2018-2019

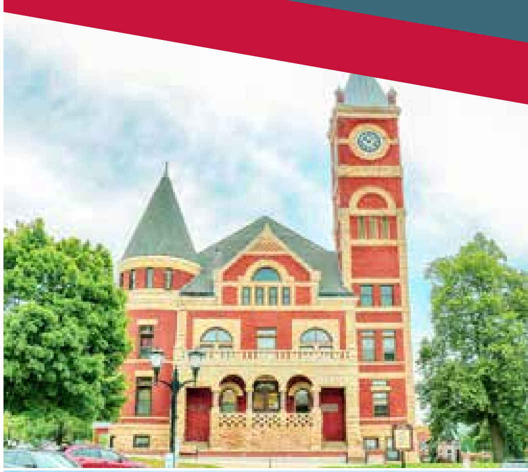
FINAL REPORT

UniverCity Year

Better • Places • Together

Improving energy efficiency at Juda School

ENGINEERING 601: INTERDISCIPLINARY DESIGN FOR ENERGY & SUSTAINABILITY



UniverCity Alliance

UNIVERSITY OF WISCONSIN–MADISON

Executive Summary

The following document describes a project undertaken in conjunction with the UniverCity Year in which we, a group of 4 UW-Madison students, worked with the Juda School in order to improve their energy efficiency. Juda is a K through 12 school located in southern WI that is seeking to be more sustainable, an effort led by Juda educator Scott Anderson. While Juda has taken many steps toward sustainability, including installing a 7.5kW solar array, there is room for improvement, and finding that "room" as economically and efficiently as possible was the main objective of this venture. Our client, Scott, specifically requested that we aim for the "low-hanging fruit" solutions--that is the cheapest possible solutions that would make an impact. We determined that any energy-idea that we recommended to Juda would have to be practical, economical, and politically feasible given that any major changes made at Juda would require district approval. Ultimately we have come up with a list of 10 possible solutions that, if implemented, will save Juda energy and money.

Proposed solutions fall into two categories: behavioral and structural. Behavioral solutions were heavily emphasized as they are very inexpensive compared to their structural counterparts. Additionally, Scott expressed a desire to begin cultural change at Juda in regards to sustainability, as, in his opinion, school-wide energy saving behaviors were severely lacking. In this spirit, two behavioral solutions are aimed at instigating long term change at Juda. The first is the Cool Choices program which uses friendly competition and an interactive game to instill good habits in staff and students that will continue to save energy even after the game ends. The second is to institute stickers above every light switch that gently remind the last person to leave a room to turn off the light. These slight changes in behavior save a surprising amount of energy. The other behavioral solutions are one-time changes that will save energy moving forward, including lowering sleep settings on school computers and other electronics and using smart

power strips to eliminate phantom energy consumption when teacher workstations are not in use. All of these behavioral solutions cost very little--two are even free--thus demonstrating the benefit of this type of intervention.

The portion of our recommendations with the biggest energy saving potential, as well as the biggest budget, are the structural solutions. The benefit of these solutions, in addition to the obvious advantage of saving large quantities of energy, is that once they are implemented, they require little further effort: all 6 structural solutions have a lifetime of at least 10 years. These solutions include external building improvements, such as roof coating and window insulation, as well as modifications of current Juda systems, such as HVAC insulation and modification of occupancy sensor time reductions. Some of the most impactful solutions, however, involve the addition of new appliances including replacing the remainder of Juda's non-LED lights with LEDs and installing occupancy sensors in the rooms that currently lack them. Though some of these solutions have a high price tag, the benefits they return outweigh the initial cost, with payback periods within the lifetime of the product. Included in this report is one solution, the installation of smart thermostats, that is not currently feasible at Juda, but has been included for potential future application if the opportunity should arise.

The combination of all of these proposed solutions could reduce Juda's energy consumption, taking both electricity and gas into account, by 8.5 percent. Considering in the last year Juda consumed over 2,365,000 kWh, this is a significant improvement. We hope that Juda can use these solutions going forward in their pursuit of sustainability.

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1.0 Problem Definition

1.1 Background information and problem statement

Juda School is a K through 12 school in Green County, Wisconsin with approximately 300 students, 28 teachers, and 49 staff.

In terms of their energy efficiency, Juda has made significant strides in the last decade to reduce their energy use by making energy saving structural upgrades to the school with a 2016 referendum, installing a solar array in 2014, and expanding that array in 2015. Currently, the 7.5kW system accounts for roughly 1.67 percent of Juda's total electricity consumption (Appendix A.1). At the start of this project, the goal was to reduce energy consumption at Juda by improving the energy efficiency of the school so that the solar array would contribute 10 percent of Juda's load.

Based on the background research done on Juda, which includes interviews with Scott and site visits, three main energy drains in the facility were identified and those are: AC, heating and lighting. AC units are turned on for a long period, including during the weekend when the school is unoccupied, to maintain the temperature of the building within a range of 70 to 80 degrees Fahrenheit. The heating runs constantly even in the presence of a large number of occupants, while the lights are left on, and even when the room is empty. The electrical appliances are also not energy efficient, such that some parts of the building, like the gym in the Palace, still use fluorescent light and that some of their air handling units (AHU) are not fully insulated.

While some efforts in conserving energy are already taking place, such as lowering the AC temperature at night and replacing some fluorescent lights with LED lights, the behavior of occupants also contribute to much of the energy wastage in Juda; this includes not turning off the lights when leaving the room or leaving electrical appliances, such as computers and smart boards, on after using them.

1.2 Solution requirements

Scott has laid out a few points that we have to consider in coming up with our recommended solutions to improve the energy efficiency in Juda. First of all, our proposed solutions should be economical but still balance out with the benefits they could offer as to minimize the total cost that will be inflicted to the school. Also, the solutions should be fairly easy to be implemented and adopted in Juda, where they should not deter or interrupt the flow of class and function of the school. We are also required to address the structural and behavioral problems in the school, hence several structural improvements that may include improving building insulation and lighting or installing devices that promote energy saving, as well as behavioral solutions that motivate occupants to be more energy conservative should be our focus as we progress into the project.

2.0 Solution

2.1 Approach overview

To address all the requirements set by the client, we have decided to take on two main approaches to the project, behavioral and structural.

Behavioral approaches are designed to change the behavior of occupants through direct and indirect approaches. The solutions should incorporate fun and visual cues to facilitate changes in behavior without making it burdensome for occupants, and also utilize devices that can indirectly reduce the energy consumption without the occupant's conscious effort. They are more so designed to be relatively economically savvy and to eventually be assimilated by the population who is the target of the behavioral solution.

Structural approaches, on the other hand, revolve more around maintenance and actual designs upgrades to improve energy efficiency that has nothing to do with human behavior. They are an essential part of sustainability because they are energy saving options that require no effort after they are installed, and work all the time, not just when people are consciously choosing to be energy efficient.

To help with the brainstorming for potential structural solutions, we asked Scott and the students at Juda to help us get an initial sense of the school with a building asset energy assessment. This included data such as the compositions, measurements, and thermal properties of roofs, walls, floors, windows, and also included all of the light bulbs and light fixtures throughout the school. Other data involved heating and cooling systems, water, fan and distribution systems. We are aware that this is a lot of information and it is also not always necessarily easy-to-find-info; because of this, albeit not because of the great effort put forth by Juda, some info was not able to be obtained and thus we were not able to compare Juda's current status of some of their infrastructure to the normal performance and function of buildings

2.2 Behavioral solution description

2.2.1 Changing sleep setting

Changing behavior is difficult. However, this does not have to be an obstacle when one could introduce measures to ensure the ease of those changes. Juda currently does not have any sleep setting set up for their computers. One solution in the category of behavioral solution is to change the sleep settings of the monitors and desktops to 10 minutes for monitors and 30 minutes for desktops According to the EPA, the optimal recommended computer sleep settings for monitors is 5-20 minutes and for desktops it is 15-60 minute[1]. To determine if changing the sleep settings of computers would actually decrease the electricity usage of Juda, a test was carried out using a device called the watts up meter. Watts up meter (Appendix B.2) measures the electricity usage in Wh of electronic devices by plugging the plug of the device into the watts up meter and plugging the plug of the watts up meter to the outlet. By doing so the electric current flows through the watts up meter and then to the electronic device. The watts up meter directly measures this flow of electricity to the device in units of Wh. Using the watts up meter, we measured in 15 minutes intervals the Wh of the desktops and the monitors when they are running normally and also when they are on sleep mode. Our results showed that the desktops and monitors use less electricity during sleep mode. The table in (Appendix B.3) shows the exact electricity usage of the monitors and desktops during sleep mode and normal functioning.

Based on the EPA recommendation and our calculations (Appendix B.4), the most ideal change would be to set the sleep setting of the monitors at 10 minutes and the desktops at 30 minutes. These are the changes in regards to Juda's computer usage behavior that would contribute to their total energy usage reduction by at least 10%.

2.2.2 Smart power strip

One behavioral approach that we investigated was the use of smart power strips. Smart power strips are similar to regular power strips/surge protectors except that they have an extra function purely made to save energy when certain appliances and electronics are not being used. Before we go over how smart power strips work, we first have to go over and understand the concept of phantom energy use. Phantom energy refers to the energy draw of electronics and other appliances that stay plugged in even when they are not in use: this includes things like hair dryers, toasters, routers and modems. It also includes electronics that have sleep settings such as: computers, computer monitors, television sets, video game consoles, and phones and chargers. Even when on "sleep" mode, these electronics still have a significant energy draw that goes unnoticed by many homeowners. These electronics even have a name; they are coined energy vampire appliances.

These electronics are the main target of smart power strips. Smart power strips are designed to reduce the phantom energy load created by the energy vampires. They do this by the format of the outlets. A standard smart power strip has one master control outlet, four apprentice outlets and two hot outlets. The hot outlets are always on and act like a normal power strip. The master outlet controls the other four apprentice outlets. It does this by managing the current going to the apprentice outlets. When the master outlet is on and being used, current is also directed to the other four outlets. However, the smart power strip is manufactured to detect sudden drops in the master outlets energy output: such as when an electronic goes into sleep mode or is completely turned off. When this drop in energy need is detected, the master outlet shuts off the four apprentice outlets so that no energy at all is directed to them. This allows for the four apprentice outlets to be completely turned off and avoids them from adding to the overall phantom load. The only phantom loads being created are then the master and the two hot outlets if they are being used. Obviously, this does not account for a lot in the short term, but eventually those phantom loads add up and can equate to quite a large waste of energy and monetary resources.

https://www.adorama.com/ssscg3

The average house has a phantom load of approximately 200-300 watts[15] and that number could fluctuate both higher and lower depending on the house size, number of occupants, and how many electronics they have. This could add up to anywhere from twenty to forty dollars each month added on to an electricity bill. That also depends on the price of electricity in the area.

To test out this behavioral solution before we made a final decision on whether to recommend it to Juda, we acquired a single, smart power strip and implemented it into a teacher's office station in place of the regular power strip they were previously using. We also brought two Watts up devices to measure the total energy being used by the teacher's power strip set up. We left the smart power strip and the watt-measuring devices with Juda and were planning on measuring the total energy used in a week with the smart power strip and the total energy used in a week with the regular power strip. Those values were then going to be compared and give us some experimental data on how effective smart power strips really could be. Since we were not able to be there the whole week to measure the watt readings and to eventually switch over the power strips, we asked Scott and the engineering students at Juda to switch the power strips at the end of the week. Unfortunately, we were not clear enough in our directions and the measurements using the Watts up were never taken and the power strips were just switched without taking the data. Due to this, experimental data was never taken and for the rest of our research into smart power strips, we were forced to rely on more in-depth research, theoretical data and experimental data from other sources. Using these other resources, an estimate of the annual energy that could potentially be saved by completely implementing smart power strips in every teacher's office station was calculated. The approximate energy saved by a smart power strip for an average office station is around one-hundred twenty kWh per year[15]. In Juda's district, Alliant charges $0.05168/kWh so that is about $6.2 saved per year. Obviously, that is not a staggering amount but considering a standard smart power strip only costs about $20-30, the payback period is relatively short, about three to four years. Also, when the average office station savings is multiplied by how many office stations there are in an office building or school, for example, that number can actually add up to something a little more impressive than thirteen dollars. For Juda's specific situation, they have 28 teachers and thus, $6.2 multiplied by 28 office workstations is nearly $174 saved each year and that is also 3,360 kWh saved each year for Juda just from smart power strips.

2.2.3 Reminder stickers

The next behavioral solution we are recommending is placing stickers over every light switch panel in Juda encouraging the last person to leave a room to turn the lights off as they go. Juda has already taken steps to reduce energy waste in this area by installing occupancy sensors, but by turning the lights off instead of waiting for them to turn off on their own, even more electricity can be saved. We are recommending that Juda purchases custom stickers from Jakprints[20], an environmentally friendly printing company, to accomplish this task. We hoped that by using custom stickers, the friendly reminders to turn off lights and appliances when leaving a room unoccupied could be tailored to Juda's specific culture and sustainability goals. This recommendation is based on a study conducted which evaluated how effective visual prompts were in encouraging people to turn off lights in unoccupied bathrooms. This study showed that washrooms with small signs, which is what we are recommending to Juda, were 6 times more likely to have their lights off when checked as compared to washrooms with no sign[16]. The washrooms with small signs had their lights turned off 38 percent of the time compared to 11 with no signs. This figure factored into calculations (Appendix C) which predicted that the implementation of "Turn the lights off" stickers at Juda will save approximately 1,295 kWh each year. This reduction in electricity usage will save Juda roughly $67 each year, giving the reminder stickers a payback period of 3.74 years.

2.2.4 Cool Choices

A behavioral solution that we strongly recommend Juda implements is the Cool Choices program. In our initial discussions with Scott, he repeatedly mentioned the lack of energy saving culture at Juda and that generally, there was significant room for improvement in establishing sustainable habits. This cultural change as a tool for achieving long-term reductions in energy consumption is the main goal of the Cool Choices game. In this game, students and/or staff are encouraged to make sustainable choices by taking specific actions each day. Such actions range from carpooling to school to turning off lights when exiting a room, to using reusable containers for food and beverages rather than generating waste. The game ramps up the involvement of its players, gradually raising the number of actions that can be taken each day. This aspect of the program aligns with one of our criteria for behavioral solutions: that our proposed changes do not burden staff and students. In fact, the game is designed to be fun, motivating players with friendly competition and the allure of “bragging rights”. It is our belief that through active participation in an all-staff game in early 2019, Cool Choices can help raise awareness of sustainable practices at Juda and kickstart major cultural changes that will ultimately save energy and money.

In just a 4 week game with a limited quantity of Juda occupants playing the game, over 6,500 kWh of electricity was saved. Appendix D details the assumptions that were made to estimate that the implementation of a staff Cool Choices game in early 2019 could save Juda 33,000 kWh per year[21].

Cool Choices is free to Juda through the Green and Healthy Schools program, so the payback period is 0! That being said, implementing an all staff Cool Choices game could save Juda roughly $1,700 annually in electricity savings. (Appendix D).

2.3 Structural solution description

2.3.1 Lighting replacement

The architecture of an educational institution such as Juda is comprised of numerous rooms as well as hallways that are in constant need of reliable lighting for extensive hours. The constant use of these lights significantly contributes to Juda's total energy use, and as such requires special attention in the project our team undergoes to reduce Juda's energy use by at least 10%. The majority of the classrooms at Juda is illuminated by T8 fluorescent light bulbs as of now. On average, a fluorescent bulb has a lifespan of 8,000 hours and costs $52 annually for electricity. In comparison, an LED bulb has a lifespan of 25,000 hours and costs $30 annually for electricity. In the context of Juda, an LED replacement would cost $49,050 based on the information in the Energy Innovation Grant, and it would save Juda $5942 on their annual energy usage. The $5942 that Juda would save on energy comes from the energy efficiency of the LED lights that they would replace the fluorescent lights with[13]. In other words, the current fluorescent light bulbs in Juda's building are responsible for an avoidable excess use of energy.

2.3.2 Repainting 2005 roof section

An additional structural solution explored through the course of this project was altering the 2005 roof section, currently coated in black rubber, in order to make it more energy efficient. Early on, we eliminated the possibility of completely redoing the roof section as it is only 13 years old and not only would it be wasteful to replace it so soon, but it would be politically difficult to get funding for such a project. From there, research was primarily focused on finding a reflective roof coating, a measure recommended by Energy Star[22] in order to reduce energy use due to air conditioning. Initially, a number of reflective elastomeric roof coatings were evaluated and while economical, were not applicable to the 2005 section because of the elastomers inability to properly bind to the pre-existing rubber surface. The option we are ultimately recommending is a LO-MIT radiant barrier coating by low emissivity coating from SOLEC[23], an Energy Star Certified product. This silicone-based coating can be applied to most roof surfaces, including rubber, but is less expensive than other silicone coatings. The primary function of this coating is to reduce air conditioning costs by reflecting energy from the sun on both the visual and infrared spectrums thus reducing the heat absorbed by the roof. Additionally, the LO-MIT coating is unique when compared to most other silicone coatings in that it is a low emission coating and therefor slowly releases the heat that is absorbed by roof back into the atmosphere. Not only does this reduce heating cost in the winter, but it also extends the lifetime of the roof on which it is applied by 5 to 10 years[2] because the gradual heat release assists in controlling the expansion and contraction rate of the roof. The typical expansion and contraction of the roof due to temperature fluctuations contributes to the wear and thus the longevity of it. The lifespan of this product is approximately 15 years.

Energy savings from the roof coating will end up being a combination of electricity and gas savings. Because the LO-MIT roof coating reflects energy from the sun, thus keeping the building cooler, the air conditioning load is reduced. The resulting reduction in electricity usage has been calculated to be 1,405 kWh per year (Appendix E). At this time, we were not able to obtain data describing the reduction of energy usage due to building heating in colder months as manufacturer studies have yet to be conducted. While this coating will reduce Juda's gas consumption, we cannot report a specific number of how much gas it will save.

The total cost of coating the 2005 roof section with LO-MIT radiant barrier coating is approximately $15,000 for professional installation and $7,500 for self installation. For the included design matrix, professional installation is assumed.

Total cost savings as a result of the new 2005 roof section coating is difficult to estimate as it is based on reductions in electricity and gas usage as well as saving associated with extending the life of the pre-existing roof 5 to 10 years. Cost savings due to reduction in electricity is estimated as $134.53. The total payback period is heavily depended on savings due to the extension of roof life.

2.3.3 Window insulation

The next structural solution we recommend Juda implement is insulating window film to reduce the energy that is wasted due to heat gain and loss from Juda's windows in the summer and winter months respectively. Specifically, we are recommending 3M Thinsulate 75 film (See Appendix F for distributor information). In the summer, this film blocks UV rays and heat reducing extra air conditioning loads currently experienced by Juda as a result of uninsulated windows. Similarly, in the winter months the film blocks heat loss[18] reducing the energy needed to heat the school. It is estimated that installing this film could reduce Juda's electricity consumption by approximately 14,400 kWh per year and gas consumption by 38,500 kWh per year with a total savings of $1,847.09. (Appendix F)

Midwest Glass Tinters, a Madison based distributor of Thinsulate 75, was provided with Juda's window dimensions, totaling roughly 1,042 ft^2, and gave a complete estimate of $20,915 to install the film on all of Juda's external windows. When considering the amount of money saved each year in energy costs, the payback period for this product is 11.3 years. According to the distributor, 3M Thinsulate 75 lasts a minimum of 15 years so, despite the long payback period, it would be advantageous for Juda to install this window insulation film.

2.3.4 Smart thermostats

Unlike regular thermostats where it allows users to manually control of the heating and air conditioning, smart thermostats automatically adjust the heating, air conditioning as well as the humidity of the building throughout the day according to local weather and occupants' behavior. This means that the smart thermostats will either turn up or turn down the temperature of the building according to the outside local temperature, hence allowing optimal temperature adjustment that is otherwise difficult to do manually. Since it also tracks occupant's behavior, it can improve the recovery time for the heating and cooling of the building by minimizing the amount of time the HVAC unit will have to operate, hence reducing the overall energy consumption and cost.

This is especially relevant to Juda since Juda has a wide range of temperature throughout the day and year, where the average temperature difference throughout the year in Monroe, which is the closest city to Juda with existing climate data, is approximately 20.9°F[6]. Also, since not all rooms in Juda is occupied at the same time, for example, classrooms are occupied in the morning while other rooms such as the gym or band rooms are not, smart thermostats can aid in reducing the temperature for rooms that are unoccupied using its tracking system, ensuring the comfort of occupants while efficiently conserving energy. Since the smart thermostats work in the background, it requires little to no effort from users and claimed to be able to save 23% of heating and cooling bill annually[7].

The particular smart thermostats that we would like to recommend is ecobee4 with room sensors. The ecobee4 smart thermostats has functions as mentioned above, added with some extra features that can help the owner to further understand the energy usage in the school. This includes providing data of energy conserved for each month, alerting owners if any equipment is not optimally functional as well as allowing flexibility for owners to control each room through their smartphone application. The room sensors that come with it are also convenient since rather than having to buy smart thermostats for every room, owners can opt to put room sensors instead since one ecobee4 can pair up to 32 room sensors. The ecobee4 smart thermostats can last up to 10 years while the room sensors can last up to 2 years on battery life—which is replaceable[7].

However, after further consultation with ecobee agent, the current thermostats wiring in Juda uses proprietary functionality which is not compatible with ecobee smart thermostats. In order to install the ecobee, the Interface Module of the current thermostats will need to be bypassed and this requires splicing the thermostats wires wire by wire directly to the wires connecting to the furnace. Doing so may also result in loss of proprietary functions such as fan variable speed, where ecobee smart thermostats only allow either on or off function for the fans. Ultimately, it is up to Juda to either install the smart thermostats or not, but looking at potential savings and prospects that smart thermostats could offer from our research, we think it is worth mentioning it as one of the options for our solutions.

2.3.5 Installing new motion sensors

Motion sensors work by automatically shuts off lights in a room when it detects no motion or heat—depending on the type of sensor. According to U.S. Environmental Protection Agency (EPA), installing motion sensor can save energy ranging from 13% to 80%, depending on the type of room and area usage[8]. Since typically lighting accounts for 9 to 11% of electrical consumption[9], where specifically in Juda it accounts for 20% (Appendix G.4), reducing the lighting operation hour can have an impact on the overall energy and electricity bill saving on Juda.

Currently, Juda doesn't have motion sensors installed in the Palace and the Pits, which is where the gym, performance center as well as other conventional classrooms like wood shops, art rooms, and metal shops are located. We were also informed that the lights in some rooms like the storage rooms, were usually kept on for long period—which could last up to weeks, due lack of traffic. In fact, occupants often do not turn off the lights even in rooms that have frequent traffic, making the need of motion sensor installation in these areas more necessary in order to conserve more energy.

The particular motion sensor we would like to recommend is the Lutron motion sensor that can be paired up with Lutron relay switch. The relay switch can pair up to 6 motion sensors and has a maximum load of 16A with radio frequency range of 30 ft. It also has the option of integrating to the HVAC unit of the buildings hence allowing simultaneous control for both lighting and temperature of an area based on occupancy[10]. The motion sensor, on the other hand, is a passive infrared (PIR) sensor which senses the heat emitted by moving objects, switching the lights on when the sensor is triggered and is more resistant to false triggering. It connects to the relay switch wirelessly within 60 ft line-of-sight or 30 ft if through walls, reducing the need for rewiring. The sensor also has a wide range of coverage from 1500 ft^2 to 3000 ft^2 and has the option of either 180° field of view or 90° field of view. For the gym, the 180° field of view should be used in order to cover the entire space while for a smaller area, it is recommended to use the 90° field of view and mount it to the corner of the room to reduce false triggering that may come from any movements beyond the classroom door[11]. It is also important to note that the motion sensor shouldn't be placed somewhere where its range of view could be obstructed. Since the motion sensor is connected wirelessly, it runs on battery but the battery itself is replaceable and last up to 10 years on one replacement[12]. The time delay can be set to 1, 5, 15 or 30 minutes, however, a time delay of 15 minutes is recommended[8].

For installing new motion sensors in Palace, we found the total material cost with current lighting (Fluorescent T5 high output) can go up to $1143.14, where the materials include relay switches, motion sensors, as well as motion sensor guard as to avoid the motion sensor from being damaged by incoming forces from the activities that took place in the gym. However, if the lighting in Palace is replaced with all LED, the total material cost goes down to $450.84 due to lesser total load from the LED lights. This reduces the number of relay switch needed to cover the load for the lightings in the gym. (Appendix G.1)

As for the estimated annual energy savings from installing motion in Palace, the energy savings with current lighting (Fluorescent T5 high output) is 6998.4 kWh, which is 20% saving on lighting based on no motion sensor installation in Palace, 5.58% saving on lighting based on the lighting usage for the entire building, and 1.11% saving based on the entire annual electricity usage in Juda (Appendix G.4). The annual lighting bill saving, on the other hand, is estimated to be $361.68. The annual energy saving for motion sensor with all LED replacement lighting can go up to 23 904 kWh, which is 68% savings compared to the energy used for current lighting with no motion sensor installation, 19.07% savings based on the lighting usage for the entire building, and approximately 3.81% saving based on the entire annual electricity usage in the school (Appendix G.4). The estimated annual lighting bill savings, on the other hand, is $1235.36. (Appendix G.1)

For motion sensors in Pits, we estimated the total material cost with current lighting (a mixture of fluorescent T8, T12) to be $3197.09, where the materials include relay switches and motion sensors. However, if all the lighting for the Pits is replaced with LED, the material cost goes down to $2387.82, due to the lesser load that LED lighting poses on the relay switch hence requiring less relay switch quantity. (Appendix G.2)

As for the calculated estimated annual electrical energy savings with current lighting is 16 551 kWh, which is 20% savings on lighting energy compared to with no motion sensor installation, 13.21% saving based on the lighting usage for the entire building, and approximately 3.74% savings based on the entire annual electrical usage in Juda (Appendix G.4). As for the annual lighting bill saving, it can go up to $855.36. If we consider replacing all lighting in Pits with LED lighting, the estimated annual energy saving for motion sensors is 78 982.20 kWh, which is 95% savings compared to no motion sensor installation with current lighting, 63.02% savings based on the lighting usage for the building and approximately 12.56% of the entire annual electrical energy usage in Juda with the annual lighting bill saving of $4081.8. (Appendix G.2)

The payback period for installing new motion sensors is the Palace with current lighting is 6.09 years while with LED lighting is 1.73 years (Appendix G.1). As for installing new motion sensors in Pits, the payback period with current lighting is 6.61 years while with LED lighting is 1.19 years (Appendix G.2). It is important to note that these payback periods only take account of material cost for motion sensors, relay switches, and motion sensor guards, as well as the estimated labor cost for installing motion sensors. We, however, did not include the LED replacement material and labor cost in the payback period for motion sensors with LED lighting, hence, the final payback period may differ if we take other costs into consideration.

2.3.6 Reducing time delay on motion sensors

Based on the Building Energy Assessment provided by the engineering students in Juda, Juda currently has motion sensors installed in all of their classrooms. However, since the time delay of the motion sensors is set to maximum, which is 30 minutes, the lights are almost never turned off despite the room is unoccupied. Based on the EC&M website, it is recommended to set the time delay to 15 minutes[8].

Adjusting the time delay on already installed motion sensors require configuring each motion sensor individually. This can be done by unscrewing the cover of the motion sensor and adjusting the time delay setting on the unit itself.

The annual energy savings for Juda for reducing the motion sensor time delay with current lighting, which is a combination of fluorescent T8 and LED lighting, is 3028.75 kWh, which is approximately 40% savings based on current time delay setting and 0.48% savings based on the entire annual electrical energy usage in Juda (Appendix G.4). The estimated annual lighting bill saving, on the other hand, is $156.53 (Appendix G.3). However, if Juda replaces all its lighting with LED, the estimated annual energy saving goes up to 5014.87 kWh, which is approximately 55% savings comparing to the energy used with current time delay setting and lighting with approximately 0.80% savings based on the entire annual electrical energy usage in Juda while the estimated annual lighting bill saving is $259.17. (Appendix G.4)

Reducing time delay for motion sensor does not have a material cost associated with it since users will only have to adjust the time delay setting on each motion sensors that are already installed in Juda.

2.3.7 HVAC insulation

Juda has a total of 10 air handling units (AHU) that are connected to the heating and cooling system, and 6 of them are insulated while 4 are not. These AHUs deliver, control the temperature and the humidity of the air throughout the whole building. When the air is being delivered, a lot of its conditioned temperature is lost through the delivering ducts of the AHUs when the ducts are not insulated[2]. This extends the work hour of the AC or heater in order to keep the conditioned air at the desired temperature. This extension in work hour results in unnecessary energy usage that should have been preventable. By insulating the ducts with foil and fiberglass duct insulations, this could reduce the energy lost through AHU ducts and increase the efficiency of the heating and cooling system by as much as 20%[3]. Foil and fiberglass duct insulations are sheets of fiberglass that are wrapped and taped onto the AHU ducts to insulate and prevent heat transfer between the ducts and the surrounding atmosphere.

The ability of a material to resist heat change is measured by its R-value. The larger the R-value, the more heat resisting the material is. The material of the AHU ducts at Juda is steel, which has a fairly low R-value of $0.61 Km^2/W$[4]. By insulating the ducts with foil and fiberglass duct insulation that has an R-value of $6\ Km^2/W$, Juda could greatly reduce the energy lost through the AHU ducts[5]. To calculate the cost for the insulation, we asked the engineering students at Juda to measure the duct surface area of the four uninsulated AHUs. The measurements are as follow:

AHU-6 = 150 square ft

AHU-10 = 80 square ft

AHU - 2 = 80 square ft

AHU-7 = 60 square ft

By adding all of the measurements, we get a total surface area of 370 square ft. The recommended material for duct insulation is the Foil and Fiberglass Duct Insulation from Home Depot[5]. The unit cost is $11.98 E/O 12 in. x 15 ft. for a total of $295.50. This would ultimately contribute to our main objective of improving Juda’s energy efficiency and increase the solar array contribution to Juda’s load by at least 10%.

3.0 Final Result

3.1 Assessment

To assess these potential solutions that our team came up with, we created decision matrices with specific criteria directed towards our behavioral and structural solutions. The criteria for our behavioral decision matrix are located in Appendix H.1. The total scores for each solution are based on multiplying the weightage of the criterion by the score given to the solution for that topic and then adding up its total points. Based on the information withheld in Appendix H.1 we have determined that the behavioral solutions that have the strongest chance of being effective and suitable for Juda are: Cool Choices, smart power strips, computer sleep settings, and reminder stickers. For the structural solutions, we had a little more deducing and discussing to do in order to decide on which would be most beneficial to Juda but through discussion and utilizing the structural decision matrix in Appendix H.2, we have concluded that the best possible structural solutions for Juda are: replacing all remaining non-LED lights with LEDs, covering the black portion of the roof with the low emissivity coating, finish insulating the AC units, reduce time delays of already installed motion sensors, window insulation and installing motion sensors in the Palace and Pit.

3.2 Sustainability Impact

Adding up all of the potential energy savings per solution based on our calculations, it is estimated that these solutions could save Juda up to 202,169 kWh per year. These annual savings would substantially decrease Juda's annual energy usage and, in turn, greatly reduce their monthly bills as well. The impact on the environment if our solutions are were to be appropriated by Juda will be negatively minimal to possibly even positive overall. This is because when the reminder stickers are ordered, the company will plant a tree for every order. The other solutions will not really greatly impose any effects on the environment. Cool Choices, actually, because of the nature of the game, will also positively affect the environment.

3.3 Final recommendation

Based on our finalized research, investigations, and decision matrices, our team has concluded that the most luculent solutions for Juda to attempt to adopt and implement are:

- ❖ Behaviorally, Cool Choices, Smart power strips, computer sleep settings, and reminder stickers are the best options for Juda to assimilate into their culture at the school.
- ❖ Structurally, LED lights, low-emissivity roof coating, motions sensors in the Palace and Pits, reducing motion sensor time delay, window insulation, and additional AC insulation on the units that have yet to be fully insulated.

These solutions were chosen because they exhibit the best, overall qualities that are helpful in the goal of improving the energy sustainability of the Juda institution. They were based on such attributes such as: energy-saving ability, cost (which included both initial price and payback period), practicality, appeasibility, and lifetime. Those are the qualities that we decided were most cogent to the overall goal of this project. We believe that by embracing some or all of these various proposed solutions, Juda will be able to gradually reach their goal of the solar array supplying approximately 10% of their total energy usage and hopefully, even beyond that.

4.0 References

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5.0 Appendices

Appendix A: Background info

A.1:

Electricity purchased from Alliant between November 20, 2017 and November 16, 2018 (12 billing statements, approximately 1 year): 619,840 kWh (Source: Juda's electric bills)

Electricity produced by the solar array within those same dates: 8,006 kWh (Source: sunnyportal.com) (Note at no time did electricity production from the array exceed the school's demand. As a result, it is assumed that all produced electricity was used)

1 year electricity consumption= 619,840 kWh + 8,006 kWh = 627,846 kWh

In 2018, solar array did not provide electricity in May or June so the year total from 2017 was determined to be a more appropriate estimate of the array's yearly capabilities.

2017 solar array output: 10,512 kWh

Assuming 2018 and 2017 are representative years, estimated percent of electricity consumption provided solar array:

$$10{,}512\ kWh \div 619{,}849\ kWh = 0.01674 \times 100 = 1.674\%$$

Appendix B: Changing Sleep settings

B.1: This is the watts up meter we used to measure the Wh usage of the computer monitors and desktops.

B.2:

Computer Component	Desktop	Monitor
Number	106	106
Normal Energy usage (Wh/min)	0.273	0.233
Sleep Energy usage (Wh/min)	0.02	0 (negligible)
Total energy potentially saved with sleep setting (Wh/min)	26.818	24.698

Table B.2.1. Shows the normal and sleep electricity usage in Wh/min of the desktop and monitor and the total potential energy savings with sleep setting set at 10 minutes for monitors and 30 minutes for desktops.

B.3:

English Room Energy savings (assuming the computers are turned on at 9am and shut off at 3pm) 3hr/computer:

Energy Usage with Sleep setting:

30 desktops x 3hr usage x 60 = 5400 min/day

Desktop energy usage = 5400 min/day x 0.237= 1474.2

Monitor Energy usage = 5400 min/day x 0.233= 1258.2

Total energy usage with sleep setting= 1474.2 + 1258.2 + (245.7+69.9) x3 + 108= 3787.2

Total energy usage without sleep setting = 5464.8

Total energy savings = 5464.8 - 3787.2= 1677.2 Wh/day

Student Computers (not including English room, assuming computers are turned on at 9 and turned off at 3pm) 1.25 hr/computer:

76 Computers

75 min/day x 76 computers= 5700 min/day

Desktop energy usage = 5700 x 0.273 =1556.1

Monitor energy usage = 5700 x 0.233 = 1328.1

Total energy usage with sleep setting= 1556.1+ 1328.1 + 3x(622.44+177.08)+5.9=5288.66

Total energy usage without sleep setting= (28120 x 0.233) + (28120x 0.273)= 14228.72

Energy saving= 14228.72 - 5288.66 = 8940.06 Wh/day

Appendix C: Reminder stickers

To calculate energy saved from introducing reminder stickers, it was assumed that turning the lights out instead of waiting for the occupancy sensors would be comparable in energy savings to occupancy sensors set to 20 seconds (see App C, Table C.3.3). As a result, if the reminder stickers were 100% effective Juda would save 3,407 kWh/year. However, Please turn off the lights: The effectiveness of visual prompts suggest that small reminder signs are 38% effective so the estimated energy savings is reduced to 1,295 kWh/year.

$$3{,}407\ kWh/year \times 0.38 = 1{,}294.8\ kWh/year$$

At Juda's regular electricity rate of \$0.05168/kWh, this brings annual savings to \$67

$$1{,}294.8\ kWh/year \times \$0.05168/kWh = \$66.91/year$$

The rough cost estimate for 1000 custom stickers is \$250 (2).

$$\$250 \div \$66.91/year = 3.74\ years$$

Appendix D: Cool Choices

Despite the success of the trial game saving over 6,500 kWh in just 4 weeks, we decided to make conservative assumptions on how much Juda could save as a result of this program moving forward. After looking at the actions related to electricity usage taken by Juda students and staff during the game, many of the actions that would be expected to contribute heavily to the amount of energy saved were taken at home, such as unplugging a second refrigerator or switching to LED lights, or were statements about structures Juda already has in place, such as occupancy sensors, and therefore would not be saving Juda money or electricity compared to current usage. As a result, we estimated around 1,000 kWh were saved by making sustainable choices at school. This game included 14 people, but an all staff game such as what we are recommending would have 77 people and could reasonably be assumed to save energy proportionally, saving approximately 5,500 kWh due to in-school choices. It is expected that the commitment to this behavior will drop after the daily reminders the game provides comes to an end to an estimated 2,750 kWh/month (about half). As a result we would estimate that the implementation of a staff game at Juda could save roughly 33,000 kWh annually, especially if this game is repeated to keep sustainable practices fresh.

$$2{,}750\ kWh/month\ \times 12\ months/year = 33{,}000\ kWh/year$$

This is approximately 5.3% of Juda's annual electricity consumption and electricity cost savings can be estimated to be

$$33{,}000\ kWh/year \times \$0.05168/kWh = \$1705/year$$

Appendix E: Repainting 2005 roof section

Approximate roof area calculated using Google Maps measurement tool

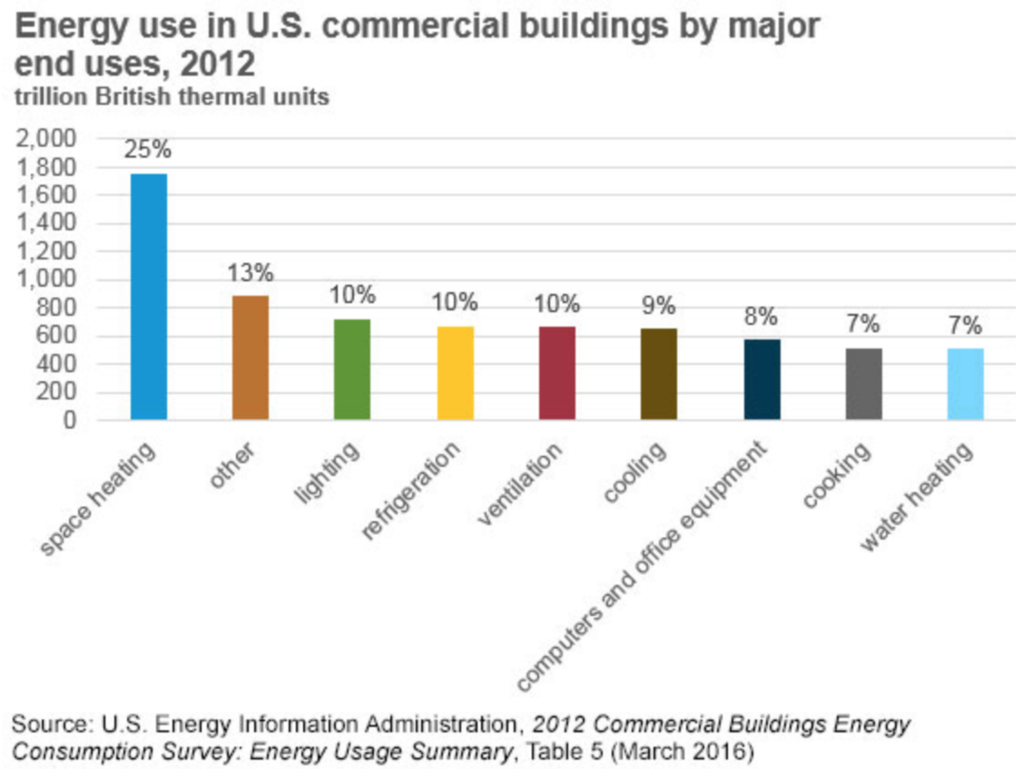
2005 Roof portion: calculated to be approximately 15,038.3 ft^2 smoothed for further calculations to 15,000 ft^2

Entire roof: calculated to be approximately 79,884.5 ft^2

Percent of roof to be coated: $15{,}038.3 \div 79{,}884.5 = 0.18825 \times 100 = 18.825\%$

This number was calculated in order to understand how Juda's heating and electric bills would be affected by the roof coating. If manufacturer estimates suggest that the roof coating will reduce the air conditioning load by 3.5%, it is estimated that for coating just this section of roof will reduce the load by 0.66% because it is assumed that the amount saved will be proportional to the amount of roof coated.

In order to calculate the amount of energy saved due to air conditioning, estimates had to be made in regards to how much of Juda's energy usage is due to air conditioning. The basis of our estimations was the following diagram from the U.S. Energy Information Administration[17].



While this diagram[17] is for a general commercial building and not Juda specifically, for the sake of calculations it is assumed to be applicable. To start, Juda has a total annual electricity consumption of 627,846 kWh annually (see Appendix A.1). When Juda's gas bills are also considered (approximately 1,741,416 kWh/year) Juda's total energy consumption can be calculated.

$$627{,}846\ kWh + 1{,}741{,}416\ kWh = 2{,}369{,}262\ kWh/year$$

The following calculation approximates Juda's cooling energy consumption.

$$2{,}369{,}262\ kWh/year \times 0.09 = 213{,}234\ kWh/year$$

SOLEC estimated that the application of the coating could reduce air conditioning load by 2-5%, estimated here as 3.5% (adjusted to 0.66% based on amount of roof being coated).

$$213{,}234\ kWh/year\ \times 0.0066 = 1{,}405\ kWh/year$$

The application of this coating would save 1,405 kWh/year in air conditioning use along.

To calculate cost savings, the regular rate of $0.05168 per kWh was used. Additionally, we calculated that Juda's energy bill is on average 40.5% composed of charges associated with On-Peak Demand Charge, spending roughly $27,315 a year because of this charge. The addition of the LO-MIT coating will reduce electricity consumption during those high demand period, thus saving money. 1,405 kWh is approximately 0.23% of Juda's yearly electrical costs so it is reasonable that peak demand costs will be reduced by the same amount. Annual total savings due to reduction in cooling costs is calculated below.

$$\$27{,}315 \times 0.00227 + 1405\ kWh \times \$0.05168/kWh = \$134.53$$

Estimated cost is based on manufacturer estimates, raging from $0.50/ft^2 to $2.00/ft^2. Self installation would be at the very low end of this spectrum.

$$15{,}000\ sqft \times \$0.50/sqft = \$7{,}500$$

A reasonable estimate for professional installation would be $1.00/ft^2 because the $1.00-$2.00 provided by the manufacturer includes materials and labor for coating application as well as material and labor costs for roof preparation such as necessary sealing and cleaning. This roof section is relatively new and as a result it was estimated that little prep work would be required.

$$15{,}000\ sqft \times \$1.00/sqft = \$15{,}000$$

Commercial vendors of this product are able to purchase it at approximately $0.20/ft^2 so material costs, regardless of application method, will be approximately

$$15{,}000\ sqft \times \$0.20/sqft = \$3{,}000$$

Appendix F: Window Insulation

Technical Data Sheets and Specifications

3M™ Flat Glass Window Film – Double Pane ¼" (6mm) Clear Glass

Film	SHGC	VLT	Visible Reflection Exterior	Visible Reflection Interior	U Value	LSG (Light to Solar Gain)	UV Block	SC	TSER	Glare Reduction	Heat Loss Reduction	Heat Gain Reduction
Dual 1/4" Clear	0.70	79%	15%	15%	0.47	1.1	NA	0.80	30%	NA	NA	NA
Thinsulate CC75	0.51	66%	21%	17%	0.35	1.3	99.9%	0.58	49%	16%	26%	27%

CONFIGURATION	U VALUE (W/m2-K)	U VALUE (Btu/ft2 -F)
Single Pane Clear	5.8	1.03
Single Clear with Thinsulate™	3.6	0.63
Double Pane Clear	2.7	0.45
Double Clear with Thinsulate™	2.0	0.35
Triple Pane Clear	1.8	0.31

The above table was provided to us by Midwest Glass Tinters, a local distributor of the 3M Thinsulate film, and it lists Heat Loss and Gain Reductions to be 26% and 27% respectively with the application of Thinsulate 75 to double pane clear glass. These numbers were the basis of our calculations for predicted energy savings in applying this film to Juda's windows.

Using the same methods described in Appendix E. it was determined that Juda's energy consumption due to air conditioning is 213,234 kWh/year. The department of energy estimates that heat loss and gain from windows account for 25-30% of heating and energy usage. (1)

$213{,}234\ kWh/year \times 0.25 = 53{,}308.5\ kWh/year$ (energy wasted through window heat gain)

$53{,}308.5\ kWh/year \times 0.27 = 14{,}393.3\ kWh/year$ (energy potentially saved by film)

$14{,}393.3\ kWh/year \times \$0.05168/kWh = \$743.84 year$ ($ saved due to electricity reduction)

$14{,}393.3\ kWh/year \div 627{,}646\ kWh/year \times 100 = 2.29$ (% of Juda's electricity consumption)

$\$27{,}315 \times 0.0229 = \$626.19$ ($ saved in reduced Peak Demand charge)

$\$743.84 + \$626.19 = \$1{,}369.93$ (predicted annual savings due to reduction in air conditioning load)

Similar calculations provide estimated energy and cost savings due to reduction in heat loss as a result of the film.

$2{,}369{,}262\ kWh/year \times 0.25 = 592{,}316\ kWh/year$(energy consumed for building heating)

$592{,}316\ kWh/year \times 0.25 = 148{,}079\ kWh/year$ (energy wasted through window heat loss)

$148{,}079\ kWh/year \times 0.26 = 38{,}500\ kWh/year$ (energy potentially saved by film)

$38{,}500\ kWh/year \times 0.034095\ therm/kWh = 1312.7\ therm/year$ (unit conversion)

$1312.7\ therm/year \times \$0.3635/therm = \$477.16/year$ ($ saved due to heating load reduction)

Between the $1,369.93/year from electricity savings and $477.16/year from gas savings, the application of the 3M Thinsulate window film could save Juda $1,847.09 each year. With a total insulation cost of $20,915, the payback period of this film is 11.3 years.

$$\$20{,}915 \div \$1{,}847.09/year = 11.32\ years$$

Thinsulate Film Contact:

Carol Myers, Midwest Glass Tinters

carol@midwestglasstinters.com

Link to proposal: Midwest Glass Tinters Inc Proposal

Appendix G: Motion sensor

G.1: Motion sensor in Palace

Notes:

1. Current lighting in gym: fluorescent T5 high output
2. The wattage and voltage of fixture, number of fixture and lamp per fixture for both fluorescent and LED lighting are provided in the Building Energy Assessment.
3. The power factor used for both fluorescent (0.60) and LED (0.95) are the value for a typical fluorescent and LED lights

To calculate the number of relay switch that are needed in Palace, we will have to calculate the total load in Ampere as each relay switch has a maximum load of 16 A.

To calculate A for alternating current, the following formula is used:

$$A = \frac{W}{V \times Power\ Factor}$$

Lighting	Fluorescent T5 high output	LED lighting
No. of fixture	36	28
lamp/fixture	6	1
W/lamp	54	165
Total W/fixture	324	165
V/fixture	120	120
Power factor	0.6	0.95
A	4.5	1.447
Total A for all fixture	162	40.52

Table G.1.1 shows the total Ampere for both fluorescent and LED lighting in Palace.

From there, we could calculate how many relay switch is needed by dividing the total Ampere to 16A.

Lighting: Fluorescent T5 high output

Product	Number needed	Price/unit	Total price	Note
Relay switch	10	98.90	989.00	Max load per switch

16R-DV-B				is 16 A
Lutron LRF2-OWLB-P-WH	2	56.52	113.04	Wireless, battery life up to 10 years (replaceable)
Motion detector guard (for gym)	2	20.55	41.40	To protect motion sensor from external forces from activities in gym

Table G.1.2 shows the material cost for each individual materials in Palace using current lighting.

Total price for material (not including labor) : **$1143.14**
Assuming the labor cost for each relay switch installation is $108 (reference), the total price for installing motion sensor in Palace with current lighting is **$2223.14.**

Lighting: LED lighting

Product	Number needed	Price/unit	Total price
Relay switch 16R-DV-B	3	98.9	296.7
Lutron LRF2-OWLB-P-WH	2	56.52	113.04
Motion detector guard for gym	2	20.55	41.1

Table G.1.3 shows the material cost for each individual materials in Palace using LED lighting

Total price for material (not including labor): **$450.84**
Using the same assumption as above for labor cost ($108 per relay switch), the total price for motion sensor installation in Palace with LED lighting is **$1530.84**

Total energy potentially saved for motion sensor in Palace
Assumptions:

1. Operation period before motion sensor installation is 3000 hours/year
2. Operation period after installation reduced by 600 hours (may vary with usage)
3. Based off the info provided in pamphlet by vendor : 50-60% energy saved by replacing 400W metal halide fixture operating 3000 hours a year with a 196 W fluorescent fixture operating 2400 hours a year.

The energy savings per year is calculated using the following formula:

$$Energy\ saving\ (\%) = \frac{[illegible]}{[illegible]} \times 100\%$$

	Pamphlet	Juda	LED fixture
metal halide wattage (W)	400	-	-
Initial operation hour/year	3000	3000	3000
Total lighting wattage (W)	196	11 664	4620
Final operation hour/year	2400	2400	2400
Savings claimed/year (%)	60.8	**20.0**	**68.3**

Table G.1.4 shows the estimated energy saving for motion sensor installation in Palace

Total annual lighting bill saved for Palace:
Assumptions:
1. Operation hour before motion sensor installation is 3000 hours
2. Operation hour after motion sensor installation is 2400 hours
3. Regular energy charge: $0.05168/kWh (from 7am to 8pm)
4. Saving is compared to lighting bill for fluorescent lighting with no motion sensor

The annual bill is calculated using the following formula

$$Annual\ lighting\ bill\ = \frac{Total\ wattage\ \times operation\ hour}{1000} \times 0.05168\frac{\$}{kWh}$$

Lighting and motion sensor	Estimated annual bill ($)
Fluorescent lighting, no motion sensor	1808.387
Fluorescent lighting + motion sensor	1446.709

LED + motion sensor	573.0278
Saving with motion sensor installation (fluorescent lighting)	361.6773
Saving with motion sensor installation (LED lighting)	1235.359

Table G.1.5 shows the annual saving for lighting bill in Palace for both fluorescent lighting and LED lighting.

Payback period

The payback period is calculated using the following formula

$$Payback\ period\ = \frac{Total\ cost}{annual\ saving}$$

Lighting	Total cost ($)	Annual saving ($)	Payback period (year)
Fluorescent lighting	2223.14	361.68	6.15
LED lighting	1530.84	1235.36	1.80

Table G.1.6 shows the payback period for motion sensor installation in Palace

G.2: Motion sensor in Pits

To calculate the number of relay switch needed in Pits, we need to calculate the total Ampere for each rooms since each relay switch has a maximum load of 16A.

To calculate A for alternating current, the following formula is used:

$$A\ = \frac{W}{V \times Power\ Factor}$$

The power factor for fluorescent light is 0.60.

Wattage for Fluorescent T8 is 69W while for T12 is 48W.

Room no.	Fixture no	Lamps/fixture	Watt total	fixture type	V/fixture	A
154	10	4	2760	industrial	120	38.33333

154	3	4	828	strip	120	11.5
155	8	4	2208	industrial	120	30.66667
157	9	3	1863	troffer	127	24.44882
158	4	3	828	troffer	127	10.86614
159	17	3	3519	troffer	127	46.1811
164	12	3	2484	troffer	127	32.59843
166	20	3	4140	troffer	127	54.33071
177	16	6	4608	high bay	120	64
154 closet	1	2	138	industrial	120	1.916667
157 office	1	2	138	wrap	120	1.916667
159 closet	1	2	138	wrap	120	1.916667
164A	12	3	2484	troffer	127	32.59843
174A	3	3	621	troffer	127	8.149606
175 storage	6	2	828	wrap	120	11.5

Table G.2.1 shows the total A for each rooms in Pits with current lighting

From there, we can calculate the total number of relay switch by dividing the total A to 16A, and rounding up the number.

Notes and assumptions:

1. Relay switch 16R-DV-B: cost is $98.90/unit
2. Motion sensor Lutron LRF2-OWLB-P-WH cost: $56.52/unit
3. Assume lighting only used from 7am to 8pm range (Regular energy charge:

$0.05168/kWh)

4. Operation hour before motion sensor installation: 3000 hours
5. Operation hour after motion sensor installation: 2400 hours (may vary with usage)

Room no.	No. of relay	No. of motion sensor	Material cost ($)	Initial usage (kWh)	Usage after installation (kWh)
154	3	1	353.2	8280	6624.0
154	1	1	155.4	2484	1987.2
155	2	1	254.3	6624	5299.2
157	2	1	254.3	5589	4471.2
158	1	1	155.4	2484	1987.2
159	3	1	353.2	10557	8445.6
164	2	1	254.3	7452	5961.6
166	3	1	353.2	12420	9936.0
177	4	2	508.6	13824	11059.2
154 closet	1	1	155.4	414	331.2
157 office	1	1	155.4	414	331.2
159 closet	1	1	155.4	414	331.2
164A	2	1	254.3	7452	5961.6
174A	1	1	155.4	1863	1490.4

175 storage	1	1	155.4	2484	1987.2
TOTAL			3673.5	82755	66204.0

Table G.2.2 shows the material cost and estimated energy usage in Pits

Assuming that the cost of labor for 1 relay switch is $108, the total cost for installing motion sensor in Pits is **$6641.52**.

The estimated annual energy saving calculated by subtracting total energy usage before installation by total energy usage after installation: 82755.0 kWh - 66204.0 kWh = **16551 kWh**

The estimated annual lighting saving is calculated by multiplying the energy saving by regular energy charge: 16551 kWh ×0.05168 $/kWh = **$855.36**

Lighting: LED light

Notes:

1. Power factor for LED lighting : 0.95
2. LED wattage is based off the wattage proposed in PSC Grants

Room	Fixture no	Lamps/ fixture	LED replacement wattage (W)	Watt total (W)
154	10	1	12	120
154	3	1	12	36
155	8	1	12	96
157	9	1	12	108
158	4	1	12	48

159	17	1	12	204
164	12	1	12	144
166	20	1	12	240
177	16	1	18	288
154 closet	1	1	12	12
157 office	1	1	12	12
159 closet	1	1	12	12
164A	12	1	12	144
174A	3	1	12	36
175 storage	6	1	12	72

Table G.2.3 shows the total ampere for each rooms in Pits if using LED lighting

From here, we can see that the total relay switch needed is 1 for each room.

Notes:

1. Relay switch 16R-DV-B cost: $98.90/unit
2. Lutron LRF2-OWLB-P-WH cost: $56.52/unit
3. Assume lighting only used from 7am to 8pm range (Regular energy charge: $0.05168/kWh)
4. Operation hour before motion sensor installation: 3000 hours
5. Operation hour after motion sensor installation: 2400 hours (vary with usage)

Room	no. of relay	no of motion sensor	material cost ($)	usage with no motion sensor (kWh)	usage after motion sensor installation (kWh)
154	1	1	155.42	360	288

154	1	1	155.42	108	86.4
155	1	1	155.42	288	230.4
157	1	1	155.42	324	259.2
158	1	1	155.42	144	115.2
159	1	1	155.42	612	489.6
164	1	1	155.42	432	345.6
166	1	1	155.42	720	576
177	1	2	211.94	864	691.2
154 closet	1	1	155.42	36	28.8
157 office	1	1	155.42	36	28.8
159 closet	1	1	155.42	36	28.8
164A	1	1	155.42	432	345.6
174A	1	1	155.42	108	86.4
175 storage	1	1	155.42	216	172.8
TOTAL			2387.82	4716	3772.8

Table G.2.4 shows the total material cost, energy usage before motion sensor installation and after motion sensor installation.

If we assume that the labor cost for each relay switch is $108, the total material cost for motion sensor in Pits with LED lighting (not including LED lighting material and labor cost itself) would be **$5355.82.**

The estimated total energy saving is done by subtracting the total energy usage before motion sensor installation with current lighting (fluorescent) with total energy usage after motion sensor installation with LED lighting: 82755.0 kWh - 3772.8 kWh = **78982.2 kWh**

The estimated total lighting bill saving is done by multiplying the total energy saving by regular energy charge: 78982.2 kWh ×0.055168 $/kWh = **$4081.8**

G.3: Reducing time delay on motion sensor

Notes and assumptions:

1. Current time delay setting in classrooms is 30 minutes
2. Operation hour is 6 hours/day and school is operating for 180 days/year[14]
3. Energy saving percentage is based off the data provided Electrical construction and maintenance website (40% - 55%)
4. Operation hour falls within the regular energy charge period : $0.05168/kWh
5. LED lighting wattage replacements is based off the wattage proposed in PSC Grants
6. Annual saving with LED lighting is compared to with current lighting and current time delay setting number.

motion sensor time delay	operation hour/day	estimated energy saving (%)	operation hour/year
min time delay (20 seconds)	2.7	0.55	486
max time delay (30 minutes)	6	0	1080
recommended (15 minutes)	3.6	0.4	648

Table G.3.1 shows the estimated energy saving and operation hour with differing time delay

		Current lighting				All LED lighting replacement			
School wing	Lighting	Watts/ lamp	Lamps/ fixture	No of fixture	Total Watts	Watts /lamp	Lamps/ fixture	No of fixture	Total Watts
High school	Fluorescent T8	23	2	50	2300	12	1	50	600
	LED	14	1	158	2212	14	1	158	2212

Elementary school	Fluorescent T8	69	3	7	1449	12	1	7	84
	LED	15	1	70	1050	15	1	70	1050
TOTAL					7011				3946

Table G.3.2 shows the total wattage usage with current lighting and LED lighting for both high school and elementary school wings.

	Current lighting			All LED lighting		
Time Delay	Energy used (kWh)	annual lighting ($)	Annual saving ($)	Energy used (kWh)	annual lighting ($)	Annual saving ($)
Minimum (20 s)	3407.35	176.09	215.22	1917.756	99.11	292.11
Recommended (15 min)	4543.13	234.79	**156.53**	2557.008	132.15	**259.17**
Maximum (30 min) - current setting	7571.88	391.31	0	4261.68	220.24	171.07

Table G.3.3 shows the annual lighting bill saving for both current lighting and LED lighting for each time delay settings.

The energy saving for time delay set to 15 minutes with current lighting as compared to 30 minutes time delay with current lighting is **3028.75 kWh**, while with all LED lighting replacement is **5014.87 kWh**.

G.4: Energy savings for motion sensors
Notes:

1. Total initial annual lighting usage for all Pits, Palace and classrooms are 125318.88 kWh
2. Total Juda electricity usage is 627486 kWh (Appendix A.1)
3. Lighting accounts for 20% of electricity in Juda: 125318.88/627486×100% = 19.97%

4. Initial usage means initial energy usage with current lighting and no motion sensor installed
5. The following formula is used for energy saving to initial usage column

$$Energy\ saved = \frac{Energy\ saving\ (kWh)}{Initial\ energy\ usage\ with\ respective\ location} \times 100\%$$

4. The following formula is used for energy saving to all lighting usage

$$Energy\ saved\ = \frac{Energy\ saving\ (kWh)}{125318.88 kWh} \times 100\%$$

5. The following formula is used for energy saving to Juda electricity usage

$$Energy\ saved\ = \frac{Energy\ saving\ (kWh)}{627486\ kWh} \times 100\%$$

Location	Initial all lighting (kWh)	with motion sensor (kWh)	Energy saving (kWh)	Energy saving to initial usage (%)	Energy saving to all lighting usage (%)	Energy saving to Juda electricity usage (%)
Pits	82755	66204	16551	20.0	13.20	2.64
Palace	34992	27993	6999	20.0	5.58	1.12
Classrooms	7571.88	4543.18	3028.7	39.99	2.42	0.48

Table G.4.1 shows the energy saving with current lighting in all three locations

Location	Initial all lighting (kWh)	Motion sensor + LED lighting (kWh)	Energy saving (kWh)	Energy saving to initial usage (%)	Energy saving to all lighting usage (%)	Energy saving to Juda electricity usage (%)
Pits	82755	3772.8	78982.2	95.44	63.02	12.59
Palace	34992	11088	23904	68.31	19.07	3.81
Classrooms	7571.88	2557.01	5014.87	66.23	4.00	0.80

Table G.4.2 shows the energy saving for all three locations if using all LED lighting.

Appendix H: Decision Matrices

H.1: Behavioral Decision Matrix

Criteria	Weightage	Cool Choices	Smart Power Strips	Computer Sleep Settings	Stickers
Cost	5	5	4	5	4
Energy Saved	5	4	3	4	3
Practicality	3	4	5	5	4
Appeasibility	4	4	3	3	2
Total	-	73	62	72	55

H.2: Structural Decision Matrix

Criteria	Weightage	Window Insulation	LED lights Upgrade	Motion Sensor	Smart thermostat	Coating Roof	AC insulation
Cost	5	2	1	4	3	3	5
Energy saved	5	4	5	4	4	2	4
Practicality	3	4	5	5	1	3	5
Lifetime	4	4	4	4	4	5	5
Total	-	58	61	71	54	49	80

About UniverCity Year

UniverCity Year is a three-phase partnership between UW-Madison and one community in Wisconsin. The concept is simple. The community partner identifies projects that would benefit from UW-Madison expertise. Faculty from across the university incorporate these projects into their courses, and UniverCity Year staff provide administrative support to ensure the collaboration's success. The results are powerful. Partners receive big ideas and feasible recommendations that spark momentum towards a more sustainable, livable, and resilient future. Join us as we create better places together.

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