fan with the heat recovery model (see Appendix B.3).

Behavioral Projects

Washing Machines) This project uses posters to encourage students to use cold water for washes. The cost savings were determined based on survey results. The survey asked students, ‘would you switch from warm or hot water to cold water for washing?’ Out of 111 responses, 32 said they would.

Appliance Usage) This project reduces the overall use of appliances in KHvR by (1) having the sustainability coordinator periodically remind students of their usage and (2) placing posters that promote saving energy on dorm floors. The cost savings were determined by assuming a 10% reduction in appliance usage. Appliance usage rates were obtained through a survey.

Electricity Usage Website) This project uses a website to display electricity meter readings to students in ways that they would comprehend. The project is a collaborative effort between Student Senate, ENGR 333, and resident life. The website will 'go live' during 'Kill-a-Watt' as a way to help students monitor their progress. In the future, when the process of recording meters becomes more foolproof, savings incentives will be discussed with budget committee. The website can be viewed at www.energymonitor.x10host.com.

Results

The calculated saving results are presented in the figures and table below.

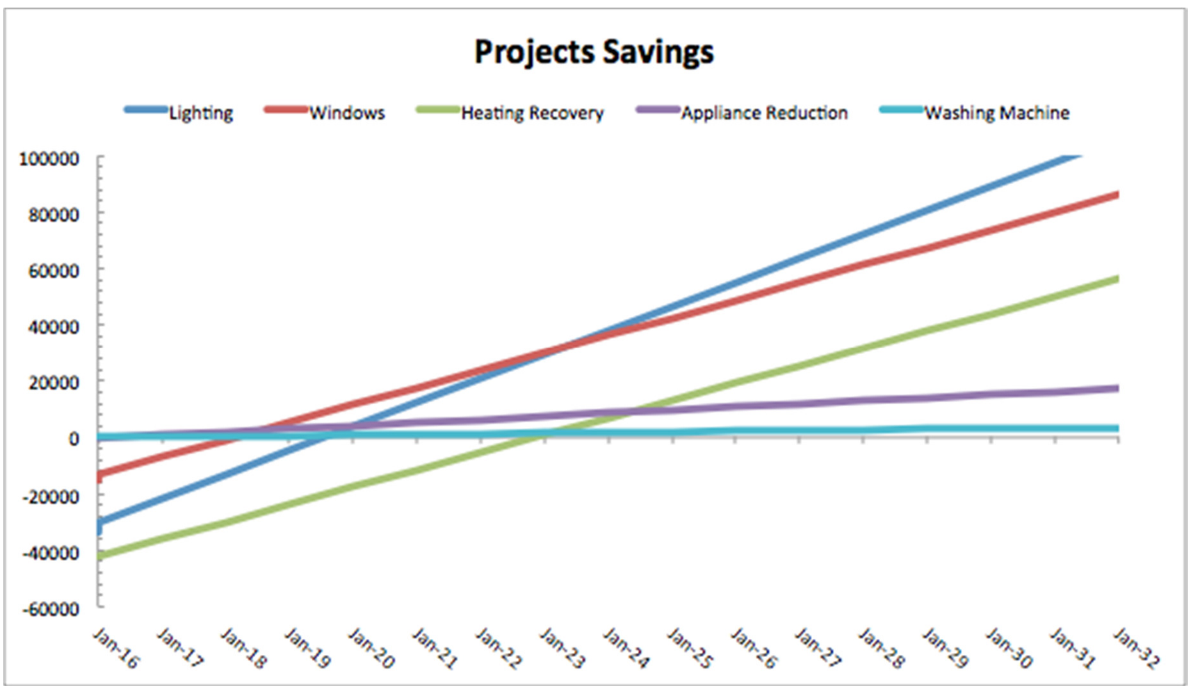


Figure. 4 Saving Summary for Projects

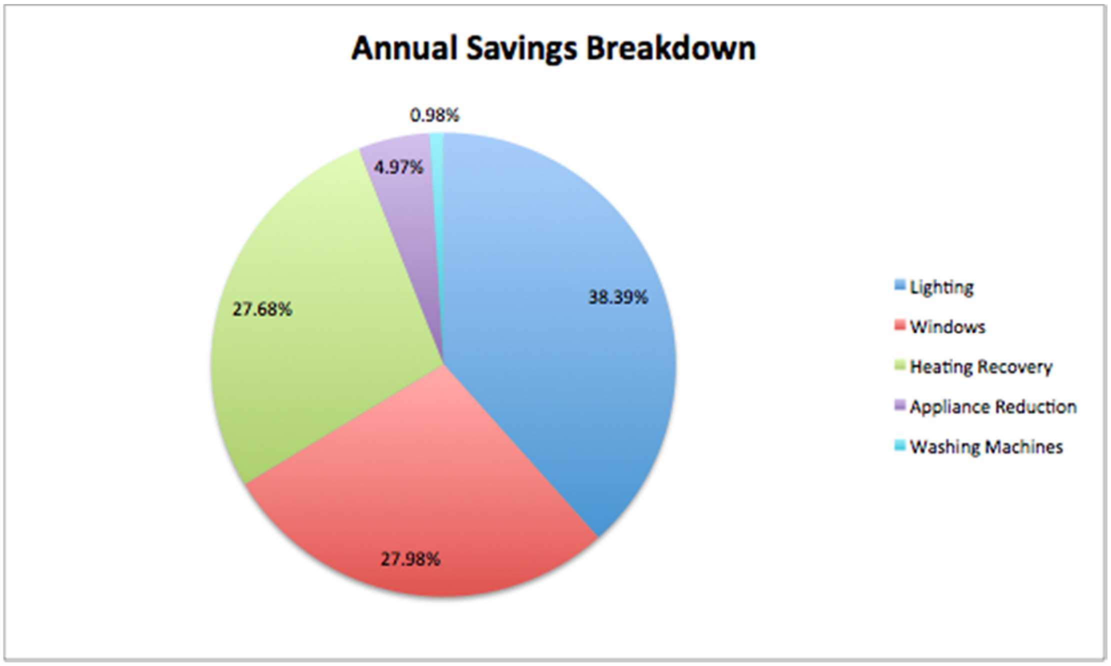


Figure 5: Breakdown of Annual Cost Savings by Project

Table 4: Summary Savings from Evaluated Projects

Project	*Initial Cost*	*Initial Cost Uncertainty*	*Rebates*	*Annual Savings*	*Savings Uncertainty*	*Payback Period*
Lighting (Delamping)	$ 33,600	$ 1,538	$ 3,565	$ 8,522	$ 970	3.52 years
Windows (Reflective Coating)	$ 15,163	$ 2,274	$ 1,859	$ 6,210	$ 348	2.14 years
Appliance Reduction	$ 270	$ 0	$ 0	$ 1,103	$ 100	0.5 years
Heating Recovery	$ 42,144	$ 3,000	$ 0	$ 6,144	$ 630	6.86 years
Washing Machines (Behavioral)	$ 0	$ 0	$ 0	$ 218	$ +66.5/-35.5	0 years
Total	**$ 91,177**	**$ 6,812**	**$ 5,424**	**$ 22,197**	**$ 2,118**	**3.8 years**

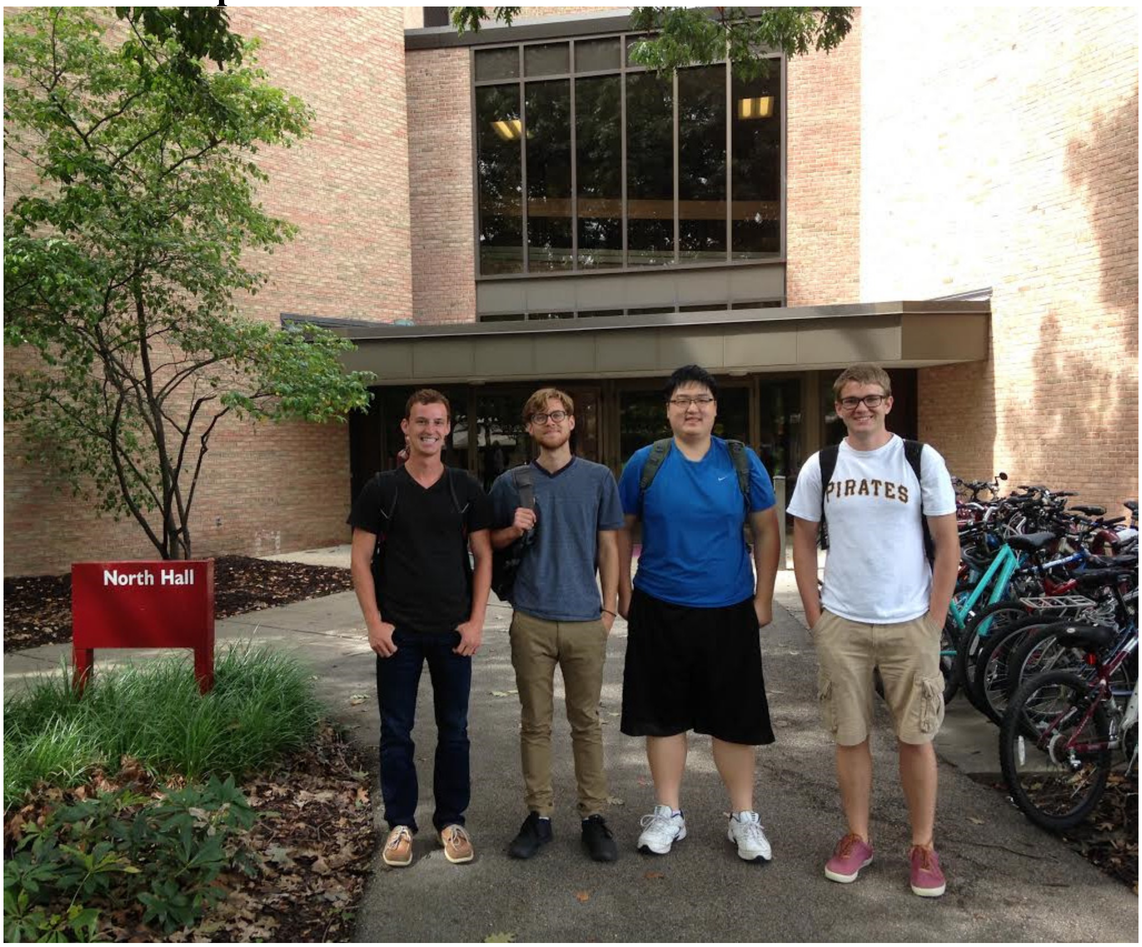
Discussion

The total initial cost of all recommended projects is around $91,177 with a rebate of around $6,812. The predicted annual savings for KHvR is around $22,200 /year with a payback period of about 3.8 years. The majority of the savings come from the lighting project. The energy usage monitoring website will be implemented as soon as possible, but was not included in savings due to the open-ended nature of the project.

Conclusions

For KHvR, 92% of the savings come from energy efficiency projects. However, the behavioral projects have the shortest payback period and smallest initial cost. The projects the team recommends are not limited to KHvR, but can be applied to all dorms. There are seven dorm buildings on Calvin campus; the saving potentials from implementing these projects in all of them would be very large.

Appendix A.3
Science Complex



From Left to Right:
Mitch DuBois, Jacob Milhorn, Joseph Cha, and Andrew Bouma

Introduction

Team 3 chose the Science Complex, which consists of North Hall, the Science Building, and Devries Hall. The sheer size of this complex made several sweeping efficiency initiatives quite fruitful according to the models developed by the class. However, the broad scope of the complex also allowed for some unique changes that likely would not have made nearly as much of an impact in other buildings.

Approach

There were primary categories into which the cost savings projects were divided: lighting, heating ventilation and air conditioning (HVAC), operational changes, and behavioral changes.

Within the Science Complex, there are many light fixtures that could either be de-lamped, or completely replaced. Either option has potential to save on lighting costs, however not all fixtures justify the initial investment to replace them. For this reason, a balance of the two methods reaps the most benefit.

HVAC cost savings were broken down into three categories: windows, thermostat change, and heat recovery ventilation (HRV). For each, a model of the thermodynamic scenario was developed and savings decisions were extracted. For instance, the windows model output the savings numbers for multiple avenues and upon comparison of each, a decision was made as to which would yield the highest savings.

Changes to save on operational costs were also considered for the Science Complex. One opportunity involved reducing the housekeeping frequency in areas that are cleaned every day and do not seem to need daily cleaning. The daytime and nighttime housekeeping managers were consulted to determine the number of workers they employ and how many hours a week are worked. A general worker-hour reduction of one-sixth and one-third were both considered, and a reduction of one-sixth was recommended.

Finally, energy efficiency improvements would be incomplete without behavioral changes. Although behavioral changes involving students would be much more beneficial in the dorms, faculty and staff behavioral changes could be very helpful in the Science Complex. Reducing the number of appliances in faculty offices was recommended, based on a relatively recent survey conducted by the provost’s office which indicated significant savings were possible.

Results

Table 5. Final Savings Projections for Science Complex

Project	Initial Cost	Rebate	Annual Savings	Payback Period
Lighting	$156,654	$22,523	$20,759	6.46 years
Windows	$14,223	$3,311	$6,495	1.68 years
Heat Recovery	$200,190	$2,275	$32,974	6.00 years
Thermostat	$0	$0	$15,896	0 years
Housekeeping	$0	$0	$10,867	0 years
Office Appliances	$0	$0	$4,100	0 years
Total	$371,067	$28,109	$91,091	3.77 years

Discussion

On a per fixture basis, lighting savings are low for fixtures in closets, bathrooms etc. It was therefore our recommendation that fixtures are only replaced in high usage areas, or where de-lamping is not feasible. For a detailed description of the assumptions made, see Appendix B.1.

The window savings are estimated based on a low-e and reflective film applied to all Science complex windows. The thermodynamic analysis is seen in Appendix B.4, as many assumptions were made in order to get the results.

Heat recovery model uses building exhaust data for the science complex that was collected from the original building plans. Since DeVries Hall already uses an HRV system, it was excluded from the analysis. The assumption made is that the collected data holds accurate even though the building has been renovated and the exhaust system potentially altered.

The thermostat adjustment cost savings are estimated by using a ratio of square footage of the science complex to the square footage of the campus as reported on last year's utility bill.

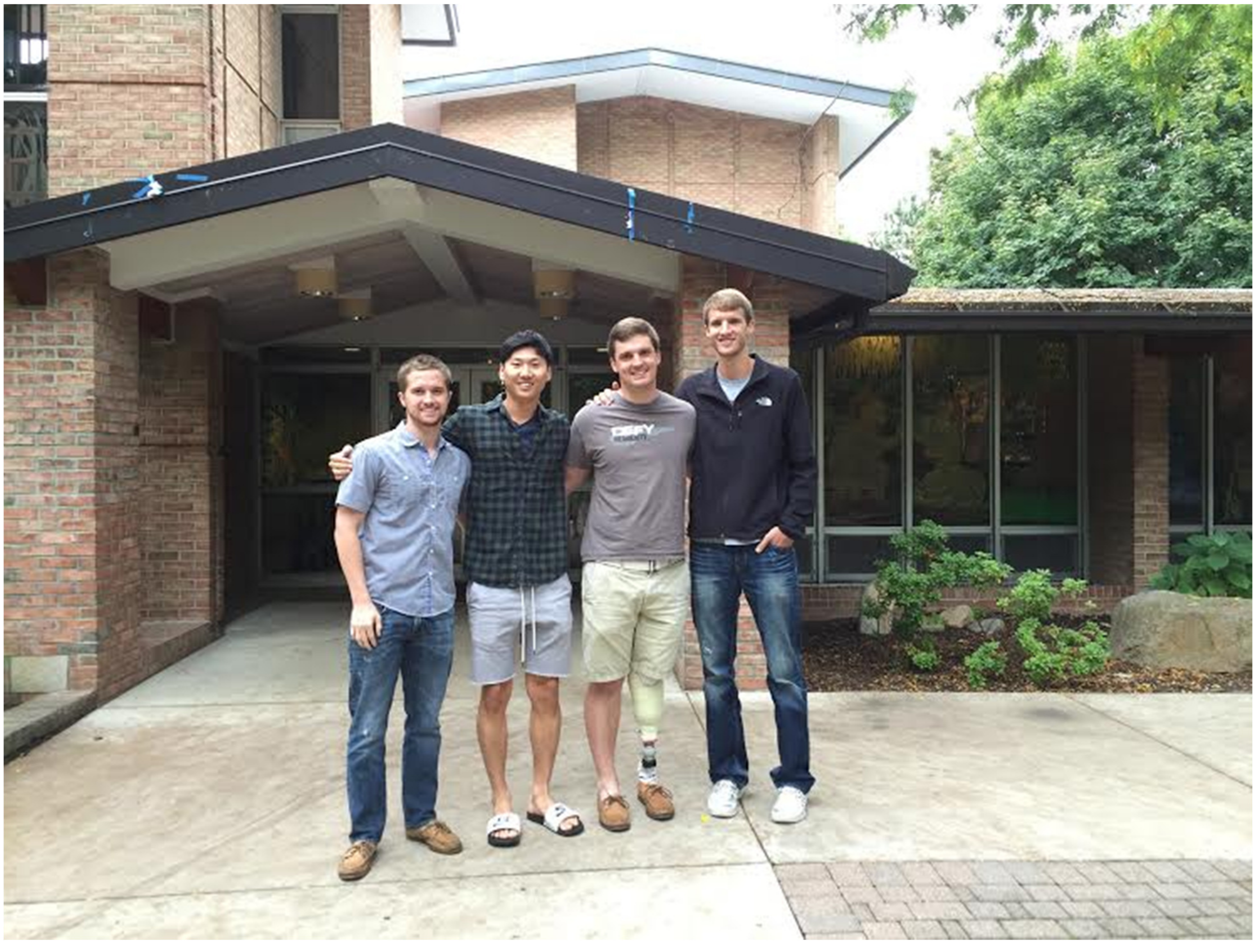
Housekeeping cost savings were analyzed by using collected information on APPA standards and Calvin housekeeping hours. Our primary assumption is that a small reduction in cleaning will be negligible in terms of the buildings overall cleanliness. This assumption works because they clean to freaking much as it is.

Finally, the faculty appliance cost savings were calculated assuming that all major appliances are banned from offices.

Conclusions

Lighting and HVAC led the way for cost savings in the Science Complex. This leaves much room for further savings in operations in the Science Complex.

Appendix A.4
Schultze-Eldersveld



From Left to Right:
Lance Jensen, Se Ge Jung, J. Alex Karr, and Stephen Lander

Introduction

Team 4 chose the dorms on the south side of the Knollcrest Way as its building operational project. Specifically, the team focused on the dorm, Schultze-Eldersveld. Since the dorm is relatively small when compared to other academic buildings, the team expected the savings to be less than the other group's savings. The team brainstormed many ideas on how to save energy and reduced the number down to the best ideas to analyze.

Approach

The team chose different systems to analyze. These systems included lighting, heating, ventilating, and air conditioning (HVAC), water, and behavioral changes. The lighting consisted mainly of changing all light bulbs to LED's with some fixture replacements. Also, since LED's appear brighter than the existing fluorescent lights, the analysis included removing as many bulbs as possible while providing enough light still. The HVAC included a revolving door, reflective coating, and heat recovery ventilator. The water included new and more efficient toilets. Finally, the behavioral side of this project included a key card lighting system to decrease the wasted energy lighting unoccupied rooms and decrease shower times to save on heating water.

Results

For the lighting analysis, a "light model" was created by the lighting cross team which would calculate the savings along with the payback period. The payback period for this project would be 4.4 years. This project is highly recommended to implement as soon as possible.

There were three projects pertaining to HVAC: revolving doors, windows with reflective coating, and heat recovery ventilation. A study of revolving doors at MIT improved the team's understanding of the impact of energy usage. Revolving doors can save ⅞ of the energy that swinging doors waste. Another project modeled windows with reflective coating material with low emissivity. The team also looked at replacing the existing fans with a heat recovery ventilator. However, it is not a recommended project as the payback period is around 12 years.

Currently the toilets in the dorms take 2.5 gallons of water per flush. A new system would include a two flush system: low flow and high flow flush. The low flow flush would be used for less bulky materials and would use only 1.1 gallons per flush. The high flow flushing process would be used for bulk material and would use 1.6 gallons per flush.

The behavioral projects included an ID card for lighting and decreasing shower times. The ID card project would require students to insert their student ID's in order to turn on the lights. As for as using this in the dorm rooms the savings would not be worth the initial investment. Since the basement dorm lights are on almost 24 hours a day, 7 days a week, implementation in the basement is recommended. The average shower on Calvin's campus is 7.7 minutes long. There will be savings if this were to decrease down to 5 minutes. These timers would need to count down in order to keep students from having competitions as to how long they could keep their showers running. The project confirmed that part of being a good steward is sustaining and using energy efficient than a year. The list of projects and costs, along with savings, are shown in Table 6 while the overall rebates, initial costs, and savings are shown in Figure 6.

Table 6: List of projects with recommendations and costs

Projects		Initial Cost [$]	Rebate [$]	Annual Savings [$]	Payback Period [years]
Lighting	Delamping	56,835	8,870	10,894	4.40
	ID Card Basement	4,746	896	1,843	2.09
Behavioral	Shower Time Reduction	320	0	409	0.78
	Appliances	280	175	1,036	0.10
HVAC	Revolving Main Door	5,000	210	1,250	3.83
	Reflective Coating	0	0	1,036	0.1
Total		67,181	10,151	16,468	3.46

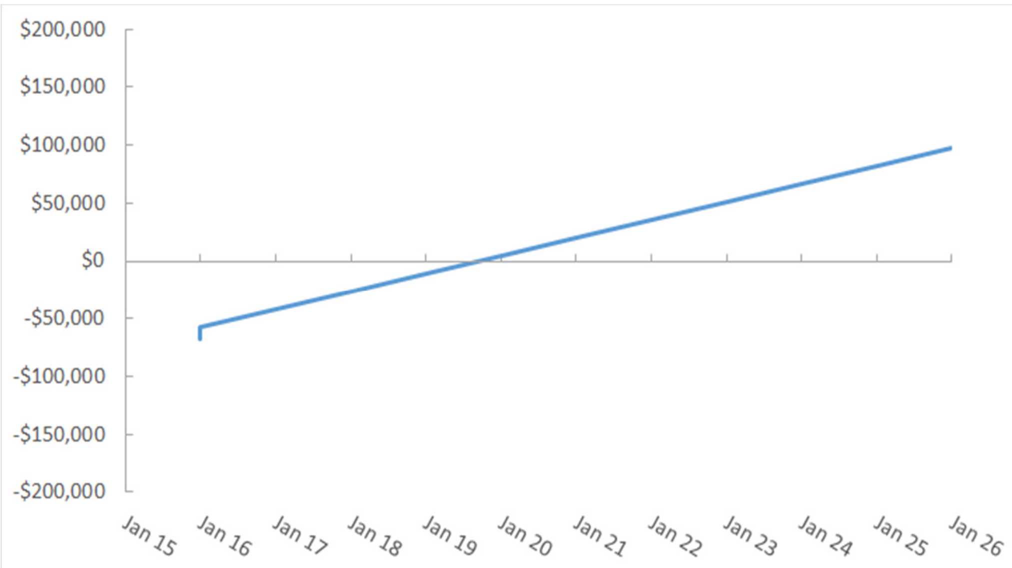


Figure 6: Overall savings for recommended projects

Discussion

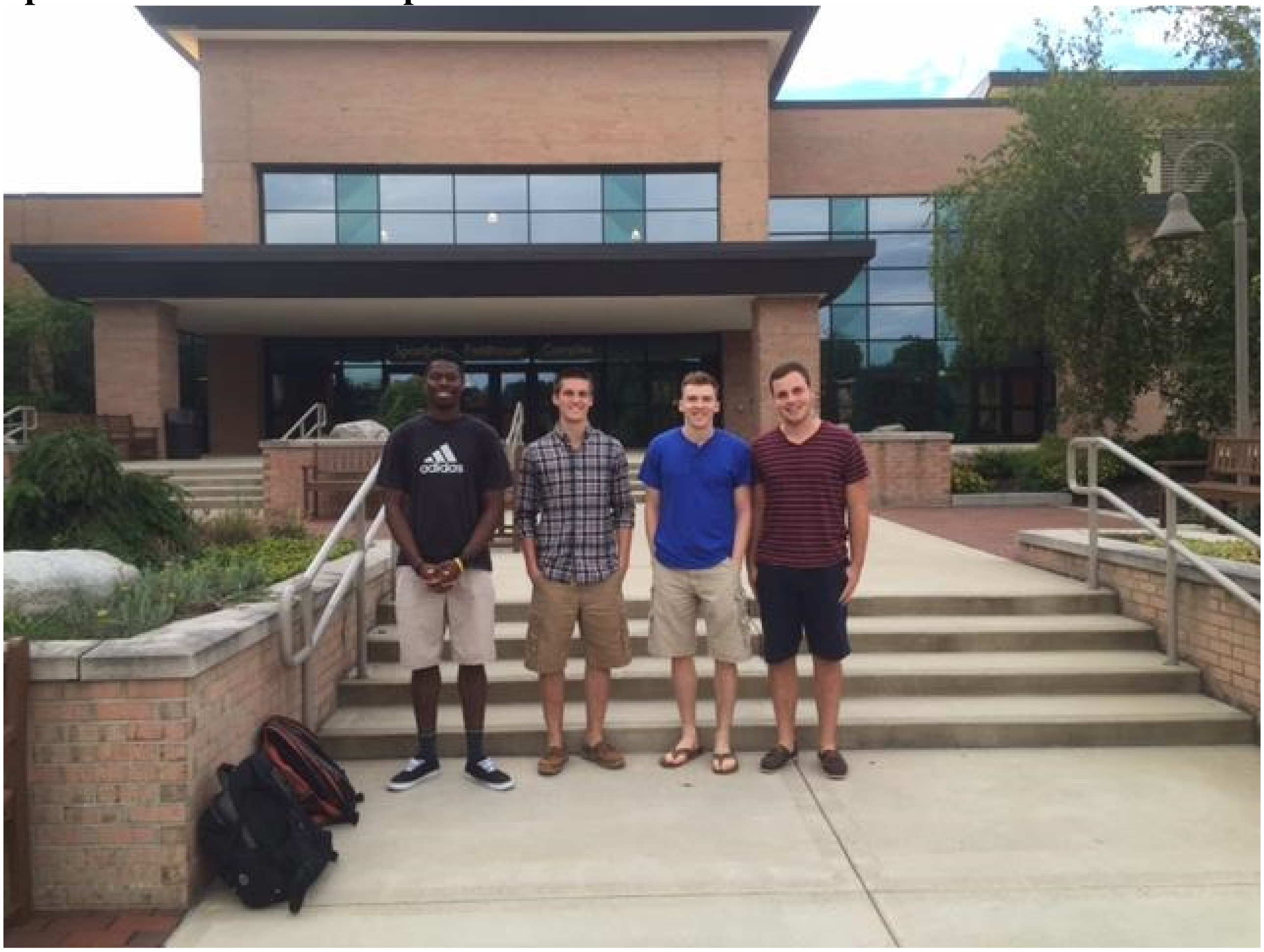
The lighting models would be verified using hobo light sensors. The sensors will verify the time the lights are on and the occupancy. For the revolving doors, flow sensors and door opening sensors may be utilized to verify the amount of heat escaping. The effectiveness of the reflective coating will be measured by temperature sensors.

It is worth mentioning about some of the rebound effects of projects. The low flow toilet implementation may lead to students hitting the button more than once. The ID key card implementation may allow students to bypass the system by placing generic key cards in the slots causing the lights to remain on. A rebound effect might be that students leave lights on longer because they know LED's are more efficient.

Conclusions

This project allowed the team to realize the potential energy savings by analyzing a certain building on Calvin College's campus. Also, this project made the team conscious of using unnecessary energy. We believe there is huge potential for savings through behavioral changes

Appendix A.5
Spoelhof Fieldhouse Complex



From Left to Right:
Justin Cooper, Zach Veenstra, Ross Tenney, and Phil Van Strien

Introduction

Team 5 selected the Spoelhof Fieldhouse Complex (SFC), which includes Van Noord Arena, Venema Aquatic Center, Huizenga Track and Tennis Center, Hoogenboom Health and Recreation Center, Morren Fitness Center, and the Calvin Climbing Center. This is one of the largest building complexes on campus, as well as one of the newest. Most of the sub-buildings were built or renovated in 2009. The young age of the building meant the technology was relatively new, which reduced the opportunities for savings, but because of the size of the building, it is one of the biggest users of energy.

Approach

Team 5 investigated a variety of project savings initiatives within the SFC. The first step involved research on the STARS website for project ideas from other colleges and universities as well as initial walkthroughs of the Spoelhof Fieldhouse Complex. The team compiled an exhaustive list of project ideas based on these two investigative approaches. After meeting with Phil Beezhold and Jack Phillips, the project list was shortened to focus on project initiatives that were feasible as well as had the greatest savings opportunities.

Lighting - LED Conversion

A LED lighting model developed by the lighting team, which is described in Appendix B.1, was used for the hallways and offices located in the SFC since these lights are scheduled on consistently from 5:45 a.m. to 1:00 a.m. This determined the potential savings for changing fluorescent and incandescent bulbs to LED bulbs or delamping which is simply the removal of a certain number of bulbs from a fixture. In most cases, delamping was possible, and because of the lower installation cost of this method, it was recommended over replacing fixtures. Some hallways, particularly those around the Hoogenboom center, would benefit from an update in lighting because the light is very yellow and unappealing. CERF already converted the lights in the Aquatic Center and Track and Tennis Center.

Windows-Reflective Coating

One of the models developed by the HVAC team determined the cost savings from installing low emissivity films to the windows to reduce solar heat gain in the summer and reduce IR heat loss during the winter. This model is detailed in Appendix B.4. These coatings would be most effective in the Aquatic Center, which is because the temperature in that building is kept at about 80°F, which is much higher than the rest of the complex. However, these films also produce good savings throughout the building and have a relatively low cost of implementation.

Heat Recovery Ventilator

The heat recovery ventilator cost savings model described in Appendix B.3 was used by Team 5 to estimate the possible savings in the SFC. The HVAC team recommended implementing heat recovery ventilators only in new buildings or large buildings, which includes the SFC. Since many fans and a high rate of airflow are required as part of the HVAC system in the fieldhouse, it would be worthwhile to implement heat recovery ventilators to save on heating and cooling costs. For simplicity, the team calculated the savings of implementing 5 ventilators, which includes one for each of the Arena, Aquatic Center, fieldhouse lobby, Track and Tennis Center, and Hoogenboom

Center. In reality, there are likely more fans than this in the complex, so the potential savings could be even higher.

Thermostat Change
One of the biggest potential savings initiatives that Team 5 investigated was changing the temperatures that the building is heated and cooled to. This model is described in detail in Appendix B.2. The temperatures would be changed from 70°F in the winter to 69°F and from 72°F in the summer to 75°F. The size of the building requires a great deal of energy required for heating and air conditioning, which is one of the biggest reasons for the high savings potential from this initiative.

Behavioral - Shower Time Reduction
Team 5 also investigated water usage within the fieldhouse. Since the most of the toilets were already low gallons per flush and showers were low flow options, the next initiative the team focused on was reducing shower times in the locker rooms to 5 minutes. The team used shower data from CERF for average shower time, water temperature, and flow rate from the dormitories with small alterations for the fieldhouse locker rooms. The behavioral change would be implemented in the men's, women's, family and team locker rooms with the number of showers per year based on sports team shower utilization during their respective seasons and general public shower use. The savings would be from both water usage reduction and the cost of heating the water from natural gas. The initial cost would be from implementing countdown timers shown in Figure 7 next to each shower. A possible rebound effect from count up timers would be students avoiding the 5 minute mark and pushing shower times to see how long they can go. By implementing countdown timers, the only notification is when the 5 minute time is complete to hopefully mitigate the rebound effect. As a behavioral change, shower time reduction savings in the fieldhouse will ultimately be determined by the students and public obedience to the 5 minute shower times. However, the measurement and verification of savings would be from CERF implementing shower gauges throughout the year as currently done in the dorms and KE apartments.

Figure 7: Countdown Shower Timers[1]

Legacy Lighting Restrictions

Another project initiative involved restricting the usage of the lights within the trophy cases, shown in Figure 8 and on the hall of fame plaques, which the team termed as "legacy lighting." Currently the trophy case lighting is linked to a motion sensor; however, since the area in front of the trophy cases is heavily utilized, these lights are on a majority of the day. The team assumed the lights were on 5100 hours per year. The hall of fame plaques were on with the same lighting schedule with the rest of the building from 5:45 a.m. to 1:00 a.m. The recommended usage for the legacy lighting would be only during sporting events and other major public activities, which was analyzed to be 390 hours per year.

[1] https://www.inkhead.com/eco-water-saver-shower-timer/14729/?reftypeid=11&adpos=1o2&creative=58961556743&device=c&matchtype=&network=g&gclid=CI7Vv6ezmckCFYM_aQodg_AMAQ

Figure 8: Legacy Lighting within the Spoelhof Fieldhouse Complex

Game Lighting Restrictions

Team 5 also looked into the game lighting within both the Venema Aquatic Center and Van Noord Arena. Currently, there are 50 1 kW performance lights in the Venema Aquatic Center, shown in Figure 9 and 52 1 kW performance lights in the Van Noord Arena, shown in Figure 10. The team noticed during walkthroughs that these performance lights were on even when sporting events and/or swimming meets were completed. This time when the lights are on is a waste of electricity and energy as well as utility costs. In order to determine how overused the lights were, the team placed light sensors in the Aquatic Center as well as other various locations within the fieldhouse. After an extended period of acquiring data, a graph of the lighting usage for the Venema Aquatic Center was composed as shown in Figure 11. From this graph, the team was able to determine the amount of hours that the performance lights were overused on average during the year. The recommendation would be to only have the performance lights on in Venema Aquatic Center and Van Noord Arena strictly during sporting events.

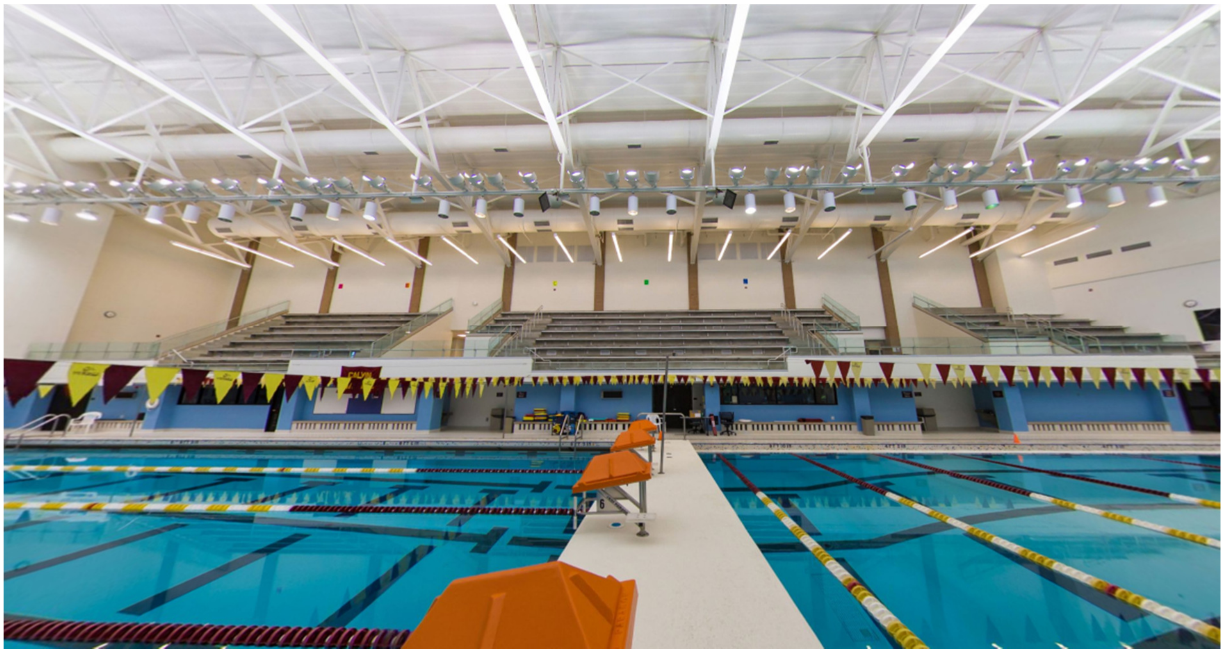


Figure 9: Performance Lighting within the Venema Aquatic Center

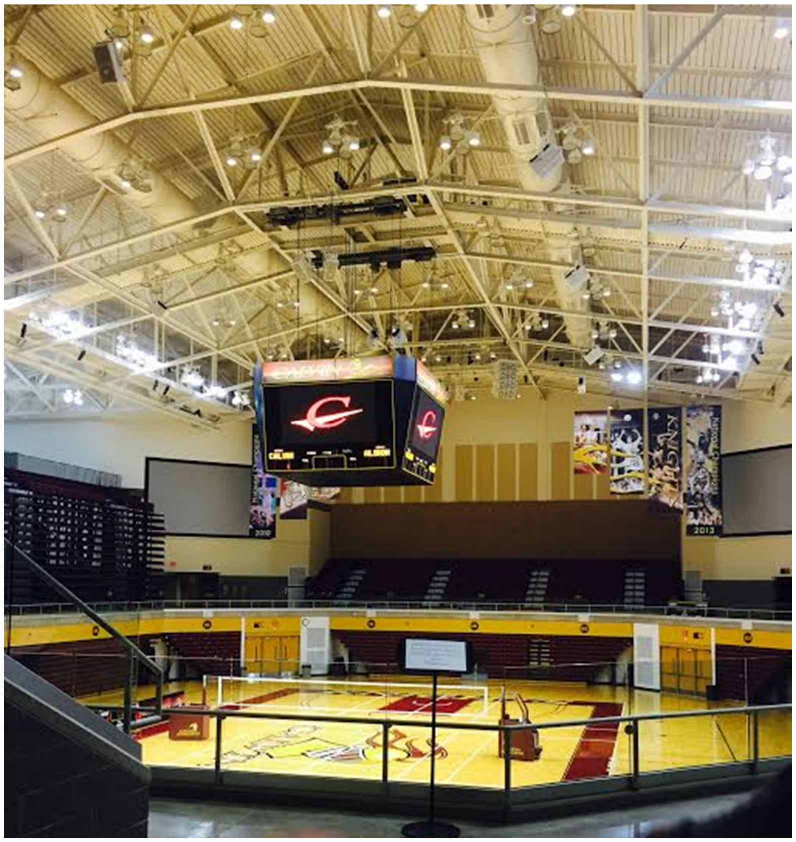


Figure 10: Performance Lighting within the Van Noord Arena

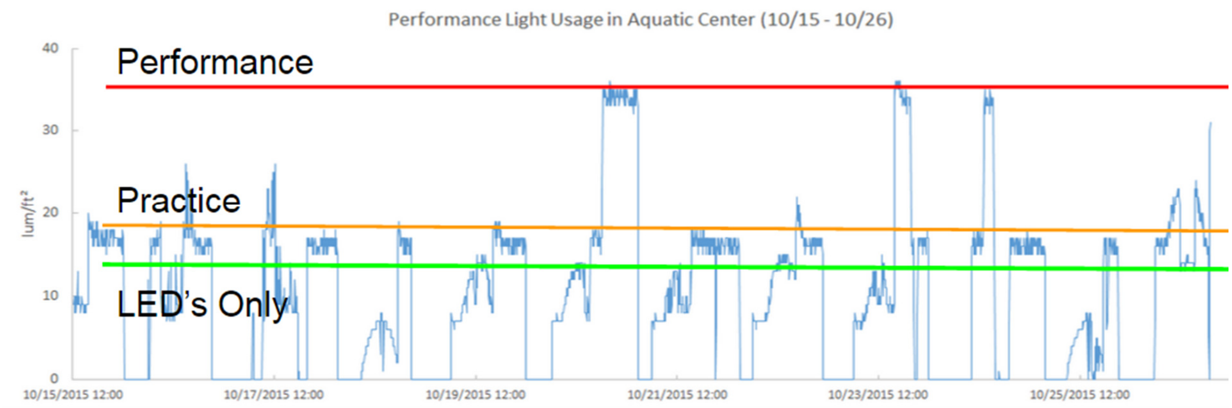


Figure 11: Lighting Sensor Data for Venema Aquatic Center

Aquatic Center Practice Lighting Reduction

Team 5 noticed that the practice lights in the Aquatic center were on a lot of the time, even when there weren't people in the pool. The practice light setting was 2 of every 5 1 kW performance lights on at a time. These lights originally were only intended for swim team use during practice. The reality was that these lights were used for many times outside of practice. Team 5 proposes that the use of these lights are reduced back to being used for practices only before events. Figure 11 above shows the levels of lighting in the aquatic center and when the practice lights were on. Over an 11 day trial period, the lights were on for an average of 8.5 hours a day. This number can be reduced greatly.

Pool Cover

The final project initiative within the Spoelhof Fieldhouse Complex is implementing a pool cover within the Venema Aquatic Center for overnight use. Since currently there does not exist a pool cover large enough for an Olympic-sized pool, the pool cover will incorporate four sections to cover the pool, which also allows for customized pool coverage. Larry Van Hoe was contacted in order to acquire pool data including water temperature, air temperature, relative humidity, and water volume. The data was used in order to calculate the evaporation rate of water from the pool and heat supplied to the pool. Based on the assumption that around 50% of the utility bill comes from heating, cooling, and ventilation,[2] the amount of energy for producing the make-up air inside the aquatic center was determined. Savings from the pool cover were from water reduction, assumed to around 40% reduction (range of 30-50%),[3] pool water heating costs, assumed to be around 60% savings (range of 50-70%),[4] and make up air reduction from the air-conditioner, assumed to be 50%. The capital cost would be from the pool cover costing $2.00 per square foot for the four sections.[5] However, Calvin College would receive a rebate of $6,728 for the pool cover. [6]

[2] http://energy.gov/energysaver/tips-heating-and-cooling
[3] http://www.energy.gov/energysaver/swimming-pool-covers
[4] http://www.energy.gov/energysaver/swimming-pool-covers
[5] http://www.recreonics.com/thermal_pool_covers.htm
[6] https://www.consumersenergy.com/eeprograms/BHome.aspx?id=5425

Results

Through the use of each of the models mentioned previously, the following results of projects and the savings from them was generated. This can be seen in Table 7 below.

Table 7: Project Costs, Savings, and Payback Periods

Project	Initial Cost	Rebate	Annual Savings	Payback Period
LED Lighting Conversion	$ 94,120	$ 14,620	$ 8,768	9.07 years
Windows - Reflective Coating	$ 7,740	$ 1,461	$ 9,009	0.70 years
Heat Recovery	$ 33,195	$ 0	$ 4,732	7.02 years
Thermostat Change	$ 0	$ 0	$ 31,500	0 years
Behavioral- Shower Time Reduction	$ 482	$ 0	$ 373	1.29 years
Legacy Lighting	$ 0	$ 0	$ 750	0 years
Game Lighting Restrictions	$ 0	$ 0	$ 1,500	0 years
Aquatic Center Practice Lighting Reduction	$ 0	$ 0	$ 3,374	0 years
Pool Cover	$ 27,000	$ 6,728	$ 18,073	1.12 years
Totals	**$ 162,537**	**$ 22,809**	**$ 78,079**	**1.79 years**

Overall there are huge savings opportunities in the Spoelhof Fieldhouse Complex. With a total investment of $162,537± $8,186 and total savings of $78,079± $10,736 a year with a payback period of just under two years. This can be seen graphically in Figure 12 below.

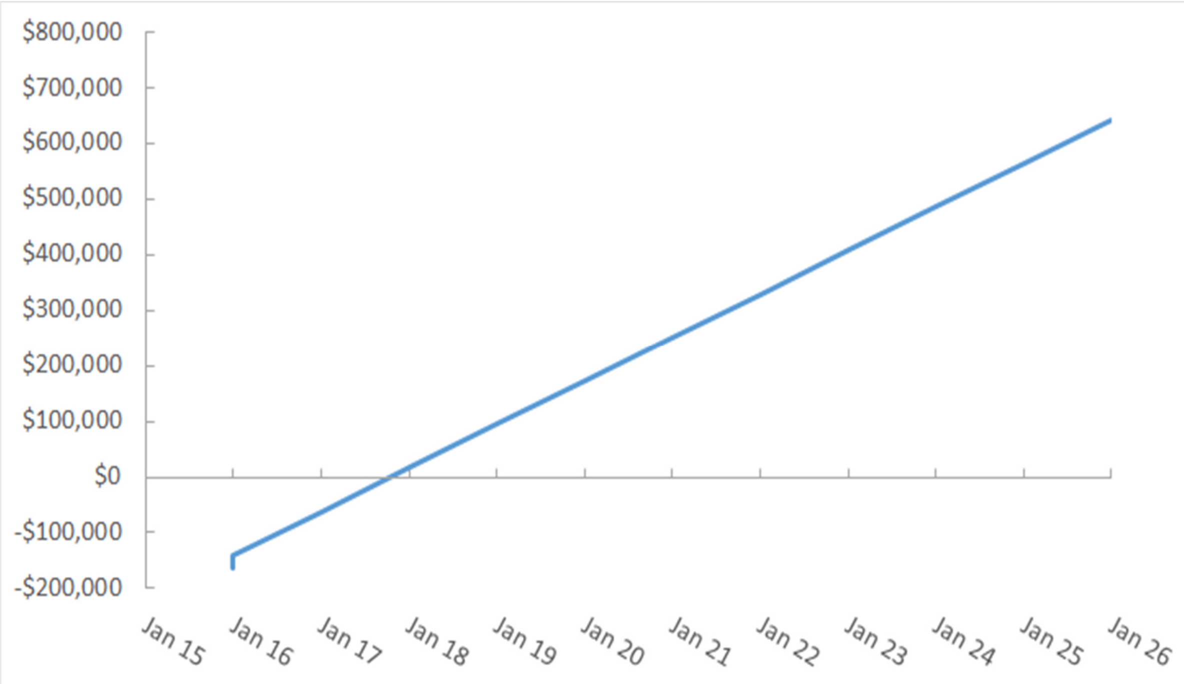


Figure 12: Total Savings Graph for Spoelhof Fieldhouse Complex

Discussion

These results were achieved through a large amount of time and effort put into each respective models and the savings shown by them are a good indicator of what can be done to help improve Calvin's sustainability through some operational changes. Although more projects were investigated than shown above, the cutoff for recommended projects was dictated by payback periods of 10 years. LED conversion within the fieldhouse is an expensive project with a rather long payback of about 9 years. This project is recommended as it fits within our payback cutoff and has relatively good savings. The next project was adding a reflective coating to the windows. This project could be extremely beneficial with savings of around $9000 a year with less than a year payback. This would be especially beneficial to implement in the aquatic center as the difference in inside to outside temperature in the winter is much greater than other parts of the building. Adding Heat Recovery Ventilators is one of the projects that is rather expensive to implement, but will be paid for with its savings within 7 years. It is suggested that this project be looked into further, as there is opportunity for more ventilators to be added than what was accounted for in the results above.

There are several projects that have no initial costs and have reasonable savings, so they would be crazy not to implement. The largest of these savings comes from the thermostat changes. If Calvin changes its summer and winter temperatures to match that of Western Michigan University, savings of $31,000 a year could be achieved. Other simple savings could come from the closer monitoring of the large performance lighting within the aquatic center and main gym. These lights should only be used for events. This could produce a sum of savings of around $5000 dollars a year.

A final project that should be considered is the addition of a Pool Cover that will be used during the nighttime hours to prevent heat loss and humidity changes. This project could save $18000 a year with a large rebate which would pay itself off in just over a year. There was question whether or not this project would be implement due to safety concerns, but these issues should be able to be quickly resolved through several signed waivers of the employees that have to administer the pool cover in the mornings and evenings.

Conclusions

The Spoelhof Fieldhouse Complex is one of Calvin's iconic buildings. It receives much attention and recognition due to the sporting events that occur there. This being said, it is important that the building is operated as efficiently as possible so that the people that visit the building can recognize Calvin College for its sustainability efforts. There are large savings opportunities available in this building with an average payback period that is excellent. Team 5 recommends that each of the above projects be implemented in the coming years to help Calvin reach its goals in operational efficiency.

Appendix A.6
Extra Buildings

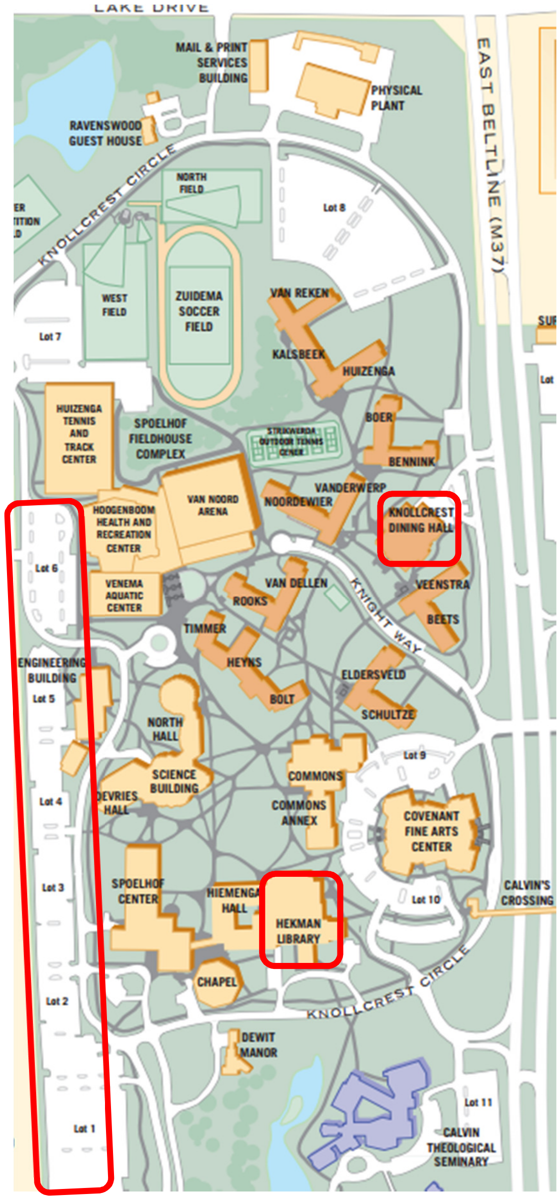


Figure 13: Extra Buildings Project Initiatives on Calvin College's Campus

Introduction

This appendix addresses the work accomplished by the extra buildings team, one of the four major cross-cutting teams for the Engineering 333 Operational Efficiency project. After the initial class breakdown into five major buildings, the extra buildings cross-cutting team was assembled in order to investigate savings opportunities in other locations on campus outside of the original five buildings. The team focused on three additional project initiatives on campus: Hekman Library, Knollcrest Dining Hall steam boilers, and parking lot lighting, as shown in Figure 13.

Approach

The extra buildings team tried to concentrate on extra buildings initiatives that were not originally in the scope of the five building teams. While there were numerous options for extra projects around campus, the team focused on three different projects involving another heavily utilized building, a component of an on-campus power plant, and a non-building initiative. Analysis was done and calculations were accomplished for each project initiative.

Hekman Library

One of the extra building project initiatives was the Hekman Library. The main areas focused within the library are the significant number of lights and windows within library, as shown in Figure 14. As this building is one of the most utilized buildings on campus, the lights are on a total of 3900 on peak hours and 600 off peak hours per year. The fifth floor alone had 661 lighting panels. The lighting project utilized the lighting model to determine the energy and cost savings for delamping and replacing the lights with LED alternatives. The extra buildings team also looked into windows for the Hekman Library. The windows model was also utilized in order to determine the savings by adding reflective coating to all the windows.

Figure 14:Hekman Library

Knollcrest Dining Hall Steam Boilers

The second project initiative investigated by the extra buildings cross-cutting team involved two Knollcrest Dining Hall steam boilers. The two large steam boilers are used for heating the dorms north of Knight Way: NVW, BV, BB, KHvR, as well as Knollcrest Dining Hall and its kitchen steam. The boilers are dated from 1962 and are rated at 225 HP and 6.5 MBTU/hr and operating at 10 psi and 240 degrees. In order to determine the savings, the NIPSCO boiler savings analysis worksheet was utilized.[7] Assuming that the steam boilers are powered draft, the seasonal efficiencies were determined based on age from the NIPSCO boiler type, age, and efficiencies table in Figure 15 to be 67% currently and 79% for the new replacements. Also based on the NIPSCO chart for heating application in Figure 15, the assumption was made that steam boilers are run as process boilers with 6000 operating hours and a load factor of 0.75. The cost of natural gas was determined to be currently 49¢/therm.[8] Equation 1 was used to determine the annual savings from replacing the current two steam boilers with new alternatives.

$$Savings_{annual} = E\left(1 - \frac{\eta_{seasonal,old}}{\eta_{seasonal,new}}\right) op_{hours} f_{load} Number_{boilers} Cost_{natgas} \quad \text{[Eq 1]}$$

7 http://tradeallyinfo.com/wp-content/uploads/2013/05/nipsco_boiler_calc_sheet.pdf

8 https://www.mge.com/customer-service/home/gas-rates-res/faq.htm

Table 1: Boiler type, age and efficiencies

Boiler Type - Age	Thermal Efficiency	Seasonal Efficiency
Standard Boiler - Natural Draft		
5-10 years old	77	75
10-20 years old	74	72
20-30 years old	71	69
30-40 years old	68	66
Steam Boiler - Powered Draft		
New	81	79
5-10 years old	78	76
10-20 years old	75	73
20-30 years old	72	70
30-40 years old	69	67
Hydronic Near Condensing Boiler		
5-10 years old	85	83
10-30 years old	83	81
New Hydronic Condensing Hot Water Boiler		
Return Temp. below 120	90+	88+
Return Temp. above 120	88	86

Table 2: Heating application

Boiler Use	Annual Hours	Load Factor
Winter Space Heating	1,300	0.75
Year Round Operation	2,000	0.75
Process	6,000	0.75

Figure 15: NIPSCO Boiler Savings Analysis Chart

The investment cost of the boilers were determined to be $52,000 per boiler based on the horsepower rating.[9] However, there are rebate opportunities of around $1,000 per MBTU for the new high efficiency rated steam boilers for a total rebate of $13,000.[10] There would also be installation costs of around $5000 per boiler.[11] The measurement and verification of these savings would be to confirm the new boiler efficiency which directly correlates to the energy and cost savings. In order determine the efficiency, flow gauges need to be implemented to measure the flow rate, temperature, and pressure for feedwater entering the boiler, steam leaving the boiler, and fuel entering the boiler. These fuel gauges are accounted for in the initial investment costs.

9 https://www.michigan.gov/documents/Vol2-36UIP12MiscellaneousIndustrialCosts_121081_7.pdf
10 http://www.centerpointenergy.com/PublishingImages/CNP/Common/SiteAssets/doc/CNP1095.pdf
11 http://www.homeadvisor.com/cost/heating-and-cooling/install-a-boiler/

Parking Lot Lights – LED Conversion

The last extra building project initiative is the parking lot lights. Currently, there are 364 metal-halide lights on campus, specifically including 58 280W, 208 175W, and 98 100W lights. Calculations were done in order to determine the costs and annual savings for converting the current metal-halide lights, such as shown in Figure 16 into LED fixtures as shown in Figure 17. Methods and assumptions for the cost analysis were based on the report from Leotek.[12] The LED conversion for each light wattage was to have roughly the same lumen output per light. Thus each 280W, 175W, and 100W metal-halide light was replaced with 141W, 108W, and 53W LED alternative light fixtures, respectively.

The total savings was composed from both energy savings from reduced wattages and maintenance savings. The maintenance savings was assumed to be $25 per year assuming a 4 year cycle of HID spot relamping, cleaning, changing igniters, ballasts, photocells, etc. for metal-halide lights versus a 10 year cleaning cycle and occasional photocell and driver replacements for LED lights. The investment costs for these lights are based on lighting prices from Grainger. There were also rebates for LED lights from Consumers Energy.[13] Installation costs were assumed to be $18,200 based on four luminaires/fixtures per hour installed at $200 per hour for a two person crew. There was also miscellaneous costs of $1000 accounted for measurement and verification for the lights using HOBO light sensors and their replacements.

Figure 16: Current 250W Metal-Halide Lights[14]

[12] http://www.leotek.com/education/documents/Leotek.LED.Streetlight.Guide.V7-101613.pdf
[13] https://www.consumersenergy.com/eeprograms/BHome.aspx?id=5435
[14] http://www.warehouse-lighting.com/cobra-head-roadway-light-fixture-250-320-400-watt?gdftrk=gdfV25804_a_7c2259_a_7c8441_a_7cRLD_d_PS_d_4T&gclid=CLnu6M_SmskCFQuraQodKsYGmw

Figure 17: Grainger 141W LED Replacement Fixtures[15]

Results

As a result of the investigation and calculations for the previously mentioned extra buildings project initiatives, cost and savings analysis was accomplished. The following results in Table 8 display the extra building projects and their initial costs, rebates, annual savings, and payback period.

Table 8: Extra Buildings Project Costs, Savings, and Payback Periods

Project	**Initial Cost**	**Rebate**	**Annual Savings**	**Payback Period**
Hekman Library - Lighting	$ 84,560	$ 7,708	$ 19,015	4.04 years
Hekman Library - Windows Reflective Coating	$ 7,003	$ 1,347	$ 2,034	2.78 years
KDH Steam Boilers	$ 114,478	$ 13,000	$ 43,542	2.33 years
Parking Lot Lighting	$ 190,736	$ 9,946	$ 17,086	10.58 years
Totals	**$ 396,777**	**$ 32,001**	**$ 81,677**	**4. 47 years**

The following savings graph in Figure 18 shows the total savings opportunities for extra buildings.

[15] http://www.grainger.com/product/ACUITY-LITHONIA-LED-Area-Light-35LP61?s_pp=false&picUrl=//static.grainger.com/rp/s/is/image/Grainger/35LP61_AS01?$smthumb$

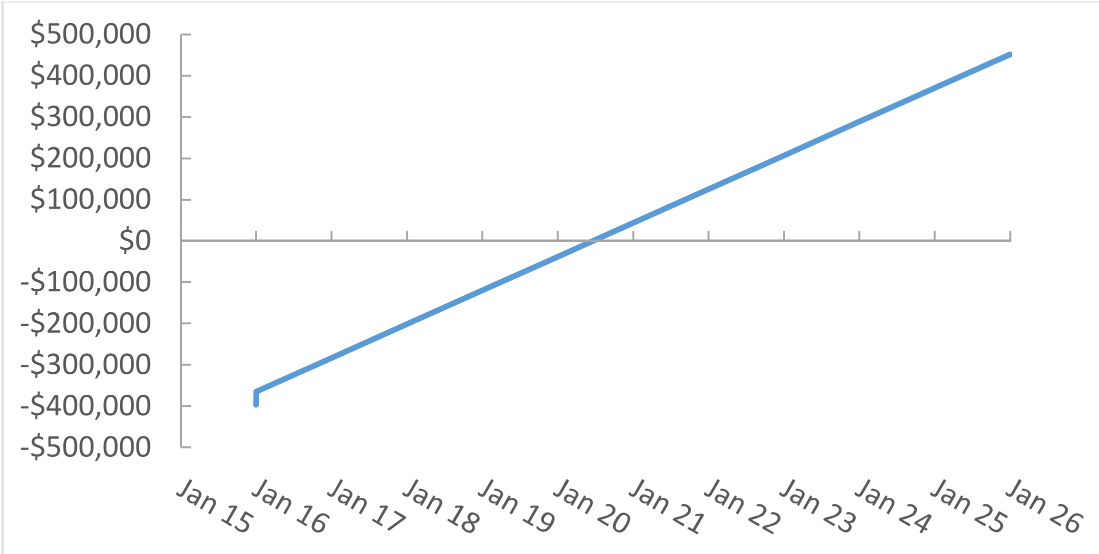


Figure 18: Total Savings Graph for the Extra Buildings Project Initiatives

Discussion

These results achieved from thorough investigation and analysis from the extra buildings team shows the possible savings opportunities on Calvin College's campus outside of the original five buildings chosen for the project. Although each project has a relatively large upfront cost, the large annual savings results a very short payback period for each project. There is a total initial cost of $396,777 ± $36,414, total annual savings of $81,677 ± $10,404, and an average total payback for all savings opportunities of 4.47 years, which is well under the guideline 10 year payback for projects. The Hekman Library and KDH steam boiler projects have the greatest savings opportunities as first deadline tier projects. The parking light LED light conversion is also a recommended project since they have solid annual savings and a long-life span; however, it might be more cost-effective to stagger the project a few years from now as LED technology advancements occur to reduce costs and shorten the payback period.

Conclusions

Although the initial project scope was to divide the class into groups to focus on energy saving opportunities on five on-campus buildings, the class decided that there were significant savings opportunities outside of those original five buildings that needed to be further investigated and analyzed. The extra buildings team focused on projects in the areas of a heavily utilized buildings, a component of a power plant, and a non-building energy user. These areas were covered by investigating the Hekman Library, KDH steam boilers, and parking lot lights. As a result of this project, it can be readily apparent that each of these extra buildings project initiatives have substantial savings opportunities which will contribute to Calvin College in its energy efficiency and sustainability efforts. The extra buildings team recommends each of the mentioned projects to be implemented in the coming years to help Calvin reach its goals of operational efficiency.

Appendix B.1
Lighting Model

Introduction
This appendix addresses the work done by the lighting team, one of the four major cross-cutting teams for the Engineering 333 Operational Efficiency project. After the class's initial meetings, it was determined that one major opportunity to save on Calvin College's operations was to convert lights from incandescent and fluorescent bulbs to LED lights. A cross-cutting team was formed to determine how to calculate the savings for this change.

Approaches
Two approaches to cutting down the costs due to lighting are de-lamping and changing the whole fixture. De-lamping is done by simply removing a number of bulbs within a fixture. This has to be done without hurting aesthetics so as not to create the appearance of a malfunctioning fixture. Therefore, this approach is only applicable to a limited number of fixtures within each building. When de-lamping cannot be done for a certain fixture, a different approach is needed and that is changing the fixture itself. A longer and more costly process would be needed to change the fixture, but that would give the chance to implement a more efficient lighting fixture to generate more savings. We suggest a balance between de-lamping and fixture replacement. When a fixture can be de-lamped without hurting the aesthetic appeal and the number of bulbs can be cut in half, it is more cost-effective to de-lamp. However, when the number of fixtures in a room can be significantly reduced or if de-lamping would hurt the aesthetic appeal of a fixture, new fixtures are suggested. When new fixtures are implemented, a fixture with the exact required brightness and the minimum possible power can be implemented. There are some rooms on campus where there is no clear decision, and the physical plant will have to make a tradeoff one way or the other to choose either higher long-term savings or a lower implementation cost.

Assumptions
For a rebate, the team assumed we could use the Consumers Energy offered rate of $0.40 per watt reduced. To find the rebate, the savings were found by finding the difference of the old wattage and new wattage and multiplying by $0.40. For installation, it was assumed that a certified electrician, at $45 per hour, could install 6 fixtures in an hour. Therefore, each fixture installation was $7.50. Additionally, it was assumed that de-lamping had no "installation costs" because it was a quick process requiring little hardware. CERF provided the cost of electricity, which depended on the time of day, since the electric company uses different prices for "on peak" and "off peak" hours. For on peak hours, which is 7 am to 11 pm, electricity costs $0.14/kWh. For off peak hours, which is 11 pm to 7 am, electricity costs $0.04/kWh. Jack Phillips provided the bulb and fixture costs, as well as the bulb wattages for the new bulbs. The assumed cost per new bulb was fixed at $35. The fixture costs varied depending on size and capacity of bulbs.

Measurement and Verification

In order to reduce uncertainties in cost saving analysis, the team used Hobo Sensors to collect accurate data on current operation hours of the light bulbs. Two sensors were used for this part, a light sensor only, and sensor that also included occupancy sensors.

For the dorms, the sensors were calibrated such that 100% represented when the light is on and 0% meant the light was off. An example of where sensors were placed is Kalsbeek Huizenga VanReken: two sensors were placed in the dorm rooms, one in a male's room and the other in a female's. One sensor was placed in the common coffee kitchen, and another in the basement. These sensors were placed in the fixtures themselves. The sensors were used to log data over a period of one week, the daily average was then used to calculate annual operation hours. The sensor data was also able to give us the hours of on-peak and off-peak usage. The same operation hours were assumed for each day in the year. This method of approach was used in both

Model

The assumptions and usage data were compiled into a comprehensive lighting model using Microsoft Excel. A screenshot is shown in Figure 19. In order to determine the potential savings from either the de-lamping or new fixture approaches, the user can input the room type, number of fixtures, type of current fixture, the new number of fixtures, and the new type of fixture into the lighting model. The output, then, is the total costs, including installation, fixture costs, and electricity, along with a rebate, steady-state savings, and the payback period in years. There are three separate pages in the Excel worksheet, one with the de-lamping model, one with the new fixture model, and one with hourly inputs and fixture types. Any given lighting project can be compared between the de-lamping and new fixture model. The third page is where fixture types are input into the model so that they can be selected from a drop-down menu. The fixture type controls the number of bulbs in the fixture, the wattage per bulb, and the fixture and install costs.

B	C	D	E	F	G	AA	AD	AE	AF
Room Number	Room Type	Number of Fixtures	Type of Fixture	New # of Fixtures	New Type of Fixture	total fixture costs	Rebate	Steady-State Savings	Payback period (Years)
Science Stairwells	Hallway	64	4' - 2 bulb T8	32	4' - 2 bulb LED	$ 6,576.00	$ 1,075.20	$ 882.77	6.23
SB Hallways (Cove)	Hallway	438	4' - 2 bulb T8	200	4' - 1 bulb LED	$ 23,300.00	$ 9,232.00	$ 7,667.28	1.83
SB 120	ENGR Labs	17	4' - 3 bulb T8	17	2' - 2 bulb LED	$ 2,813.50	$ 448.80	$ 623.08	3.80
SB 103	Classroom	14	4' - 3 bulb T8	14	2' - 2 bulb LED	$ 2,317.00	$ 369.60	$ 196.50	9.91

Figure 19: Example input and output of the new fixture model

Discussion

This Excel model is ready to be sent to the physical plant and was used by all the building teams to perform their lighting savings calculations. We are confident that if the right numbers are input into the model, the results will be accurate. The bulk of the uncertainty in the model comes from usage data. The data we collected from HOBO sensors and from CERF should be accurate. The inaccuracies in the model arise from our extrapolation from the one or two week sensor data to year-long numbers. Without having a clear picture of how often lights are on in the summer and during breaks, or how lighting usage fluctuates seasonally, the best we can do is an estimate. In order to account for the uncertainty in these estimates, we added an uncertainty of 15% to each model. Because there is also uncertainty in how the physical plant will approach the task of replacing lights and which methods they will choose in order to cut energy costs, we adjusted the overall uncertainty of lighting costs to 30%. In order to increase the accuracy, we recommend increasing the number of rooms with HOBO sensors and taking more week-long readings. If this model was going to be improved, we would recommend adding a motion sensor component to the calculations to determine how much additional money could be saved by utilizing motion sensors. Although we did not propose any motion sensor implementation after being cautioned by Jack Phillips that the cost of sensors and headaches with implementation and maintenance were not worth the cost, we believe that further investigating motion sensors in hallways would be potentially very valuable. Using the occupancy HOBO sensors could give a clear picture of how great these savings could be.

Conclusions

In conclusion, the lighting team has developed a model using Microsoft Excel that projects the expected initial cost, rebate, steady-state savings rate, and simple payback period for the conversion of lighting fixtures from their current setup to LEDs. This model was used by all building teams to calculate potential savings and is ready to be handed off to CERF, the Physical Plant, and any other potential Calvin College entities. Please contact Professor Heun to obtain an electronic copy of the model.

Appendix B.2
Temperature Change Model

Summary

The temperature change model accounts for cost savings by altering the operating set temperature of the thermostat. The initiative of this model was taken from Western Michigan University where they set the temperature to 75°F when cooling and 69°F when heating. Calvin College current sets the temperature to 72°F when cooling and 70°F when heating. This model determined how much money we could save by changing our temperatures to those used by Western Michigan University.

Method

The class received data from Jack Phillips of the physical plant about the electricity and natural gas usage of the campus. The approximate energy usage of each building was determined by using the ratio of the square footage of the specific building to the square footage of the whole campus. Next, assumptions based on research were made about how much of the electric bill goes towards running air conditioning and the fans during heating, and how much of the gas bill goes towards heating. A U.S. Department of Energy document published in 2008 states that in commercial buildings, approximately 14.2% of energy use is due to space heating and about 13.1% of energy use went towards space cooling[16]. Average outdoor temperatures for every month in Grand Rapids were also used in the model, which were found on a U.S. climate data website[17]. After determining the approximate energy usage for heating and cooling in a specific building, the model calculates how much of that energy can be saved by using heat transfer equation, and the energy saved is translated into money saved by spending less on electricity and natural gas.

Results

The model approximates cost savings by temperature change. However, there might be some discrepancy, due to the fact that utility costs for individual buildings are not available. The cost savings during cooling were found to be higher than the savings during heating since electricity costs more than natural gas. One of the biggest advantages of this initiative is that there is no initial cost to implement this change. Therefore all savings are immediately realized by the college.

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[16] Accessed December 9, 2015.
http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/bt_stateindustry.pdf.

[17] "Temperature - Precipitation - Sunshine - Snowfall." Climate Grand Rapids. Accessed December 9, 2015.
http://www.usclimatedata.com/climate/grand-rapids/michigan/united-states/usmi0344.

Appendix B.3
Heat Recovery Model

Summary

The heat recovery model calculates the energy savings from installing one heat recovery ventilator (HRV) into a building on campus. The model also calculates fuel savings, which are then converted into cost savings based on the price of natural gas ($3.1314 per Mcf – Oct 2015). The inputs into the model are the volume flow rate (CFM – cubic feet per minute) of exhaust air from the building, the fresh air (outside) temperature, the stale air (room) temperature, the effectiveness of the HRV, and the efficiency of the boiler.

Method

First, the CFM of the original exhaust fan needs to be found. For KHvR, this was found by looking at building mechanical plans at the physical plant. Next, the HRV acts as a fresh air intake fan, as well as a stale air exhaust fan. Thus, the power consumption of the HRV does not need to be accounted for in the model since it is a necessary cost for following ASHRAE building code. The properties of the HRV that need to be found are the unit price and the effectiveness. The HRV used for KHvR was the Fantech Model #SHR14104. This model had a sensible effectiveness of 0.55 @ 32 degrees F supply temperature and a sale price of $ 4,524.

The model computes the heat transferred to the fresh air using the effectiveness of the HRV, the stale air temperature, the fresh air temperature, and the CFM. The following equations were used to find the heat transfer in the HRV

$$C_h = \dot{m}_{stale\_air} Cp_{stale\_air}(T = T_{stale\_air}, P = P_{atm}) \quad \text{[Eq 2]}$$

$$C_c = \dot{m}_{fresh\_air} Cp_{fresh\_air}(T = T_{fresh\_air}, P = P_{atm}) \quad \text{[Eq 3]}$$

$$C_{min} = \min(C_c, C_h) \quad \text{[Eq 4]}$$

$$\dot{Q}_{max} = C_{min}(T_{stale\_air} - T_{fresh\_air}) \quad \text{[Eq 5]}$$

$$\dot{Q}_{actual} = \varepsilon_{HRV} Q_{max} \quad \text{[Eq 6]}$$

Then, using the actual heat transfer in the HRV, the fuel energy saved could be calculated by using the efficiency of the boiler. The fuel energy saved could then be set equal to the mass flow rate of fuel into the boiler times the lower heating value of natural gas[18].

$$\frac{\dot{Q}_{actual}}{\varepsilon_{boiler}} = \dot{m}_{fuel} LHV_{fuel} \quad \text{[Eq 7]}$$

The efficiency of the boiler that was used was 67%, which was found by Ross Tenney (Fieldhouse team). Finally, using the cost of fuel, the savings per second could be determined. The operating time that was used was 9 months because Kalsbeek and Huizenga do not have air conditioning

[18] http://www.eia.gov/dnav/ng/ng_cons_heat_a_epg0_vgth_btucf_a.htm

Uncertainty Analysis

The propagation of error technique from ENGR382 was used to determine the upper and lower bounds of the yearly cost savings. The technique was applied to find the uncertainty in the mass flow rate of fuel. The uncertainty variables were the mass flow rate of air, the fresh air temperature, and the stale room temperature. The partial derivatives of the function

$$\dot{m}_{fuel} = \frac{\varepsilon_{HRV}\dot{m}_{fresh\_air}Cp_{fresh\_air}(T_{stale\_air}-T_{fresh\_air})}{\varepsilon_{boiler}LHV_{fuel}} \quad \text{[Eq 8]}$$

With respect to $\dot{m}_{fresh\_air}$, T_{stale_air}, and T_{fresh_air} were solved for. Then, the uncertainty in the mass flow rate of fuel was solved for using the following equation

$$s_{fuel} = \sqrt{\left(\frac{\partial y}{\partial \dot{m}_{fresh\_air}} s_{\dot{m}_{fresh\_air}}\right)^2 + \left(\frac{\partial y}{\partial T_{stale\_air}} s_{T_{stale\_air}}\right)^2 + \left(\frac{\partial y}{\partial T_{fresh\_air}} s_{T_{fresh\_air}}\right)^2} \quad \text{[Eq 9]}$$

Where the uncertainty variables were estimated to be

Table 9. Uncertainty variables

$s_{\dot{m}_{fresh\_air}}$	0.3 lbm/sec
$s_{T_{stale\_air}}$	1 degree F
T_{fresh_air}	1 degree F

Based on seasonal temperature data from 2014, the cost savings for operating a HRV in KHvR for 9 months a year was found. The savings assume each wing is circulating about 3000 CFM of air (9000 CFM total – 3 wings); two of the Fantech SHR14104 HRVs was deemed sufficient to meet this requirement for each wing (6 HRVs total in KHvR). The installation cost was assumed to be $5000 per wing (Total $15,000).

Table 10: Key Variables

Total Cost	**Annual Savings**	**Payback Period**
$ 42,384	$ 5,040	8.4 years

Implementation
The following figure shows how an HRV might be implemented in a residential home.

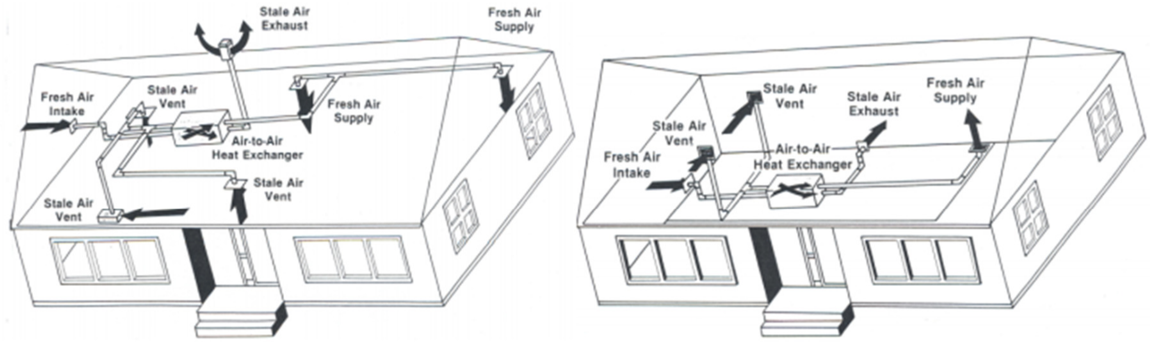

Figure 11. Attic installation of air exchanger.
(NDSU Extension Service)

Figure 12. Basement installation of air exchanger.
(NDSU Extension Service)

Figure 20: HVAC Implementation

The HRV acts as a single ventilation unit that recirculates fresh air into the building. For newer buildings that have to meet ASHRAE ventilation standards, the implementation of HRVs should definitely be considered. One of the other benefits of designing a building ventilation system with HRVs is that the size of the other HVAC equipment (furnace, ac/unit, etc.) can be much smaller. Therefore, it is suggested that HRVs be implemented in any new building constructions on Calvin's campus.

Verification of Model

In order to verify the ENGR333 model, research was done to see if any other engineers/academics had performed similar cost analysis for air to air heat exchangers. One analysis by Kenneth Hellevang and Carl Pedersen of NDSU was used to verify the ENGR333 model. The energy equation used in their analysis was the following

$$Q = CFM \times HDD \times Efficiency_{HRV} \times Cp_{stale\_air} \rho_{stale\_air}$$

Where Q is the heat transferred to the fresh air per year and HDD is the heating degree days. Both models used temperature data from 2014 in order to keep the verification honest. The results were similar for this model and are shown below

Table 11: Key Variables

Total Initial Cost	Annual Savings	Payback Period
\$ 42.384	\$ 6,144	6.9 years

The percent difference between the two models is 21%. The sources for discrepancy might be that the ENGR333 model uses the average monthly temperature to calculate savings, which is not as precise as using the HDDs. This model is also constructed by a Ph.D. and P.E. in engineering, so it is more trustworthy.

Measurement Verification

In order to verify the original model, temperature sensors should be placed at the fresh air and stale air streams of the HRV. Also, flow meters should be placed on the stale and fresh air streams in order to verify mass flow rates of air. Relative humidity sensors should also be placed as added measurements for moisture and possible risks of stale air freezing in the heat exchanger.

Conclusion

Based on research done on HRVs, Fantech is a good company that has many commercial choices for CFM, efficiencies, and cost. Installation of HRVs are recommended in new building construction and larger buildings with central ventilation units.

Appendix B.4
Window Model

Introduction

In order to assess the savings that could be obtained by altering windows in each building on campus, a thermal model of four variations of window alterations is developed. The four alternatives are: switching from single to double pane, installing reflective coatings, a combination of the first two alternatives, and a more ambitious alternative, cellular shades. The model allows the user to input the total window area, number of windows to convert from single to double pane, and solar incident data for each building in and will output initial cost, rebate, and annual savings.

Approach

There are two scenarios that are drivers of potential costs and thus potential cost savings. These scenarios, in West Michigan, are winter and summer conditions. The worksheet is designed to model two different thermal scenarios for each month. The first is convection through the window from a hot source to a cold one, as represented by Equation 1:

$$\dot{Q}_{convect} = U_{value} \times Total\ Window\ Area \times (T_i - T_o) \qquad \text{[Eq. 10]}$$

The second is thermal radiation based on the solar incident, which is represented by Equation 2 and 3:

$$\dot{Q}_{solar} = SHGC \times \dot{q}_{solar\ incident} \qquad \text{[Eq. 11]}$$

$$\dot{q}_{solar} = \sum Average\ Window\ Area \times Solar\ Radiation\ Incident \qquad \text{[Eq. 12]}$$

Where the solar radiation incident is found in Cengel's *Heat and Mass Transfer.*

These two heat transfer factors are combined based on whether the heat is coming from inside the building to the outside, i.e. during the winter, or the heat is coming from outside the building to the inside, as it does in the summer. The solar heat gain is always going into the building through the windows. Since the convection term switches direction from the summer case to the winter case, the net heat transfer is found by the difference of the terms during the winter, and the sum of the terms in the summer. This is demonstrated in Figure 21:

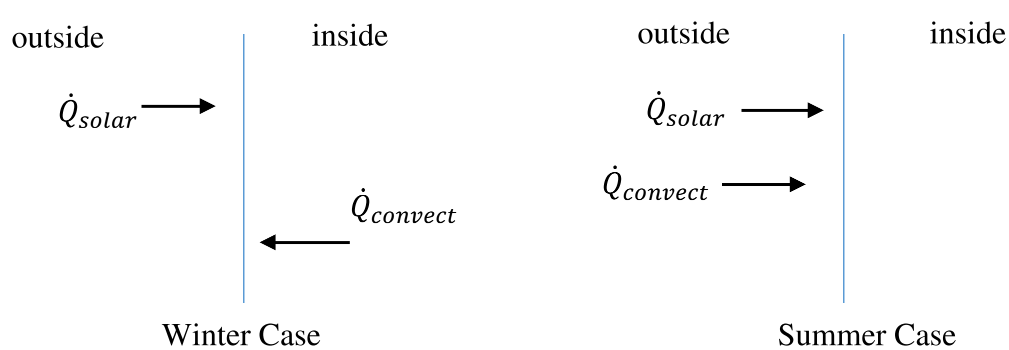

Figure 21: Two primary scenarios modeled by the worksheet.

Since there are twelve months in a year, the model is indexed from one to twelve, where each series of indexed variables represents the associated variables for that month. The inputs to the worksheet are simply the total window area of the building, the number of windows, the number of windows converting from single pane to double pane, and then the number of windows in the building that faces each direction on the compass (North, Northeast, East, Southeast, etc.). All other values necessary to the above equations are either calculated from these inputs or selected from tables in Cengel's *Heat and Mass Transfer* and *ASHRAE: Handbook of Fundamentals*.

Assumptions made are as follows. The ambient indoor temperature is set at 20°C. The temperature for each month is represented by the average temperature for that month from the previous year. U value from single to double pane windows is reduced by approximately half. The solar heat gain coefficient (SHGC) for the base case windows is 0.766. The heat transfer coefficient values are found at the assumed indoor temperature and are relatively constant. The cost of electricity is set to 14 cents per kWh while the cost of gas is set to 0.23 dollars per therm. The thermal efficiency of the heating system is approximated to 0.8 and the COP of the refrigeration cycle is set to 3.81. Several additional assumptions were made concerning the financial investment estimation. The hourly wage for labor is 8 dollars per hour. The estimates for each alternative's investment is sourced as can be found in the worksheet example next to each calculation in the document.

The mechanism that calculates the net heat transfer and then cost savings is repeated for each index, one through twelve. The sequence of operations starts with the calculation of the solar radiation incident, then the solar heat gain, by multiplying this value by the SHGC and the number of days in that month. The net heat transfer is found based on which scenario is being evaluated. Savings information is calculated by changing the SHGC for the solar term based on the alternative, or the U value for the convection term. For the cell shade alternative, both parameters change. The difference in the cost to heat or cool from the base cost due to an alternative is the savings per month that is resultant. The sum of savings for each month is found to represent the total cost savings for a given alternative for one year. The worksheet can be seen below, with values from the Science Complex entered to show the working calculations. The sheet has been altered to show only one month's calculations for brevity.

Appendix B.5
Supporting Materials

Many models, calculations, and data sheets were generated during the completion of this project. These materials are not easily included in a written report, so they are all stored in the following location on the Engineering Department shared drive:

S:\Engineering\Scratch\Operational Efficiency Project 2015