2020

Energy Efficiency and Alternative Energy Generation in Existing Buildings on a College Campus

Sameer Keshavan
South Dakota State University

Recommended Citation

Keshavan, Sameer, "Energy Efficiency and Alternative Energy Generation in Existing Buildings on a College Campus" (2020). *Electronic Theses and Dissertations*. 5003.
https://openprairie.sdstate.edu/etd/5003

ENERGY EFFICIENCY AND ALTERNATIVE ENERGY GENERATION IN EXISTING BUILDINGS ON A COLLEGE CAMPUS

BY

SAMEER KESHAVAN

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Mechanical Engineering

South Dakota State University

2020

THESIS ACCEPTANCE PAGE

Sameer Keshavan

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Michael Twedt, P.E.
Thesis Advisor Date

Kurt Bassett, Ph.D., P.E.
Head, Department of Mechanical Engineering Date

Nicole Lounsbery, PhD
Director, Graduate School Date

I dedicate this paper to my family: my dad, Keshavan Shanmugam, and my mom, Sandhya Keshavan. They have financially and emotionally supported me throughout my undergraduate and graduate school journey. I also thank Taige Tople for believing in me and proofreading my paper countless times. Lastly, I want to recognize all the instructors in my life who have made me a better student because they dedicated their life to teaching. Without the confidence and sacrifices of my loved ones, I would not have been able to complete this thesis seamlessly.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my thesis advisor, Michael Twedt, for the continued support of my master's degree research and his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in conducting quality research and. I could not have imagined having a better advisor and mentor for my thesis study.

Additionally, I would like to thank the rest of the thesis committee members: Engineering Department Head professor Kurt Bassett, Dr. Jeffery Doom, and Dr. Senthil Subramanian, for serving in my committee. Their encouragement, insightful comments, and hard questions were invaluable in subjecting my paper to continuous improvement. Also, I would like to extend my sincere gratitude to Colin Gaalsywk and Barry Mielke for their continued support by sharing the data and insight about SDSU buildings.

Overall, I express my gratitude to the SDSU Mechanical Engineering and Physics Department for allowing me to conduct my research and providing any assistance I needed. Special thanks go to Jane Boggs and Sally Krueger for taking care of the administrative paperwork, so students like myself can focus on our research.

TABLE OF CONTENTS

ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigeration & Air-Conditioning Engineers
BAS	Building Automation System
BTU	British Thermal Unit
DOE	Department of Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
GPM	Gallons Per Minute
HVAC	Heating, Ventilation, Air-Conditioning
IEEE	Institute of Electrical and Electronics Engineers
kBTU	Thousand (1000) BTUs
kWh	Kilo-Watt hour
MMBTU	Million (1000,000) BTUs
NREL	National Renewable Energy Laboratory
RPM	Revolutions Per Minute
SDSU	South Dakota State University

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

ENERGY EFFICIENCY AND ALTERNATIVE ENERGY GENERATION IN EXISTING BUILDINGS ON A COLLEGE CAMPUS

SAMEER KESHAVAN

2020

Universities and colleges are looking for ways to be sustainable and save energy costs on their campuses. In terms of raw dollars, "*America's colleges and universities spend almost $7 billion a year in energy and utilities*". Campus buildings consume more than 80% of the energy utilized by the universities and it is often used in the form of electricity for lighting, ventilation, air-conditioning, and natural gas for heating. By reducing energy use, it will translate into cost savings that could be utilized towards student programs, facility improvements, and other university initiatives. This can be achieved by energy conservation efforts and integrating renewable energy systems in campus buildings.

This thesis is focused on studying three buildings on the South Dakota State University campus and analyzing their energy consumption. Energy consumption is modeled using eQuest energy modeling software to determine current and proposed electrical, heating, and cooling energy use. Lastly, renewable energy was integrated into the buildings to offset electrical and heating loads to increase energy savings and resulting energy costs.

The total electricity consumption can be reduced from 414,490 kWh to 94,325 kWh yielding a 77% savings in energy usage. Heating loads can be reduced from 24,468 therms to 15,304 therms, resulting in 37% natural gas consumption savings by upgrading

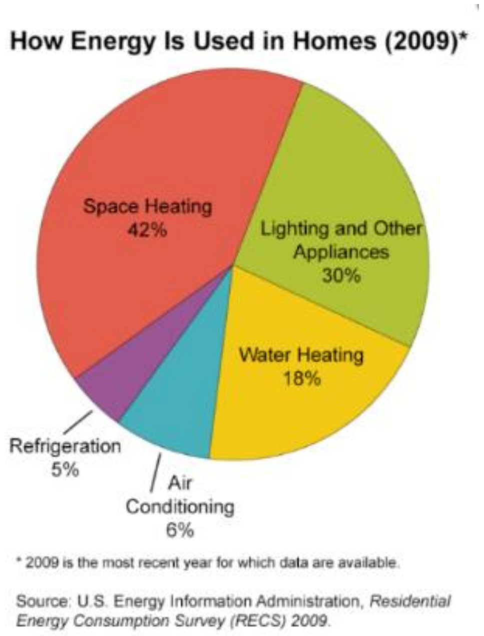
to high-efficiency mechanical systems and integrating solar wall technology. This energy savings corresponds to a monetary savings of over $20,200 annually. Additionally, these savings also contributed to saving over 281.1 tons of CO_2 per year from being emitted into the atmosphere.

Validation is an important step in the process to assess if the simulation results are accurate. The simulation results are validated using utility data provided by the Facilities and Services Department for the specific buildings.

INTRODUCTION

Typically, when people talk about the necessities of human survival, food and water usually top the list. While nutrients and hydration are important to keep people functioning on a basic level, shelter from the harsh elements and natural dangers is usually overlooked as an element of survival. Not only do buildings provide literal protection from the weather, but we also design them for leisure, utility, and symbolic purposes. Buildings are not normally a significant topic for discussion, but to talk about alternative energy feasibility on college campuses, is a topic worth discussion.

Buildings in the United States are divided into three categories: residential, commercial, and manufacturing. The first category, the residential sector, is defined as housing and mobile units owned by families. This excludes institutional accommodations such as health care facilities, school dormitories, and hotels. Energy consumption in the residential sector is dependent on space and water heating, electronics, lighting, air-conditioning, and refrigeration. Demand for air-conditioning usage has doubled since the 1980s and there has been an increase in appliance use such as microwaves, dishwashers, and washing machines over the past 30 years. The two most common sources of energy used to power the buildings are natural gas and electricity along with propane and heating oil. Figure 1 shows the distribution of energy in U.S. households.

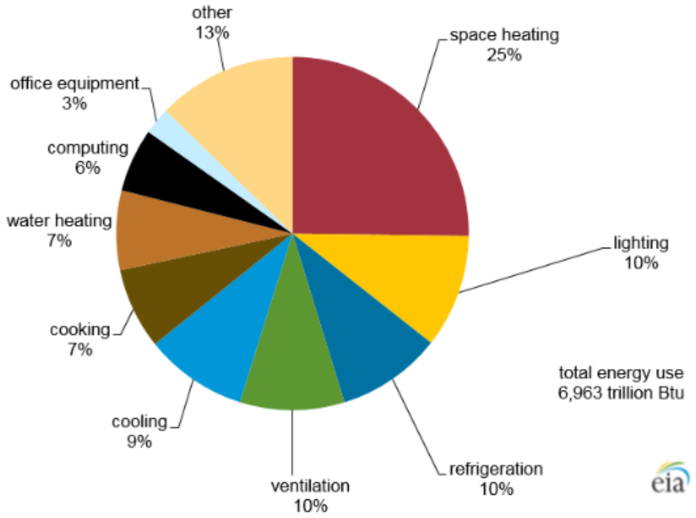

How Energy Is Used in Homes (2009)*

* 2009 is the most recent year for which data are available.

Source: U.S. Energy Information Administration, *Residential Energy Consumption Survey (RECS) 2009.*

Figure 1: Energy consumption in residential building

The second category, commercial buildings, include spaces like offices, hospitals, schools, police stations, places of worship, warehouses, hotels, and shopping malls. Commercial spaces account for about 25% of the energy consumption nationally. To maintain comfort levels, buildings must be equipped with their own individual heating and cooling systems. Figure 2 below shows the energy consumption in commercial buildings in 2012.



Source: U.S. Energy Information Administration, 2012 Commercial Buildings Energy Consumption Survey.

Figure 2: Energy consumption in commercial building

Lastly, the manufacturing sector is involved in the manufacturing and processing of items from raw materials and commodities. This means buildings involved in manufacturing exhibit massive energy demands that need to be produced for that sector. In the US, around 19,045 trillion BTU was used in 2014 to service the manufacturing industry. From a global perspective, according to the Energy Information Administration (EIA), the industrial sector uses more delivered energy than any other end-use sector, consuming about 54% of the world's total delivered energy. The industrial sector is usually categorized into energy-intensive manufacturing, nonenergy intensive manufacturing, and non-manufacturing. Gross output (U.S. Energy Information Administration, 2016) of the industrial sector is projected to exceed more than double what it was in 2012. This is also demonstrated below in Figure 3. An increase in output means the energy demand in the industrial sector is only going to increase, which is another reason we need to conserve our energy usage use our resources wisely.

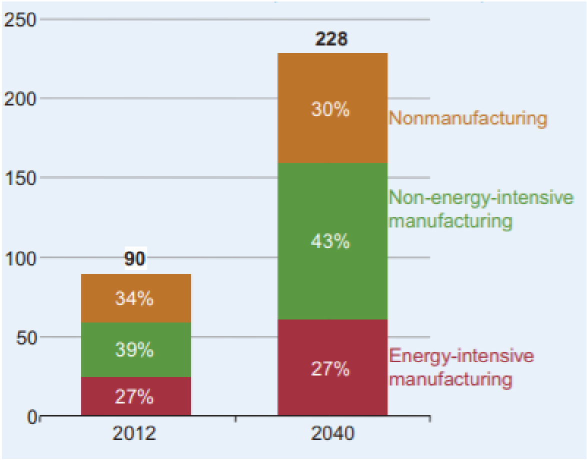


Figure 3: Gross output (in trillion dollars)

When buildings are close to each other, they could be served with central heating and cooling systems shared between two or more buildings which are often more energy efficient. When HVAC systems are used in clusters, i.e. combinations, to deliver thermal energy to a building from an outside source, they are called District Energy Systems (DES). Having DES allows for easier upgrades and maintenance as all the equipment is in one place. Secondly, it is easier to acclimate peak demand on the electrical systems and thereby creating a more reliable system for tolerating extreme weather events. Third, when district energy systems are combined with Heat and Power generation, also known as cogeneration plants, they can deliver efficiencies above 80%. Traditionally, district systems use fossil fuels such as coal or natural gas to serve the boilers for heating purposes. All of these systems consume require massive amounts of energy, which means burning more fossil fuels which are very limited. Other renewable energy sources that can be incorporated into DES (Environmental and Energy Study Institute, 2011) are geothermal, hydrothermal, solar thermal, biogas, or other types of biomass. DES not only helps in lowering costs by reducing operating costs but also minimizes the need to import fuel for heating or cooling.

LITERATURE REVIEW

The literature review is conducted to understand the need for conserving energy and how it can be implemented on a college campus. Energy conservation through major and minor upgrades will be studied to understand the different ways through which energy consumption can be reduced. Examples of case studies of universities across the U.S where renewable energy was integrated will be looked at to realize different options that can be utilized at SDSU. Each case study will involve implementing either major or minor upgrades in addition to integrating renewable energy systems into the building. These case studies will provide insight into the expected return on investment for renewable energy. Brown Hall at SDSU, which was retrofitted in 2016 with efficient mechanical systems to reduce energy consumption, will be studied to understand expected energy savings that are possible.

One key metric to assess the building's performance is to look at the Energy Use Intensity (EUI) of the building. According to ASHRAE, the EUI is defined as the total amount of energy used by a building (electricity, natural gas, and other fuels) per square foot of floor area. This square footage is defined as the gross square footage which includes the sum of the floor area of all spaces inside the building (ASHRAE Standard 105-2014). The energy consumed is calculated by adding all the energy units reflected in the utility bills. Implementing energy benchmarking provides multiple benefits when monitoring energy usage in buildings. The first benefit is that understanding building's energy consumption assists in evaluating if the building's performance is getting better or worse over time. Second, a comparison of energy usage of similar types of buildings provides insights on where a building's performance can be improved. Third, analyzing energy upgrades is easier when the building's EUI is being continuously monitored.

Fourth, assessing a building's EUI supports in developing an energy management plan and helps in making a case of capital investment for upgrading building retrofits. Lastly, this plan leads to energy savings which will result in lower energy costs and faster return on investments.

For most properties, EUI is measured in one thousand BTUs per square foot (kBTU/sf) for analyzing energy use in commercial buildings (DOE, n.d.). SDSU also analyzes the energy consumption of buildings with the same metric. This thesis will also utilize the same metric to compare the energy consumption of buildings performed to assess the performance of the buildings. Electricity can be converted from kWh to BTU by multiplying with 3,412 BTU/kWh. Similarly, natural gas can be converted from therms to BTUs by multiplying with a factor of 100,000 BTU/therm (ASHRAE, 2017).

Why Conserve Energy?

One of the big reasons to conserve energy (Legend Power Systems, 2019) is to save money, and this reason can incentivize creating a culture of conservation amongst businesses and homeowners. The average household spends \$104 and \$70 per month for electricity and water respectively (Kim P, 2017). Over the course of 10 years, it amounts to \$22,000 for utility payments. Another reason to conserve energy is using less energy means less demand for nonrenewable resources. Fossil fuels are obtained from non-renewable sources such as oil and coal, and these resources are being depleted at a fast rate. Gases that trap heat inside the earth's atmosphere are called Green House Gases (Environmental Protection Agency, 2020). Common GHG are carbon dioxide, methane, nitrous oxide, and fluorinated gases. When the concentration of these gases increases in the atmosphere, solar energy from the sun gets trapped in the atmosphere and converts to heat. A significant side effect of energy conservation would be a reduction in greenhouse gas emissions and minimizing air pollution. Energy conservation pays off both financially and environmentally.

There are several stakeholders that would play a key role in conserving energy. For example, two examples of stakeholders are local city governments and universities. City and local governments manage not only environmental policy but large amounts of people, economic activities of city departments, and the political climate of towns (Dreyfus, 2016). Local governments are in a strategic position to make key decisions that will have a huge impact when it comes to conserving energy and reducing emissions. According to the Energy Information Administration, world energy consumption is expected to grow by 28% between 2015 and 2040 (EIA, 2017). The United States alone is projected to consume about 30 quadrillion (10^{15}) British Thermal Units (BTUs) worth of petroleum and other liquids for its energy use. Worldwide, we are expected to reach over 200 quadrillion BTUs by 2040. For reference, Lake Superior has 3 quadrillion gallons of water, which is enough to submerge North and South America under one foot of water. EnergyStar suggests that by "*implementing cost-effective, energy-saving strategies would cover more than half the expected growth in energy demand through 2025 and save more than $100 billion annually."* (Energy Star, n.d.)

Currently, universities and colleges are looking for ways to be sustainable and save energy on their campuses. A college's average budget spends approximately 3.5% on energy production. According to the U.S. National Center of Education Statistics (NCES, 2013), "*In terms of raw dollars, America's colleges and universities spend almost $7 billion in energy and utilities*". This means if all college campuses reduce their energy use by 10%, it will result in $700 million worth of savings annually. These savings could be utilized towards student programs, facility improvements, and other university initiatives. University campuses (Schneider Electric, n.d.) are comprised of a variety of different building types: office space, restaurants, sports facilities, classrooms, retail outlets, laboratories, and many other buildings with unique demands. With such a diverse array of building structures, universities need to begin planning on how to manage energy in their buildings for both the present day and future. Alternative energy plays an integral role for universities in moving towards sustainability. According to Perkins + Will (Coulston, 2019) in Austin, Texas, a leading design and consulting firm, "*Buildings are one of the keyways universities maintain this legacy-focused perspective. The goal is to make sure that campus structures will last and become as iconic as the institution itself.*" In addition to having a long-lasting legacy and saving money on utility cost, using alternative energy on campus buildings provides a great example for students to learn about sustainability practices firsthand.

Energy Consumption in College Campuses

Campus buildings (Environment America, 2017) consume more than 80% of the energy utilized by colleges and universities and it is commonly used in the form of electricity for lighting, ventilation, and air-conditioning, while heating is commonly accomplished with natural gas. Annually, colleges and universities (E source Companies, 2013) spend approximately \$1.95 per ft^2 and \$0.15 per ft^2 on electricity and natural gas respectively. Figure 4 shows the distribution of how electricity and natural gas are consumed in U.S. educational facilities.

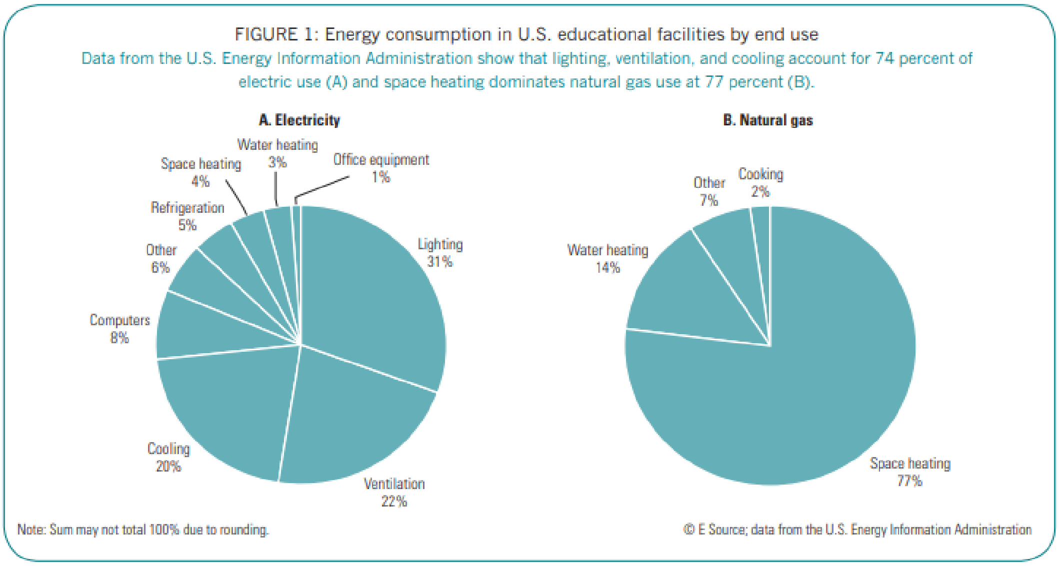


FIGURE 1: Energy consumption in U.S. educational facilities by end use

Data from the U.S. Energy Information Administration show that lighting, ventilation, and cooling account for 74 percent of electric use (A) and space heating dominates natural gas use at 77 percent (B).

Note: Sum may not total 100% due to rounding.

© E Source; data from the U.S. Energy Information Administration

Figure 4: Energy consumption in educational facilities

In terms of when energy consumption is at its peak, a study conducted at the University of Texas at San Antonio (USTA) demonstrates this phenomenon (IEEE, 2016). The University of Texas at San Antonio has 150 buildings on the main campus and four buildings located on its downtown campus. By observing overall energy consumption across campus, UTSA showed that maximum energy demand occurs on weekdays during the day and minimum demands occur during UTSA holidays when there are fewer students and staff/faculty on campus. It was observed that temperature and energy consumption are directly proportional to the downtown campus.

Another example of energy consumption rates across campus can be found in an international study conducted by the Korea Energy Management Corporation that analyzed the energy consumption of South Korean universities in 2006. According to statistics obtained by Management Corporation, "22 universities were ranked as highly energy-consuming out of all 190 universities in South Korea." The amount of energy use by universities in South Korea made up about 13.8% of the total amount of entire institutions. In conclusion, the Survey and Analysis of Energy Consumption (International Conference on Sustainable Building Asia, 2010) in Universities stated that the "*fundamental device to reduce energy consumption in university campuses is reducing energy consumption in buildings. Reduction of energy consumption in buildings is expected to bring in big profits. If universities reduce energy consumption in buildings, they can be expected big profits such as energy conservation, reduced operating costs, etc.*"

Energy Conservation in Buildings

Energy consumption can be incorporate many things ranging from low-cost or no-cost, minor improvement items, to large-scale, capital-intensive major retrofits. The following sections provide some common examples of both minor (lower cost) items that individuals have a smaller impact on energy reduction and major items.

Minor Upgrades

There are a lot of minor, economical upgrades to buildings that universities can perform to conserve energy while operating on a low, tight budget. Minor, low-cost upgrades in buildings are important because colleges can conserve energy and still have funds leftover to engage students and faculty. The following areas are examples of ways colleges and universities can conserve energy with lower individual cost items.

Computers and electronic equipment:

Computer and electronic equipment systems demand a lot of energy which also means that there is a lot of energy savings prospects (Madison Gas and Electric Company, n.d.). When the settings are enabled on-campus computers, computer management systems settings force these computers to go into sleep mode after a certain amount of inactivity. Madison Gas and Electric Company say that "*effective power management settings can cut a computer's electricity use roughly in half, saving up to $75 annually per computer*." For example, if 500 computer stations are upgraded to computer stations to computer management systems, it can yield a savings of $37,500 annually.

Lighting Control:

Keeping the rooms in a building constantly illuminated means consuming more energy and wasting money. Therefore, lights should be turned off when not in use. To guarantee that lights are turned off when not needed, there are two viable options: install occupancy sensors, which will turn off the lights in the room when there is no occupant in the room, or enlisting staff to fill in as occupancy monitors in every campus building. A study funded by the U.S. Department of Energy (Page, 2011) found that lighting controls can reduce energy consumption by 28%. For example, a $1000 lighting bill can be reduced by $280 annually. Various Factors such as building orientation, location, use, weather, occupancy, blinds, reflectance should be considered before installing to maximize saving opportunity.

Pre-wash sprayers in kitchens:

These sprayers are used in the kitchen to clean utensils before being placed in the dishwasher. Most sprayers use 5 gallons per minute (GPM), and these sprayers could be easily replaced with low flow sprayers that limit the flow rate to 1.6 gpm. The return on investment for this type of measure is typically less than two months, as low flow valves are inexpensive to purchase.

LED Lights:

Universities should consider replacing fluorescent and LCD lights with LEDs, as they are known to have a longer life and reduced life cycle cost. LED lights are an expensive investment when compared to CFL or halogen lamps. However, buildings like residence halls, where lights are often left on for long periods of time, can significantly reduce energy consumption. Since all LED fixtures are not equally effective, one must be cautious while selecting the right product for the right setting. For example, LED troffers are more effective than tubular LED lamps for ambient lighting.

Lights in parking lots:

Another use of better LED lights is in parking lots. On average, most parking lots are over lit - 1 foot of candlelight is more than enough than what is currently being in use. Traditionally, High-Intensity discharge (HID) sources like metal halide (MH) and pressure sodium were used in parking lots, but fluorescent lamps, CFLs, and induction lamps have taken over in recent years for outdoor lighting by offering good quality color and better control options. LEDs don’t just save money but also reducing light pollution in addition to high efficiency and longer life.

Building Automation Systems:

Stakeholders should ensure temperature setbacks are facilitated with building inhabitance on a quarter or semester basis. Engineers can work with grounds staff to adjust the HVAC plans for the building automation system (BAS) with anticipated occupancy that would use energy optimally. Universities should recognize buildings that are not utilized during the evening, on ends of the week, or for extensive stretches of time like semester or holiday breaks. Once these buildings are identified, the energy team should change the temperature settings in those areas. Additionally, making sure that HVAC frameworks are not set to overcool or overheat structures. For buildings with regular occupancy rates that do not have BAS, programmable temperature regulators can be used as a substitute.

Water Heater Setpoint Control:

Water heaters setpoint temperatures should be lowered (complying with health requirements) in buildings that don't have a research facility or cooking offices. Water temperature is usually set higher than expected for buildings with higher occupants like residence halls. A temperature setpoint of 120° Fahrenheit (F) is typically adequate.

Vending machines:

Refrigerated vending machines work throughout the year, utilizing 2,500 to 4,400 kWh/year and radiating heat, and adding to cooling loads in the spaces they occupy. Timers and occupancy sensors can yield significant savings in this condition since they enable the machines to turn on when a customer is available or when the compressor must be turned on to keep up the item at the required temperature. When replacing or buying additional machines, Energy Star qualified models should be purchased – each unit can bring back on average $150/year in utility bills.

Air filters:

A high-quality filter that is designed for the lowest pressure drop will reduce the energy required to push the air through the filter. This solution would see more up-front costs, but it ensures lower utility costs in the future due to less resistance in the ventilation system.

Major Upgrades

While smaller upgrades are easier to advocate for and implement, long-term energy-saving arrangements should be considered in addition to short-term solutions. Despite the large-scale implementation and more expensive financial investments, the return on investments for immediate changes of energy-saving upgrades on campus are promising. Major upgrades reduce energy consumption, which in turn, decreases the amount of fossil fuels needed to burn to power these systems, resulting in fewer carbon emissions. Some examples of major upgrades are as follows:

High-efficiency HVAC units:

Older HVAC systems (U.S. DOE, 2017) lose their efficiency over time, which means they will consume more energy and increase the cost to operate it. As they age, they also tend to break down more often, which can result in unexpected downtime and expensive repair costs. This can also lead to poor indoor air quality, productivity loss, and an overall uncomfortable environment for the occupants. An upgrade to a high-efficiency HVAC system can solve the above-mentioned issues and provide the occupants inside the building with a comfortable environment.

A high-efficiency system manages to deliver this by using a combination of different technologies. For example, variable speed fans, when used with modulating furnace and multiple stage compressors, constantly adjust the total energy output that is needed to accurately match the principal load. In situations where certain noise criteria need to be observed like in conference rooms, laboratories, and classrooms, blowers can be configured to run at lower speeds to reduce the “wind” effect throughout the building. This type of system helps in maintaining an adequate amount of dehumidification and virtually stops the system from short cycling which leads to frequent temperature rises in buildings. In addition to comfort, there are also monetary savings when higher efficiency HVAC systems are used. Replacing an older rooftop unit (Rolston, 2014) with an Energy Efficiency Ratio (EER) of 6.2 with a modern 13 EER rooftop unit can yield savings in energy costs by 52%.

Several studies performed by the Environmental Protection Agency (EPA) shows that air circulating inside a closed environment can have higher levels of pollutants than the outside air (EPA, 2017). Contaminants such as mold, mildew, pollen, and viruses can increase rapidly in older systems, specifically in older systems where water is present. A new system with advanced filters and anti-microbial technology is equipped to lower the spread of these airborne contaminants.

Demand controlled ventilation:

Demand control ventilation is a system that makes sure a building is properly ventilated, cost-effectively, and improving the indoor air quality at the same time. Usually, various sensors in these ventilation units constantly monitor and measure the room conditions in the space and provide real-time feedback to the control system. This feedback increases or decreases the exhaust fan speed to adjust the ventilation rates for precise use and habitation of the building.

Most building ventilation systems are designed to operate at constant or pre-programmed rates, irrespective of the occupancy level of the building (KMC Controls, n.d.). Ventilation rates are usually designed for maximum occupants, and this wastes a considerable amount of energy through operating exhaust fans. For example, in a university environment, spaces that have substantial swings in occupancy such as assembly rooms, recreational centers, classrooms, and cafeterias, energy consumption can be reduced by lowering the amount of ventilation provided by the HVAC system through low-occupancy hours. A demand-controlled ventilation framework detects the level of carbon dioxide in the return air stream, utilizes it as a pointer of occupancy, and decreases supply air when carbon dioxide levels are low. Demand control ventilation (Yorkland Controls, 2011) sequence can reduce energy cost by at least 10% and as much as 40% annually by adapting the building's ventilation based on occupancy rates.

Reflective rooftop coatings:

Painting the rooftop of a facility with a highly reflective color can minimize the scale at which a building absorbs heat. This solution can reduce the cooling load by 10 to

15 percent. According to the EPA, you can expect net annual savings of just under 50 cents per square foot of roof (EPA, n.d.). For example, a 5000 square feet roof could save up to $2500 annually. This value includes the capital cost such as roofing products, reduced cooling costs in the summer, lower maintenance costs over time due to the increased life span of the cool roofs compared to a conventional roof.

Tankless Water Heater

Water heating equipment is one of the major requirements for any commercial building, so the equipment needs to be reliable, economical, and meet the demands of the building. Water heating systems can be operated by using an either a gas burner or electric elements. A tankless water heater heats the water without using a storage tank. When the demand for hot water is detected, cold water goes through the system and supplies the water on demand. This eliminates the need to wait for the storage tank to be filled with hot water. The ripple effect of not having a storage tank frees up valuable space in buildings and is significantly less labor-intensive to install compared to traditional water heaters. Propane tankless water heater can also meet the need where high flow rates are required. Typical flow rates are 2-5 gallons (7.6-15 liters) per minute. In situations where a system is used for multipurpose use which include showers & dishwashers, multiple systems can be connected in parallel to meet the demands of hot water (U.S. DOE, n.d.).

As commercial buildings are moving more and more towards energy efficiency products and design, propane tankless heaters rise to provide a highly efficient system, reaching efficiency ratings as high as 98% (Cordill, 2020). This efficiency comes at a high cost. With a lifespan of up to 20 years, increased reliability, and energy cost savings, they all help offset a high capital investment. In contrast, traditional water heaters may only last for 10-15 years.

Gray-water Heat Recovery System:

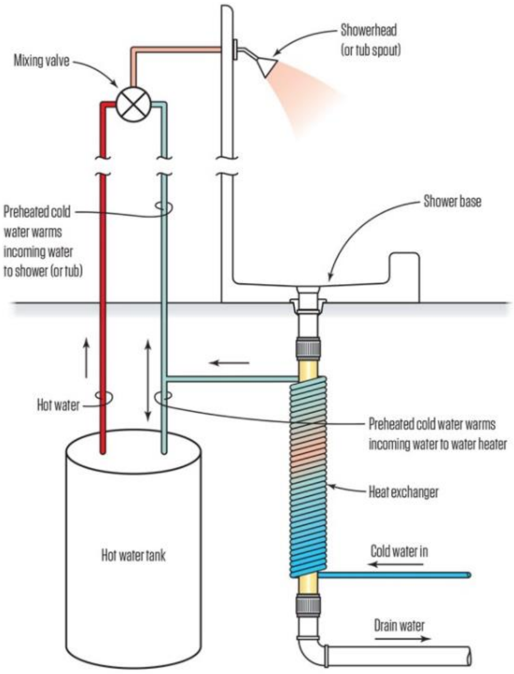


Figure 5: Gray-water heat recovery schematic

A gray-water heat recovery system is a way to salvage some of the energy lost as the hot water drains away. The hardware comprises of substituting a segment of pipe that redirects approaching cold water to a coil wrapped over a shower drain. As hot wastewater flows through, freshwater is reheated. These systems are effective when high-temperature water is required, and heated wastewater is produced. The cost to install this system is very minimal, as there are no pumps or moving parts, so it doesn't require scheduled maintenance (Baczek, 2016). Gray-water heat-recovery systems can retain 50 to 60 percent of water-heating energy when introduced in a shower duct, particularly in buildings with significant hot water use such as recreational centers and residence halls. Additionally, drainpipe heat exchangers triple the primary hour capacity of water heaters. This system typically costs less than $1000 and the average return on investment is estimated to be observed in as little as two years.

Boiler Retrofits:

Return on investment from boiler retrofits can be substantial. Updated boilers highlight an assortment of effectiveness enhancements that can make the case for substituting old boilers before they break down. Upgrades in a boiler retrofit include condensing heat exchangers, closed combustion, and electric start, and fan-assisted ignition. Compact boilers are more effective than larger ones, and grouping small boilers permits higher efficiency at each stage in addition to reducing redundancy. A small boiler can be added to a larger boiler to achieve the base heating load and saving the larger boiler to be used if additional heating is required.

Temperature Control:

The HVAC system requires the user to set the temperature. Usually, occupants set the thermostats for around 68F to 70F to feel comfortable. This temperature setting controls the coolness of the space. When you have the system in this setting, the system will continually operate. Space will be maintained at the desired temperature, but it will consume a great amount of energy to achieve the result, hence costing more money. The system works by taking the indoor air and either cools or heats this air by passing through the evaporator coil. This air is circulated back into space, cooler or hotter than before. The temperature set on the thermostat dictates how long to function. The pumping system which drives the supply flow and pressure is designed for the highest system demand. Without controls, the pump will operate at full speed. This wastes energy and reduces the life of the mechanical system overall. The heating and cooling loads can be used to modulate the system to the minimum flow required for the system to operate at optimum efficiency, hence reducing energy use and the cost associated with it.

Energy Recovery Wheel:

Building energy systems that can provide more output with less input is generally considered a good business practice. The energy recovery wheel system accomplishes exactly that by recovering up to 80% of the energy of the exhaust air. The energy recovery wheel, shown in Figure 6, consists of a circular honeycomb matrix of desiccant material, which rotates slowly with the supply and exhaust air stream of the HVAC system (Shiminski, 2012). This allows the wheel to capture the temperature and humidity of the exhaust air and transfer them to the incurrent air (Cubick, 2017). The physical property of the energy recovery wheel can then be adjusted to either heat or cool the air, as well as humidify or dehumidify depending on the desired temperature and humidity. Overall, as the fresh air is brought into the building, the air-conditioning system works less to heat or cool the space. This results in reduced energy costs and a longer life span of the equipment. By using the energy recovery wheel, energy consumption for cooling loads can be reduced by as much as 80% and corresponding costs can be reduced by thousands of dollars every year for the lifespan of the system (Sullivan, 2010). The payback period for the energy recovery wheel has been estimated to be less than half a year in multiple studies (Greenheck Inc., 1997).

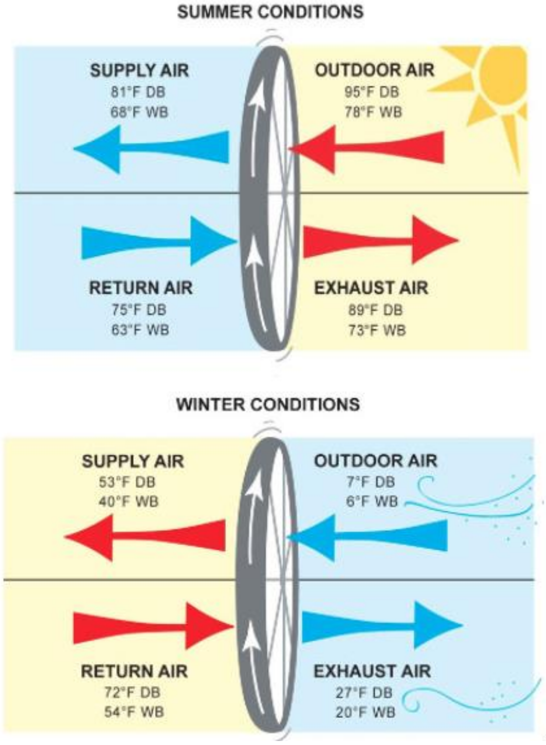


Figure 6: Energy recovery wheel

Economizer:

An economizer, shown in Figure 7, is part of the HVAC system for commercial buildings (Lawrence Berkeley National Laboratory, n.d.). If an air conditioning system does not have an economizer option, it can be added on by performing a retrofit to the existing equipment (Rosone, 2017). There are different types of economizer systems that can be considered based on weather conditions and building requirements. The first type is a dry bulb economizer that only detects the temperature of the air and not the humidity. Secondly, a single enthalpy economizer is where a sensor measures both the temperature and humidity of the outside air. And lastly, a differential enthalpy economizer uses a sensor to measure outdoor air enthalpy and return air enthalpy.

Temperature control logic controllers and sensors are used to gauge the outside air temperature and humidity levels. If the required indoor air temperature and outside air temperature are similar, the system will bring in the outside air to cool the space. The economizer uses the dampers to control the amount of air that’s brought in, ventilated, and exhausted from the building. This helps in reducing energy consumption and lowers energy costs as the air-conditioning system must run less. The snowball effect of the lower run time of AC units is increased longevity of the system as there will be fewer maintenance requirements and costs. Lastly, economizers improve the indoor air quality through increased ventilation as it brings in fresh, outside air and exhausts the stale air that is circulated in the building. A study published by the University of North Texas estimates that economizers resulted in saving between $6,000 and $16,000 by reducing sick leave (Fisk et al., 2004). Another study performed by Intel company estimated that their data center facility can save up to $144,000 annually at a 500kW facility (Energy Star, n.d.).

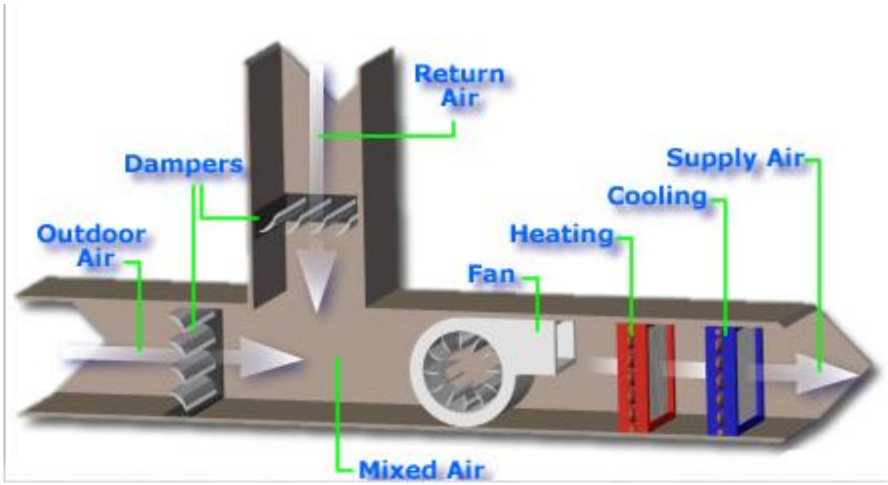


Figure 7: Typical economizer schematic

Energy Management Plan (EMP)

One way to incorporate the minor and major energy upgrades above is to design a process that allows for a systematic way to approach these changes. An Energy Management Plan accomplishes exactly that. According to Housing Services Cooperation, "*An Energy Management Plan (EMP) is a written plan in which you describe the steps and approaches you will take to increase energy efficiency and conserve energy in all areas of your building. It typically covers a three to five-year period. The plan includes a building profile, short- and long-term energy reduction strategies, reduction targets, staff responsibilities, financial considerations, and how you will evaluate progress. It's a live document that can be changed in response to results, unexpected events, and changing needs*". Once an EMP is created, it provides a clear path for universities and colleges to improve efficiency, build on progress, and manage energy costs when designing buildings (Housing Services Corporation, 2015). Having this plan ensures construction management and education administrators will be less reactive to the drastic change in budget and energy priorities. Additionally, an EMP gives a clear idea of what work needs to be done and addresses any problems before they arise. Here are some of the basic steps that need to be followed when creating an effective EMP:

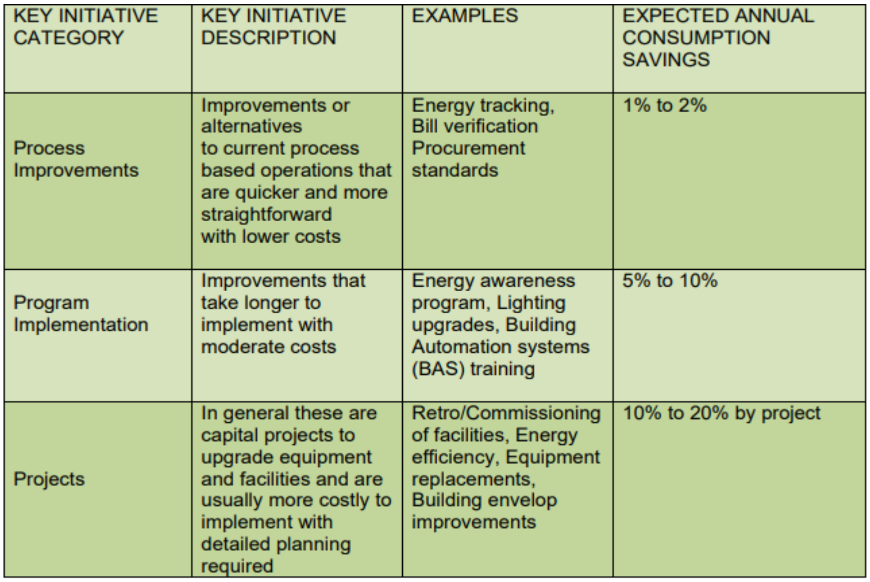
- Obtain a recent building(s) plan or building condition assessment. Energy-related upgrades should be included in these plans.
- Use your local utility reports to start tracking energy and water use. Continue to track it regularly for performance reporting purposes.
- Conclude a full energy audit for your building(s). Gas and electricity utility companies may offer incentives and cover the partial costs.
- Gather data regarding energy upgrades and planning by talking to upper management and staff about their experiences.
- Create an energy management plan outline.
- Begin implementation timetable as part of your plan. To get the process started, it is easier to schedule simple, inexpensive, short-term improvements, and higher cost initiatives for the long-term improvements. Occupants should be part of the plan as they can impact how the building operates.
- Once the draft is prepared, engage occupants to get their feedback and make sure their needs are considered.
- Track the impacts of improvements over time using utility-reports as a guide. Review the plan over time and make changes as needed to keep on track with the schedule

The Township of Scugog, Canada is a great example of how an energy management plan can be effective (Township of Scugog, 2014). The goal of energy management was:

- "*To develop strategies to reduce energy consumption by 18% below 2011 baselines by 2019;*
- *To integrate best practices into daily operations, where feasible, to reduce energy consumption;*
- *To provide a forum for discussion on energy management strategies that may benefit all departments;*
- *Increase Township awareness of the consumption of energy within each department; and*
- *To provide information for the Energy Management Plan Annual Report*"

The following table shows how the energy management plan was planned and implemented.

Table 1: Energy Management Plan



KEY INITIATIVE CATEGORY	KEY INITIATIVE DESCRIPTION	EXAMPLES	EXPECTED ANNUAL CONSUMPTION SAVINGS
Process Improvements	Improvements or alternatives to current process based operations that are quicker and more straightforward with lower costs	Energy tracking, Bill verification Procurement standards	1% to 2%
Program Implementation	Improvements that take longer to implement with moderate costs	Energy awareness program, Lighting upgrades, Building Automation systems (BAS) training	5% to 10%
Projects	In general these are capital projects to upgrade equipment and facilities and are usually more costly to implement with detailed planning required	Retro/Commissioning of facilities, Energy efficiency, Equipment replacements, Building envelop improvements	10% to 20% by project

Each of the initiative categories was further explained in detail in the EMP and measurement of success was defined as the following:

- Reduction of energy consumption and GHG emissions from 2011 baseline data
- Integrating energy management into daily operation processes and facility-based infrastructure decisions
- Energy efficiency projects included in capital asset management decisions:
- Increased capacity building and awareness regarding energy management within the Township; and
- Unique project-specific performance indicators are dependent on the project.

Energy management plans can help identify potential ways to cut energy consumption by creating a smart process, but it has a limit to how much conventional energy it can reduce. This where integrating renewable energy sources into buildings can take building design a step further and provide more energy ad financial savings than traditional sources.

Before diving into various renewable energy options, it is important to define renewable energy. The U.S. Energy Information Administration (EIA) defines renewable energy as "*sources that are naturally replenishing but flow-limited; renewable resources are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time*" (EIA, n.d.). Major types of renewable energy sources in the U.S are wind, solar, hydropower, geothermal, and biomass (ethanol, biodiesel, wood and wood waste, landfill gas, and biogas). These sources can be integrated into the buildings individually or jointly, depending on the geographical location.

In addition to the limitation of energy conservation, there are other factors that make a strong case for integrating renewable energy. First, buildings account for more than 40% of energy consumption in the United States (Hayter, 2011). This is significant because over 87% of the energy produced to operate these buildings is through fossil fuels. Fossil fuels are not only limited in resources but can be expensive and produce Green House Gas (GHG) emissions that damage the ecosystem. Second, 75% to 80% of the buildings that are already built will exist beyond 2030. Therefore, as the population rises, the demand for more infrastructure will mean more buildings and more energy production. Integrating renewable energy sources to already existing buildings reduces the demand to produce more energy from fossil fuels. Local governments, states, and countries have already started legislating policy that requires implementing energy conservation methods and integrating renewable energy in the buildings. For example, in the State of New York, building owners can claim property tax exemption for 15 years when they integrate solar systems into their buildings (Phoenix Energy Group, 2017). In addition, with a federal tax credit of 26% of the capital cost of the solar system and 25% income tax credit for metered and grid-connected solar systems, the cost of the system can be reduced by over 50%. In addition, there is also a cash incentive of up to $1000 per kilowatt of energy when the building owners switch to solar energy. All these incentives can yield savings of thousands of dollars annually in energy costs.

Case for Renewable Energy on College Campus

Universities and college campuses are in a unique position to integrate academic research, student activism, and institutional influence to promote technical and social transformation in the field of renewable energy (Abbott, 2014). Another big reason for moving towards renewable energy is economic incentives. Recent technological improvements have shown how competitive renewable energy can be. In 2013, the wholesale price of wind projects in the U.S. was just $0.025/kWh and while wholesale solar power purchase has gone below $0.025/kWh. These deals usually allow the buyers to lock in these prices for over 20 years or more, which in turn increases savings in the long term. The bottom-up demand from students is also increasing the demand for the institutions to move towards more sustainability-related programs. In a 2014 Princeton Review survey of student applicants, "*61 percent said having information about a college's commitment to the environment would impact their decision to apply to or attend a school.*" Information about campuses' sustainability track records, provided through programs such as the Association for the Advancement of Sustainability in Higher Education (AASHE) STARS initiative, has brought additional transparency to these efforts and allowed for holistic sustainability rankings.

Case Studies

Western Michigan University:

The Heritage Hall building is more than half a mile away from the steam power plant, which means more than 2600 ft of steam and condensate piping would need to be replaced to serve the building. The building was served by the campus steam system for over 100 years and was in poor condition. The building was used in a different capacity throughout its lifespan: from housing administrative offices in its early days and then as classrooms, art studios, and university archives. The building started to become obsolete settling into a mothballed state and only heated to prevent freezing. The cost of restoring the system was estimated at $820,000, while the cost of the geothermal system was $750,000. Switching to geothermal not only gave the university an immediate reduction in input cost but also enabled them to get utility tax rebates of over $54,000 and $1.80 per square foot in EPA tax deduction to help offset the construction cost.

St. Paul Port authority warehouse ‘net zero’ prototype:

For a building to be net-zero in energy consumption, it must generate the same amount of energy it consumes. The building would be 80% warehouse and the rest would function as office space. Energy use intensity (EUI – kBTU/sqft/yr) for a building is calculated as total annual energy consumption (kBTU) divided by the total gross square footage (sqft). EUI of an average warehouse is typically around 36 whereas the goal of the prototype was to get it down to 14. Having an efficient HVAC system could help greatly reduce the EUI, for example, the researchers estimated that using a geothermal heat pump instead of a conventional forced-air heating system would curb the EUI to as low as 38 and bring in savings of around $18,000 per year. The prototype also includes solar panels to cover about 32% of the flat roof to get closer to the EUI goal.

Energy System Integration Facility (ESIF):

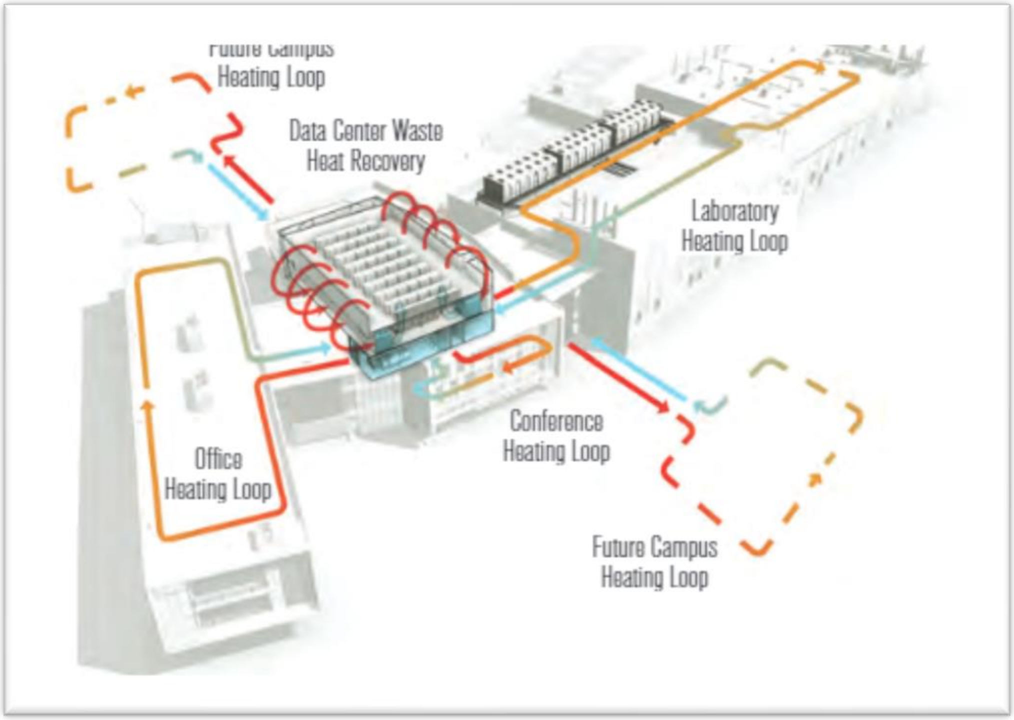
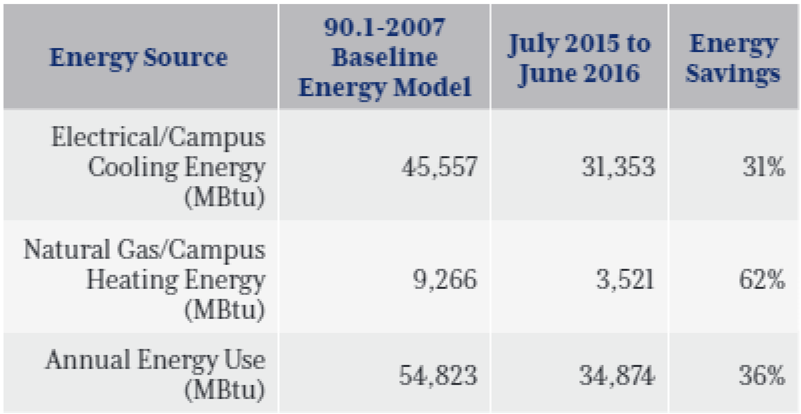


Figure 8: NREL energy system integration

This facility is owned by National Renewable Energy (NREL) in Golden, Colorado. It is located in the high desert next to the Rocky Mountains, a predominantly heating environment with dry conditions. The building's gross square footage is 182,000 ft^2 and is designed for 200 occupants. Energy demand primarily comes from office and laboratory zones of the building but the Information Technology (IT) data center requires year-round cooling, which produces low-quality waste heat as a byproduct. The heat generated from the IT data center was organized to capture the heat and was used for building heat instead of throwing it away. The datacenter was equipped with water-cooled servers, which left water temperatures from the servers in the range of 95F to 105F. This waste heat was transferred to the building heating water system with a plat and frame heat exchanger. After the completion of the waste heat optimization project, the heating load was reduced by over 50% from the year before. The table below shows data for energy consumption before and after renovation.

Table 2: NREL energy savings



Energy Source	90.1-2007 Baseline Energy Model	July 2015 to June 2016	Energy Savings
Electrical/Campus Cooling Energy (MBtu)	45,557	31,353	31%
Natural Gas/Campus Heating Energy (MBtu)	9,266	3,521	62%
Annual Energy Use (MBtu)	54,823	34,874	36%

The table shows the building performs 36% better than ASHRAE standard 90.1 – 2007 and has achieved LEED (Leadership in Energy and Environmental Design) platinum certification. During peak hours, the facility used under 30 tons of continuous cooling for the entire month. The cost of the entire project was $135 million, averaging out to be $740/ft^2. Improvements to cooling of the data center are projected to save closer to $4.5 million in capital investments over 10 years. An increase in efficiency of the data centers is also projected to save closer to $24 million over 10 years.

Boston University:

In 2006, the average energy consumed per square foot was 150 kBTU and the amount of carbon footprint amounted to 166,943 MTCO$_2$ (Boston University, 2018). In 2008, the university invested in upgrading the East campus central plant, building automation upgrades, and lighting retrofits. Over 26,000 traditional fixtures were replaced with LEDs and saving 9.4 million kWh of energy yearly. The following graph shows the decline in carbon footprint from 2006 to 2017.

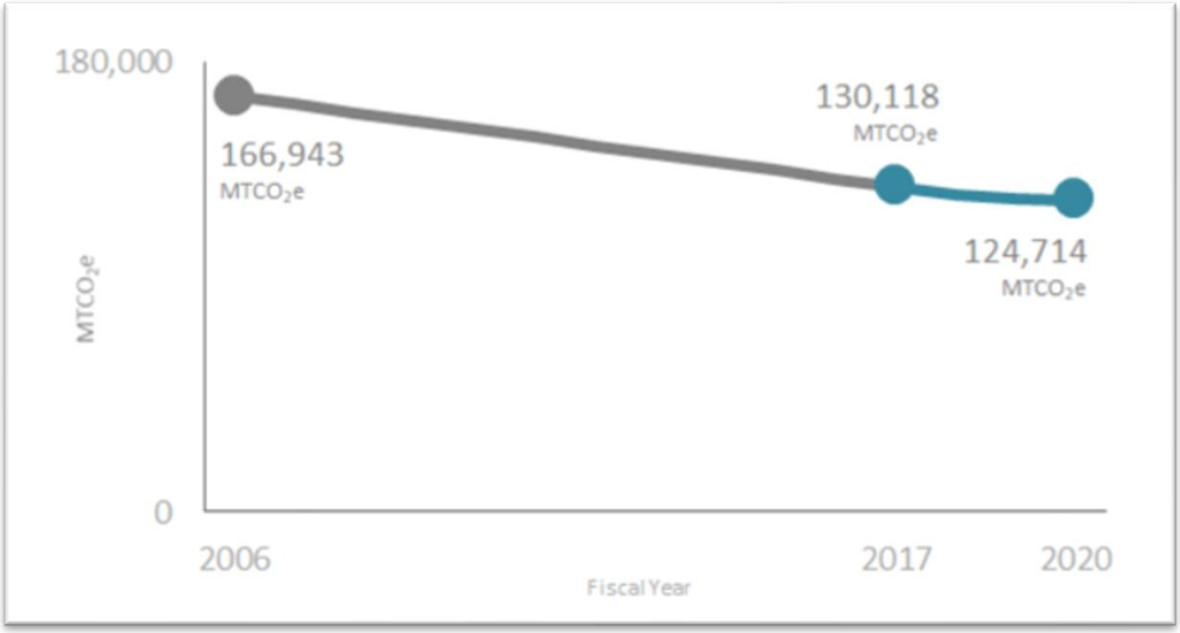


Figure 9: Boston University CO_2 reduction

In 2012, facilities and management implemented a 5-year plan to reduce their energy usage by 10%. This was primarily done by optimizing existing Building Automation Systems and estimating a savings of over 80%. Energy use was also reduced by transitioning from fuel oil to natural, thus improving efficiency and reducing overall energy consumption. Figure 9 illustrates the dependence on fuel oil and transition.

Butte College:

Butte College is in Oroville, California, and spans over 928 acres in a wildlife refuge. It is the first college to go ‘grid positive’, which means that the college produces more energy than it uses to offset the cost of electricity (Butte College, 2011). Because of its rural location, the college manages its water and sewage treatment system and recycles closer to 75% of its waste. There are over 25,000 solar panels that produce 4.55 MW of direct current or 6.5 kWh of electricity per year. To put it in perspective, it is equivalent of powering 941 medium-sized homes. Capital investment for solar energy cost $33.8 million but with rebates of $6.5 million, the resultant cost was $27.3 million. It was estimated that over 30 years, the institution will save up to $100 million. Installing the solar panels was done in three installments. The first and second installation met about 75% of the energy requirements of the campus. During this time, the size of the college also doubled in size which resulted in more buildings and demanded additional power requirements. The third installment was completed in 2011 which was planned to produce 102% of the institution's electricity demand.

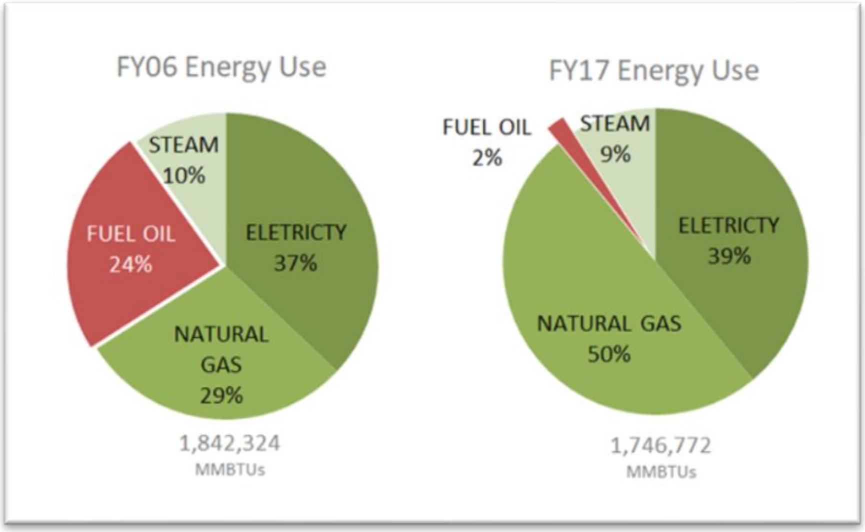


Figure 10: Butte College energy reduction

University of Notre Dame:

University of Notre Dame du Lac is a private, non-profit Catholic university located in Notre Dame, Indiana near the city of South Bend. To conserve water and energy, the university is investing in installing several geothermal systems across the campus (University of Notre Dame, 2017). Geothermal systems are sustainable, cost-effective, provide energy security, and reduce greenhouse gas emissions. The upper layer of the earth remains at a constant temperature regardless of changes in the outside air because of solar energy absorbed on the surface and rising heat from magma below the earth's surface. A geothermal system operates by using a network of water-filled pipes to transport heat from the warm ground during the winter and unload the excess surface heat in the cooler ground during the summer. The following schematic shows how a geothermal system operates during summer (left) and winter (right) time.

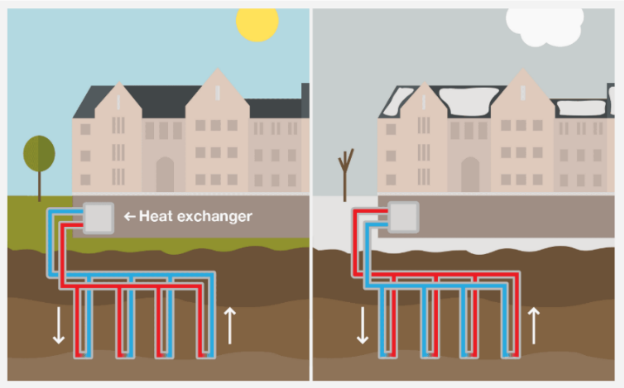


Figure 11: Notre Dame geothermal system

Systems in Notre Dame operates by circulating water in a closed loop to a depth of roughly 300 feet underneath the ground before returning it to the surface and moving across the heat exchanger. The temperature underneath the earth is found at approximately 50F to 55F throughout the year, hence reducing the amount of energy required to condition the hot or cold indoor air temperatures. The installation was completed in three phases. The first phase was a 300-ton capacity geothermal energy field for a band building which consists of 153 wells and provides 150 tons capacity, leaving the rest for future renovations. The second system was installed underneath the parking lot of the stadium which has 500 wells and a capacity of 1000-tons. This system will provide heating and cooling for future buildings in the area and serve the central campus chilled water system which could be used elsewhere on campus. The third phase has approximately 650 wells and 1350 tons of capacity and will serve the Athletic fields. This will also be connected to the new remote chiller plant that is located close by and thereby giving the option to serve the central cooling plant and campus hot water heating system. Since geothermal systems do not use fossil fuels as traditional boilers do, they emit no greenhouse gases and thereby improving air quality and reducing air pollution. After these three phases, Notre Dame will successfully reduce their CO_2 emissions by 11,8030 tons, down by 8% compared to the fiscal year of 2016. The estimated cost of installing these systems is approximately $40 million and the projected return on investment is around 15 years.

Ball State University:

Ball State University is a public research university located in Muncie, Indiana. In 2009, the Board of Trustees for Ball State University approved the university's geothermal project. This is the nation's largest ground-source, closed-loop geothermal system. This system will replace four coal-fired boilers that serve 5.5 million square feet of space which includes 47 buildings on the 660-acre campus. This system consists of closed-loop pipes that go up to 400 to 500 feet deep inside the earth (Mechem, 2017). The project required around 3,600 boreholes which are filled with grout around the pipe to provide better insulation to surrounding debris which increases the heat transfer. According to VP of governmental relations Phillip J. Sachtleben, "*Engineers expect Ball State's energy efficiency to skyrocket due to the project. An indicator called the coefficient of performance (COP) will jump from .62 to 7.77, meaning for each unit of energy we put in, we get 7.7 back"* (Lester, 2010*).*

The energy is exchanged at the energy station which will contain a heat pump and chillers which uses refrigerant R134A. Before the transition, boilers were burning through 36,000 tons of coal, costing about $3.2 million annually. The amount of carbon footprint was reduced by half with the transition in addition to tons of nitrous oxide, sulfur dioxide and particulates will also be eliminated which should provide health benefits to city residents, including relief from asthma. The university expects to save close to $2.2 million per year on energy costs after the completion of the project. The project was funded partially by the Department of Energy, the State of Indiana, and other funding sources.

North Shore Community College (NSCC):

North Shore Community College is in Danvers, Massachusetts located around the coastal region from north metropolitan Boston to Cape Ann. NSCC health professional & student services will be the first state-owned Net-zero energy building. Massachusetts Net Zero Building Task Force defined net-zero building as: "*one that is optimally efficient and over the course of a year generates energy onsite, using clean renewable resources, in a quantity equal to or greater than the total amount of energy consumed.*" The building spans over 58,000 square feet, which includes the college's health programs in addition to student and administrative support services (North Shore Community College, n.d.). The building consists of academic spaces, hospital spaces such as nursing, physical and occupational therapy, radiology, surgical care, and animal science classrooms. The building achieved a net-zero goal by incorporating various architectural and engineering methods such as natural lighting and ventilation, green roof, building orientation, chilled beams, geothermal energy, and solar energy obtained by photo-voltaic panels. The facility took advantage of southern exposure, reducing daylight use by utilizing natural light and the use of renewable sources to reduce carbon emissions and energy costs. By having a green roof, the building retained heat during the winter and reflected off the heat in the summer by not absorbing it. The geothermal system was installed in the parking lot which consists of 50 geothermal wells. A high-density six-inch polyethylene pipe was positioned 500 feet deep and grouted with thermally efficient bentonite grout. a biodegradable mix of ethanol and water antifreeze solution is circulated in the pipes leading to the heat pumps in the building. Heating, Ventilation, Air-conditioning (HVAC) systems transport the warm or cold air throughout the building to maintain temperatures closer to 70F. Over 1000 solar panels placed on the main roof and walkway canopies in the parking lot generated 342 kW to offset the energy consumed in the building over the course of the year. Rooftop and parking lot solar panels are estimated to produce 375,000 and 35,000 kWh per year on average and reducing the carbon emissions of 284 metric tons annually. A portion of the roof features a green roof that has a garden. This section improves the insulation of the building as it is covered by soil and vegetation and hence reducing energy costs. In addition to these benefits, it also increases the roof's life span, filters rainwater, reduces temperature by absorbing solar radiation and re-emitting heat. The garden is planted with vegetation called Sedum which requires little to no maintenance. Overall, the building provided three key benefits. First, annual electric consumption was reduced by 40% when comparing it to a traditionally designed building. Second, it removed an estimated 4,000 metric tons of carbon emissions over a 20-year period which is similar to removing 780 cars from the roads. Lastly, this building serves as a future design model and a learning tool for the community.

Carleton College:

Carleton College became the first college to own a commercial-scale wind turbine in the nation in September 2004 (Wind Power, 2006). The cost of the project was $1.8 million, which included a $150,000 "community wind rebate" from the State of Minnesota. For a

20-year contract, Xcel Energy will buy the electricity from the university at a rate of 3.3 cents per kWh to use in the Northfield area. Electricity from the wind turbine is being sold to Xcel Energy for local use in the Northfield area. This program is available for wind projects under 2-Megawatt (MW) capacity in Minnesota.

In addition to selling electricity to Xcel, Carleton is receiving 1.5 cents per kWh generated from the State of Minnesota via the Minnesota Renewable Energy Payment Incentive (MN REPI) program. The college expects the return on investment with interest within 10 to 12 years. After two semesters of independent study on the economics of the turbine, Holman suggests that "*Carleton should invest in a wind farm as part of its endowment because it is an incredibly good investment. Wind for Carleton has the risk level of a bond but returns like a stock with 8-12% per year. In addition to a yearly revenue stream of about $250,000, the PR value of the turbine has been immeasurable.*" The wind turbine reduces the electricity consumption by 40% which helps in lowering the carbon emissions by 1.5 million tons which is equivalent to 290,000 passenger vehicles driven in one year.

SDSU BACKGROUND

SDSU is the largest land grant university in the state of South Dakota and has been established since 1886. The campus spans over 260 acres and encompasses over 60 buildings. These buildings account for over four million square feet of space which needs to be operated and maintained throughout the year. The corresponding cost to heat, cool, and power the building is over $5 million. As a result, even small percent savings in energy reduction can save the university hundreds of thousands of dollars. For example, a 0.05% reduction in utility costs yields $500,000 in savings.

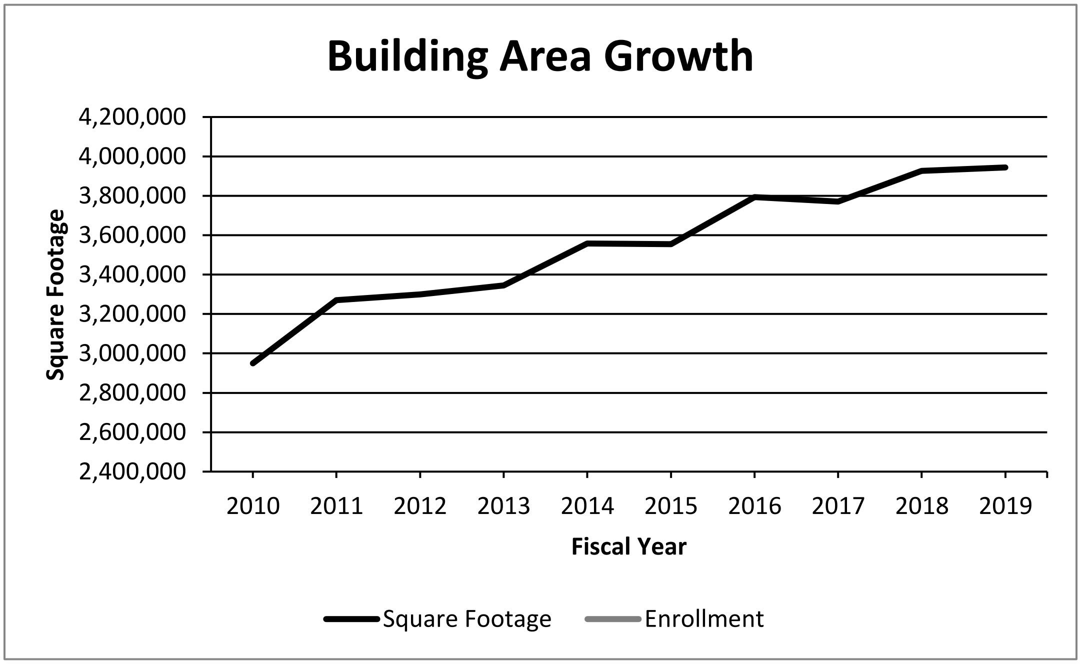


Figure 12: Increase in building space sqft

As more buildings are constructed to accommodate more students, research activity, well-being, keeping the operating costs lower is a priority for the university. As Figure 13 shows, SDSU has added over a million square feet in the building space in under a decade. Even though the amount of square footage has increased over the years, SDSU has taken active steps to keep its energy costs steady. Cost per square feet ($/sf) has remained below 1.35 for the last five years even as occupied space increased by 600,000 square feet. Energy consumption in SDSU buildings ranges from 36 kBTU/sf to 569 kBTU/sf. The average energy usage for SDSU buildings is 133 kBTU/sf. In addition to square footage, another important factor to consider when comparing energy consumption across different time periods is weather data. If the energy consumption does not account for weather, calculated differences in energy consumption can be due to changes in weather conditions between two time periods. In 2015, when normalized for the weather, the energy consumption for SDSU was 18 BTU/sf/DD. In 2019, the energy consumption decreased to 15.62 BTU/sf/DD even though the square feet of building space increased by over 600,000 sqft. This shows that SDSU is constantly working towards making the building space more efficient and has a vested interest in improving energy efficiency in buildings.

PROCEDURE

As SDSU looks to expand its campus more to accommodate more research facilities, academic and extra-curricular buildings, etc., the cost of operating those buildings result in more utilities costs if the buildings are not energy efficient. The purpose of this thesis is to analyze and propose various solutions that SDSU can utilize in minimizing energy consumption through energy conservation and integrating renewable energy sources to offset energy costs within their own buildings. By performing an energy analysis, the amount of energy that can be saved by energy conservation is highlighted.

The Agriculture Engineering building and Lincoln Music Hall are two buildings that are used in this analysis to demonstrate energy and cost savings potential when retrofitting older buildings with energy-efficient mechanical systems and renewable energy integration. In 2016, SDSU renovated Brown Hall and utilized efficient mechanical systems to reduce energy consumption. An energy analysis of Brown Hall paved the way to better understand how to energy models and this will be used to predict energy savings in Ag Engineering and Lincoln Music Hall. Energy consumption data after renovation is used to validate the results obtained from eQuest energy modeling.

BROWN RESIDENCE HALL BUILDING

Brown Hall is used to obtain a baseline analysis of how energy is utilized before and after a building is retrofitted at SDSU. This building was built in 1959 to serve as a residential hall for the university. It consisted of four floors and had gross square footage of 50,058, which housed about 400 residents. The central steam plant is used for supplying heat in the building and had no provisions for cooling.

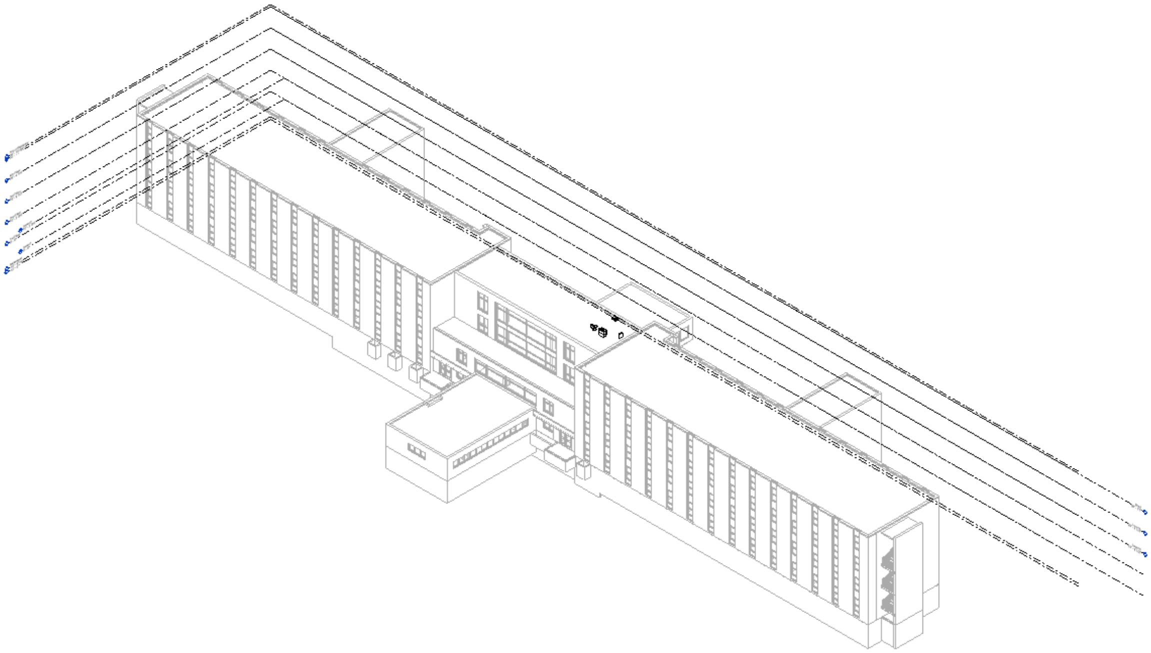
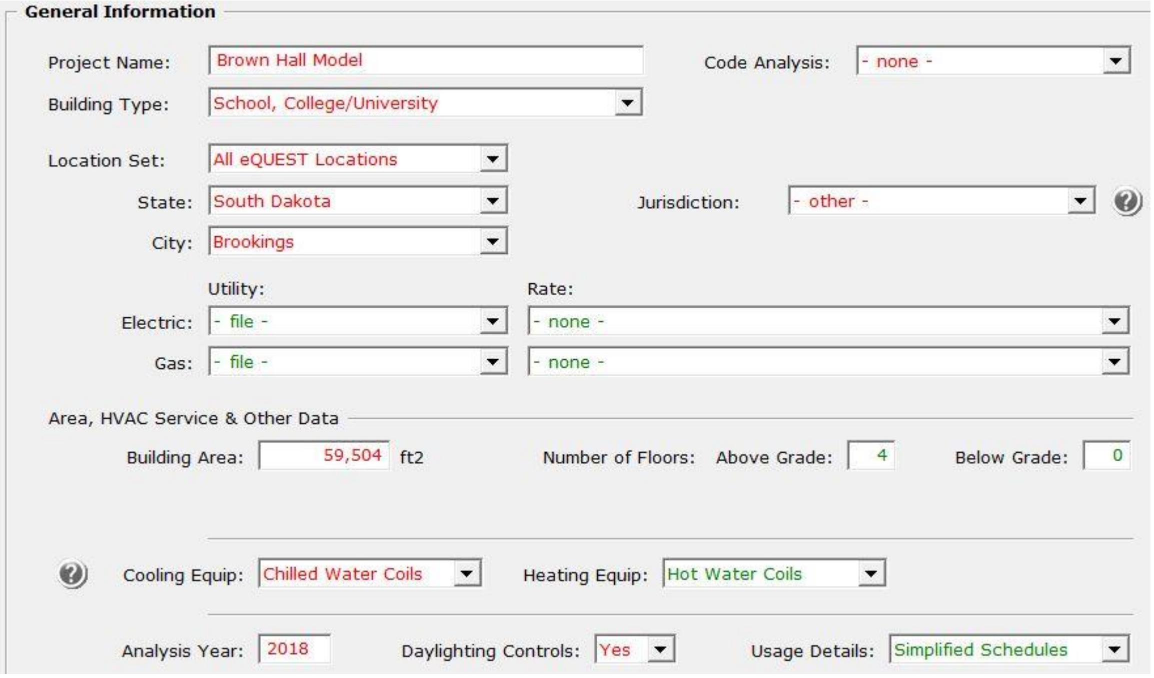


Figure 13: Brown Hall

After the renovation was completed in 2016, the second, third, and fourth-floor lobbies were interconnected which added 9,504 sqft to the building. Also, all the mechanical systems in the buildings were replaced with more efficient mechanical systems and Fan Coil Units (FCU) and Variable Air Volume (VAV) terminal units were also added to each floor. The building was connected to the central chiller plant on campus to serve the cooling loads.

eQuest Model

Building energy analysis was performed using eQuest version 3.65, a Department of Energy (DOE) software that simulates energy consumption. The simulation takes into account building orientation, HVAC zones, windows, occupants, plug loads, lighting, etc. eQuest provides wizard input screens for HVAC systems, building envelopes which are all customizable by the user. The following screenshots show the options selected to simulate the energy model of current Brown Hall energy consumption.



General Information

Project Name: Brown Hall Model
Code Analysis: - none -
Building Type: School, College/University
Location Set: All eQUEST Locations
State: South Dakota
Jurisdiction: - other -
City: Brookings

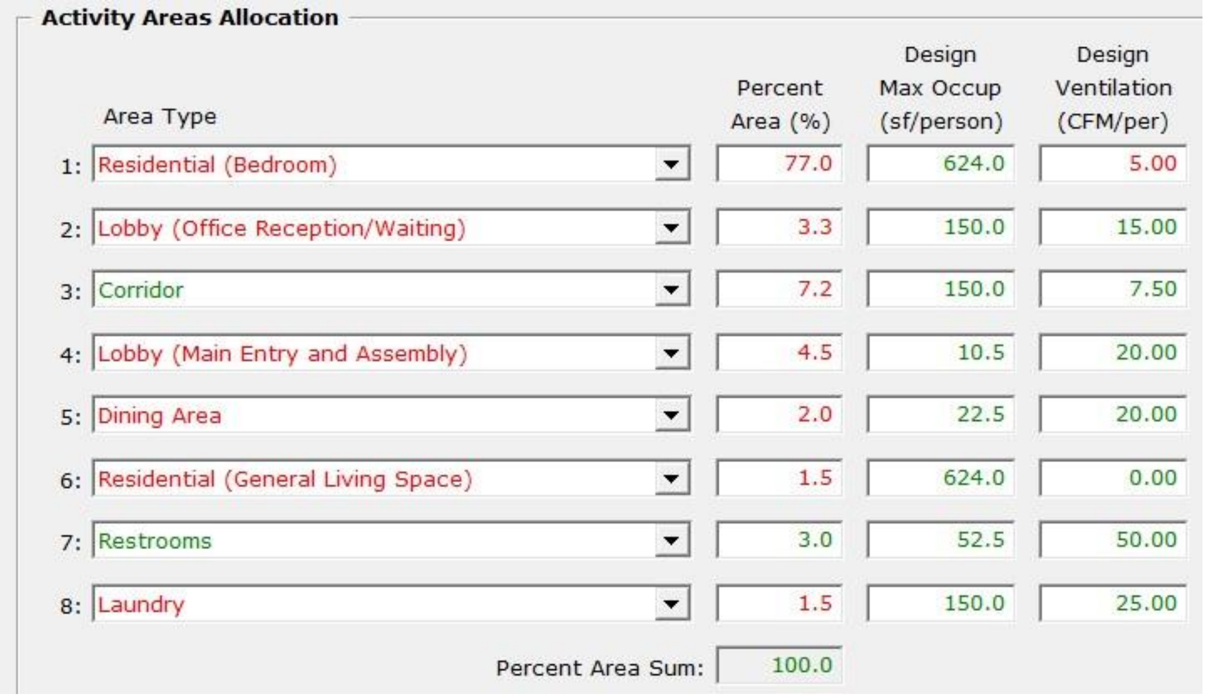
	Utility:	Rate:
Electric:	- file -	- none -
Gas:	- file -	- none -

Area, HVAC Service & Other Data

Building Area: 59,504 ft2
Number of Floors: Above Grade: 4
Below Grade: 0
Cooling Equip: Chilled Water Coils
Heating Equip: Hot Water Coils
Analysis Year: 2018
Daylighting Controls: Yes
Usage Details: Simplified Schedules

Figure 14: Brown Hall general information

Figure 15 provides the general information that was entered to generate the model. Building type, geographic location, heating, and cooling equipment are selected on this screen.

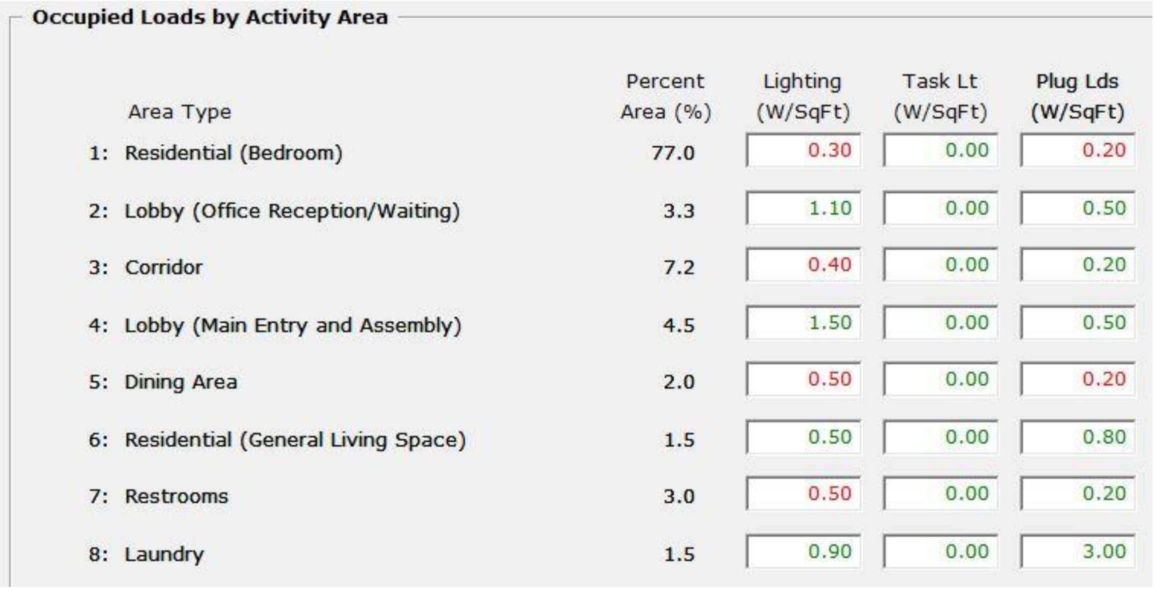


Activity Areas Allocation

	Area Type	Percent Area (%)	Design Max Occup (sf/person)	Design Ventilation (CFM/per)
1:	Residential (Bedroom)	77.0	624.0	5.00
2:	Lobby (Office Reception/Waiting)	3.3	150.0	15.00
3:	Corridor	7.2	150.0	7.50
4:	Lobby (Main Entry and Assembly)	4.5	10.5	20.00
5:	Dining Area	2.0	22.5	20.00
6:	Residential (General Living Space)	1.5	624.0	0.00
7:	Restrooms	3.0	52.5	50.00
8:	Laundry	1.5	150.0	25.00
	Percent Area Sum:	100.0		

Figure 15: Brown Hall activity areas allocation

Activities area allocation (Figure 16) screen takes into account the max occupancy and design ventilation in a given space using ASHRAE standard 62.1-2019. The percentage area for each is type is utilized further to estimate the plug loads and lighting loads.

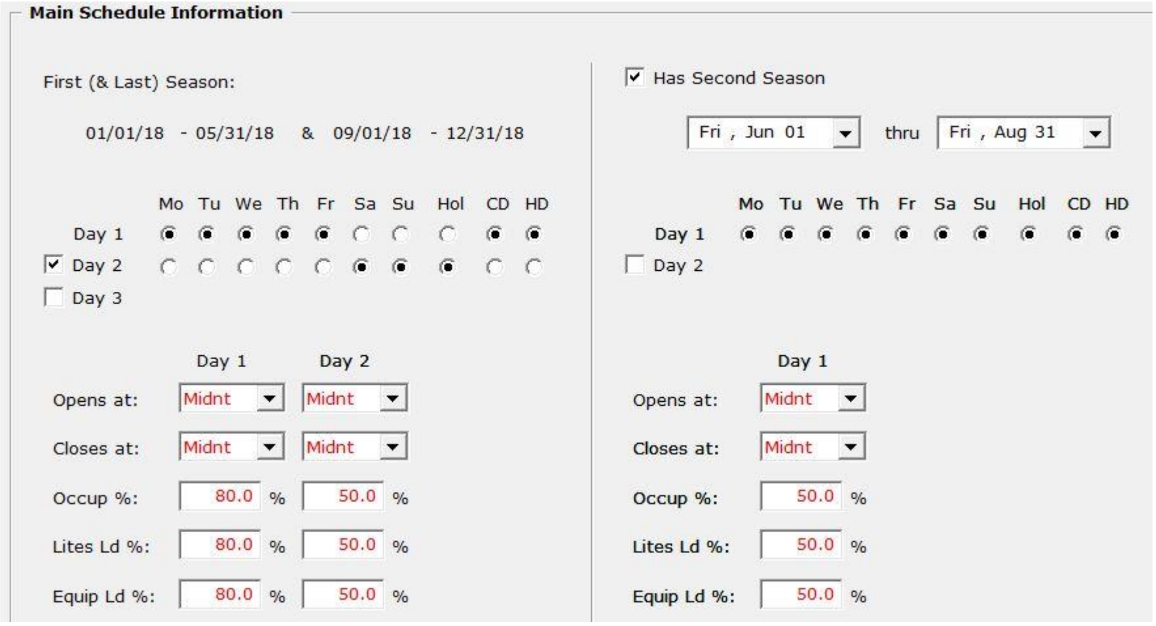


Occupied Loads by Activity Area

	Area Type	Percent Area (%)	Lighting (W/SqFt)	Task Lt (W/SqFt)	Plug Lds (W/SqFt)
1:	Residential (Bedroom)	77.0	0.30	0.00	0.20
2:	Lobby (Office Reception/Waiting)	3.3	1.10	0.00	0.50
3:	Corridor	7.2	0.40	0.00	0.20
4:	Lobby (Main Entry and Assembly)	4.5	1.50	0.00	0.50
5:	Dining Area	2.0	0.50	0.00	0.20
6:	Residential (General Living Space)	1.5	0.50	0.00	0.80
7:	Restrooms	3.0	0.50	0.00	0.20
8:	Laundry	1.5	0.90	0.00	3.00

Figure 16: Brown Hall occupied loads by activity area

ASHRAE Standard 90.1 was used to adjust the values for occupied loads in the building. Lighting and plug loads for the bedroom were reduced from 0.80 W/sqft to 0.30 W/sqft and 0.80 W/sqft to 0.20 W/sqft respectively.



Main Schedule Information

First (& Last) Season:

01/01/18 - 05/31/18 & 09/01/18 - 12/31/18

	Mo	Tu	We	Th	Fr	Sa	Su	Hol	CD	HD
Day 1	●	●	●	●	●	○	○	○	●	●
☑ Day 2	○	○	○	○	○	●	●	●	○	○
☐ Day 3										

	Day 1	Day 2
Opens at:	Midnt	Midnt
Closes at:	Midnt	Midnt
Occup %:	80.0 %	50.0 %
Lites Ld %:	80.0 %	50.0 %
Equip Ld %:	80.0 %	50.0 %

☑ Has Second Season

Fri , Jun 01 thru Fri , Aug 31

	Mo	Tu	We	Th	Fr	Sa	Su	Hol	CD	HD
Day 1	●	●	●	●	●	●	●	●	●	●
☐ Day 2										

	Day 1
Opens at:	Midnt
Closes at:	Midnt
Occup %:	50.0 %
Lites Ld %:	50.0 %
Equip Ld %:	50.0 %

Figure 17: Brown Hall main schedule

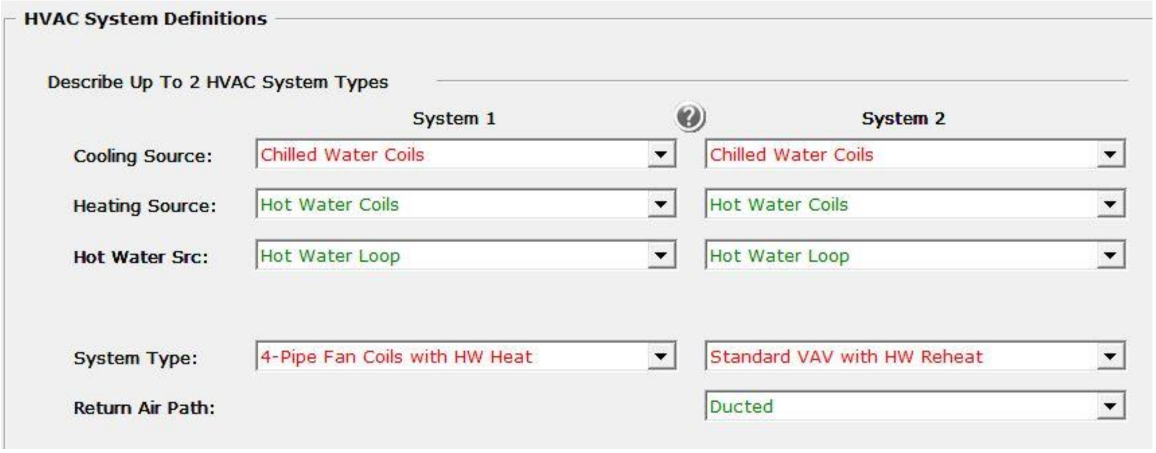
The main schedule information wizard is used to input the information on how the building is used throughout the year. Building usage is divided into two seasons: spring/fall semester as one combined season and summer semester as the second season. For the first season, when the school is in session, a residential building is operated throughout the day. About half of the students leave for home during weekends and holidays, hence Day 2 has been scheduled for 50 % occupancy loads in the buildings. For the second season, the building is utilized for summer camps and conferences. On average, only 50% of the rooms are used during the summer for these miscellaneous activities. These parameters are selected after consulting with facilities and services on how the building is currently operated.

HVAC System Fans

System(s):	1: 4-Pipe Fan Coils, HW Heat	2: Standard VAV, HW Reheat
Supply Fans		
Power & Mtr Eff:	0.50 in. WG High	3.50 in. WG High
Fan Flow & OSA:	Auto-size Flow (with 1.15 safety factor)	Auto-size Flow (with 1.15 safety factor)
Fan Type:		Variable Speed Drive
Return Fans		
		○ None ● Return ○ Relief
Power & Mtr Eff:		1.17 in. WG High
Fan Flow:		Auto-size
Fan Type:		Variable Speed Drive

Figure 18: Brown Hall HVAC system fans

The supply and return fans for VAV terminal units are selected with high motor efficiency with variable speed drives instead of constant speed, so the fans can be modulated as the demand varies throughout the day



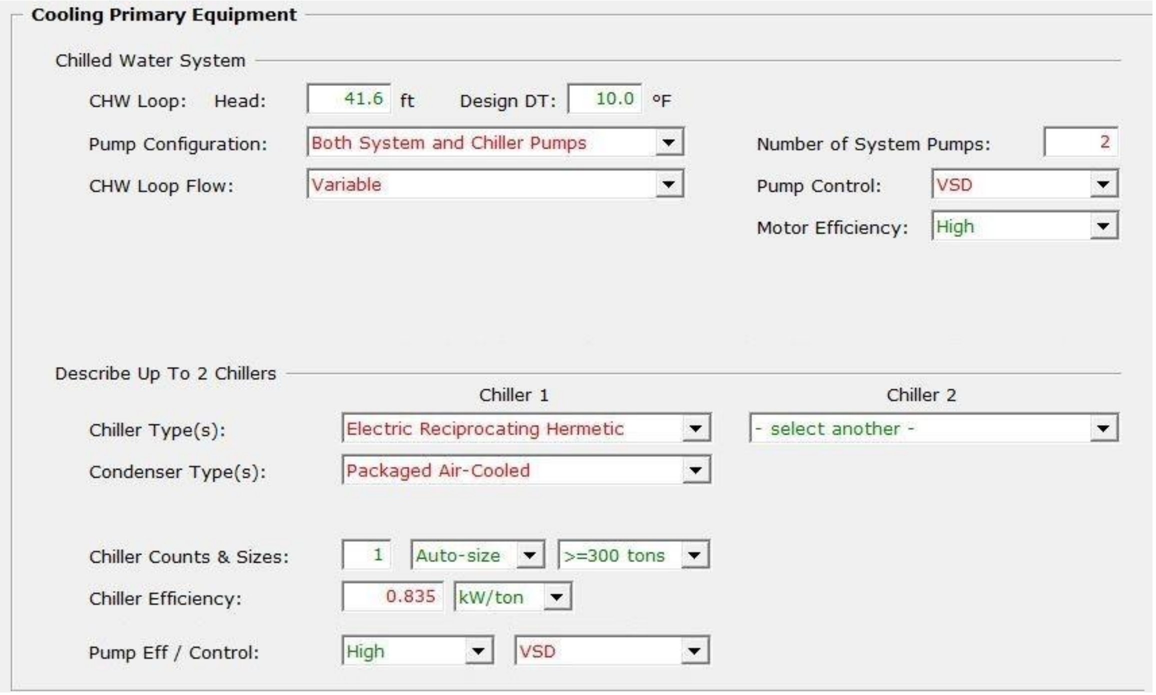
HVAC System Definitions

Describe Up To 2 HVAC System Types

	System 1	System 2
Cooling Source:	Chilled Water Coils	Chilled Water Coils
Heating Source:	Hot Water Coils	Hot Water Coils
Hot Water Src:	Hot Water Loop	Hot Water Loop
System Type:	4-Pipe Fan Coils with HW Heat	Standard VAV with HW Reheat
Return Air Path:		Ducted

Figure 19: Brown Hall HVAC system definition

Currently, the building has no option for cooling the spaces. The Ag Engineering building in the future will be cooled with chilled water-cooling coils and heated with hot water heating coils. Fan Coil Units and VAV terminal boxes with hot water reheat are used to serve the individual rooms and common area spaces.



Cooling Primary Equipment

Chilled Water System

CHW Loop: Head: 41.6 ft Design DT: 10.0 °F

Pump Configuration: Both System and Chiller Pumps

CHW Loop Flow: Variable

Number of System Pumps: 2

Pump Control: VSD

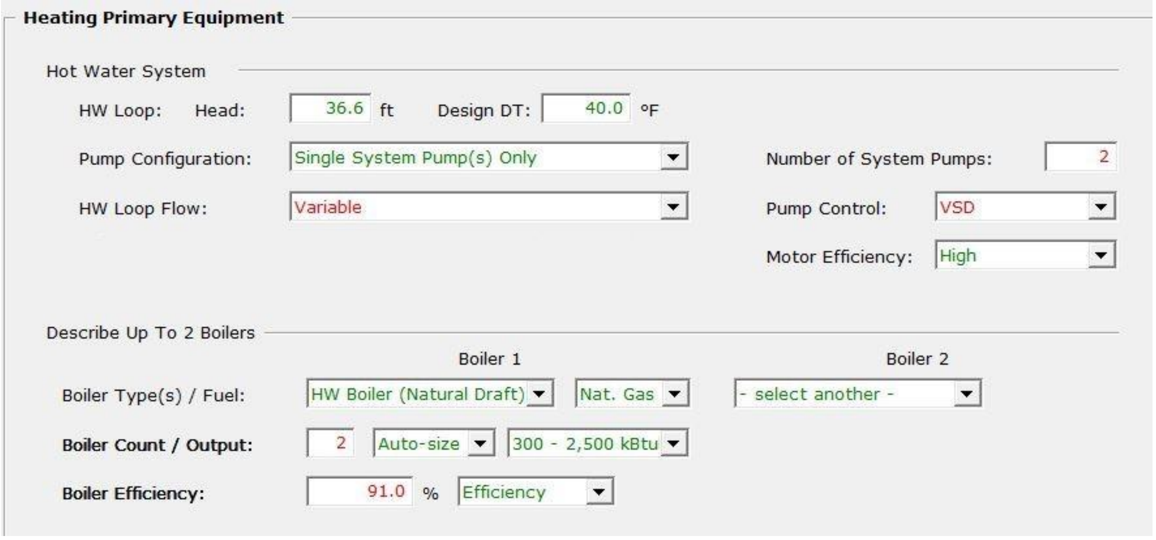
Motor Efficiency: High

Describe Up To 2 Chillers

	Chiller 1	Chiller 2
Chiller Type(s):	Electric Reciprocating Hermetic	- select another -
Condenser Type(s):	Packaged Air-Cooled	
Chiller Counts & Sizes:	1 Auto-size >=300 tons	
Chiller Efficiency:	0.835 kW/ton	
Pump Eff / Control:	High VSD	

Figure 20: Brown Hall cooling primary equipment

A chilled water system is distributed in the building with the help of two high-efficiency system pumps controlled with variable speed drives to modulate the water as needed. The chilled water system will be connected to the central chiller plant at SDSU to meet the cooling demand during the summer. The compressor type is changed from constant speed to variable speed which helps in reducing the electricity needed to run the compressor.



Heating Primary Equipment

Hot Water System

HW Loop: Head: 36.6 ft Design DT: 40.0 °F

Pump Configuration: Single System Pump(s) Only

Number of System Pumps: 2

HW Loop Flow: Variable

Pump Control: VSD

Motor Efficiency: High

Describe Up To 2 Boilers

	Boiler 1			Boiler 2
Boiler Type(s) / Fuel:	HW Boiler (Natural Draft)	Nat. Gas		- select another -
Boiler Count / Output:	2	Auto-size	300 - 2,500 kBtu	
Boiler Efficiency:	91.0 %	Efficiency		

Figure 21: Brown Hall heating primary equipment

Similar to the chilled water system, a hot water system is connected to two high-efficiency pumps controlled with variable speed drives in the building. The hot water system will be connected to the central steam plant to meet the heating demand during the winter. Boiler efficiency is changed from 80% to 91% to reduce natural gas consumption. The results of these changes are analyzed in the following section.

eQuest Simulation Results

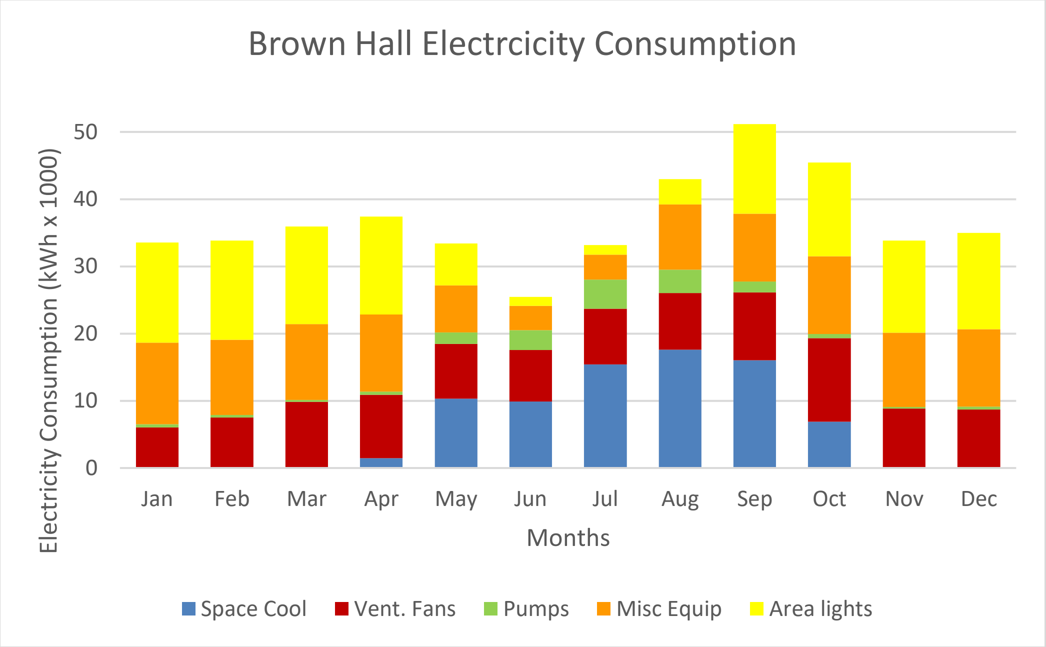


Figure 23: Brown Hall electricity consumption simulation for current system

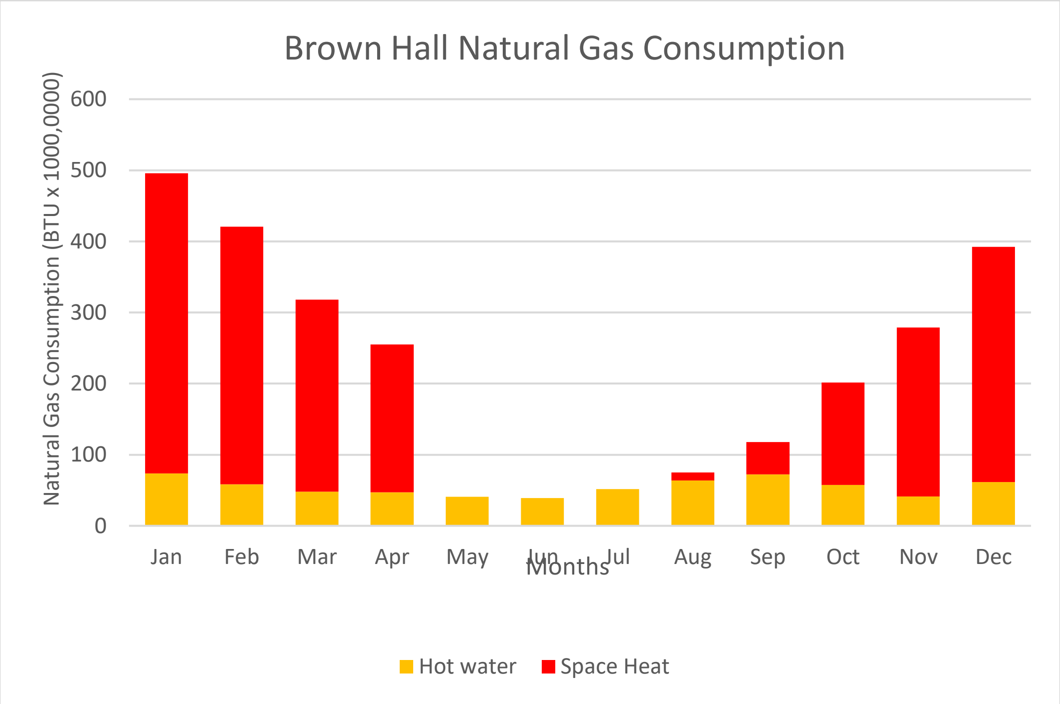
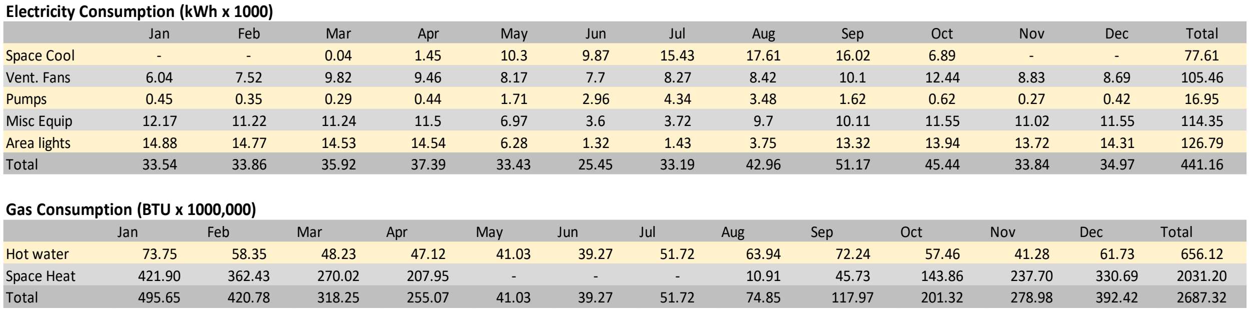


Figure 22: Brown Hall natural gas consumption simulation for current system

Above Figures 23 and 24 show the simulation results obtained from eQuest modeling. Electricity and natural gas consumption range between 25,450 kWh - 51,170 kWh and 41 MMBTU to 495 MMBTU throughout the year respectively. Instinctively, it can be seen during summer months that there is little to no use for natural gas to generate steam for heating and hence natural gas consumption is almost zero. Similarly, cooling loads for the winter months are almost negligible as well.

The results obtained from the simulation were validated by comparing it to the energy consumption data for Brown Hall provided by the Facilities and Services Department.

Table 3: Brown Hall electricity and gas consumption for current system



Electricity Consumption (kWh x 1000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	0.04	1.45	10.3	9.87	15.43	17.61	16.02	6.89	-	-	77.61
Vent. Fans	6.04	7.52	9.82	9.46	8.17	7.7	8.27	8.42	10.1	12.44	8.83	8.69	105.46
Pumps	0.45	0.35	0.29	0.44	1.71	2.96	4.34	3.48	1.62	0.62	0.27	0.42	16.95
Misc Equip	12.17	11.22	11.24	11.5	6.97	3.6	3.72	9.7	10.11	11.55	11.02	11.55	114.35
Area lights	14.88	14.77	14.53	14.54	6.28	1.32	1.43	3.75	13.32	13.94	13.72	14.31	126.79
Total	33.54	33.86	35.92	37.39	33.43	25.45	33.19	42.96	51.17	45.44	33.84	34.97	441.16

Gas Consumption (BTU x 1000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Hot water	73.75	58.35	48.23	47.12	41.03	39.27	51.72	63.94	72.24	57.46	41.28	61.73	656.12
Space Heat	421.90	362.43	270.02	207.95	-	-	-	10.91	45.73	143.86	237.70	330.69	2031.20
Total	495.65	420.78	318.25	255.07	41.03	39.27	51.72	74.85	117.97	201.32	278.98	392.42	2687.32

The following Figures 25 -30 show the electricity and natural gas consumption of Brown Hall from 2016 to 2018. The average consumption of 2016-2018 is then compared to eQuest energy modeling results in Figures 31 and 32 for electricity and natural gas consumption.

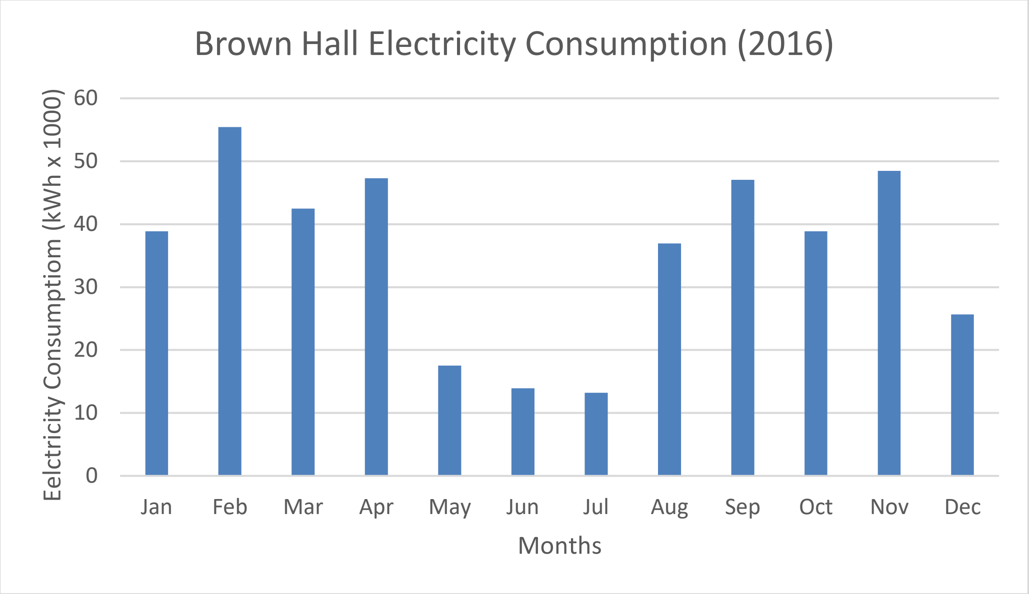


Figure 24: Brown Hall electricity consumption 2016

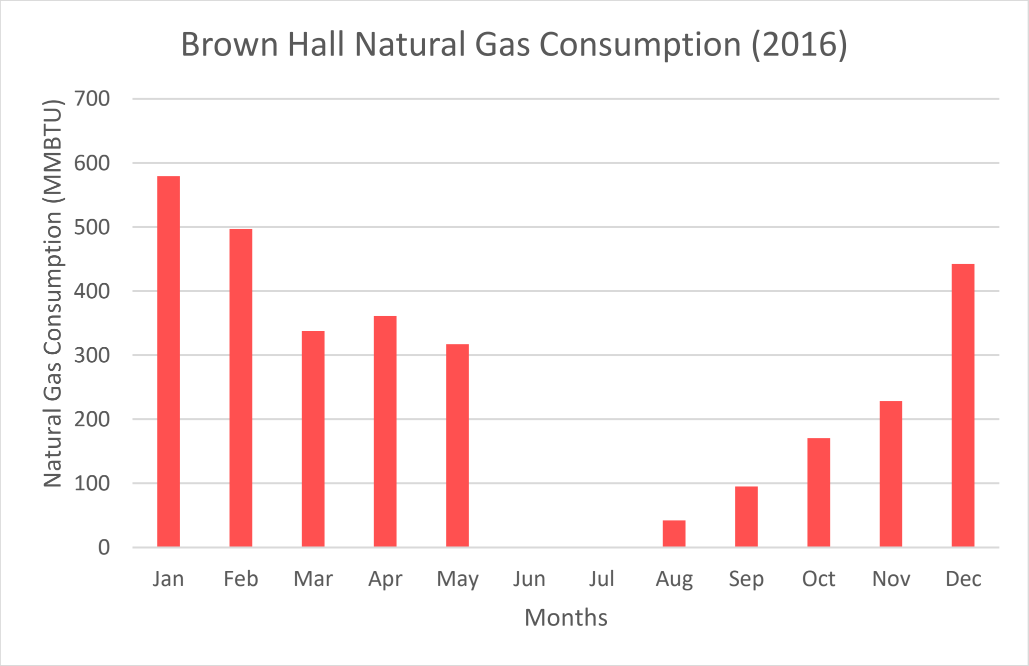


Figure 25: Brown Hall natural gas consumption 2016

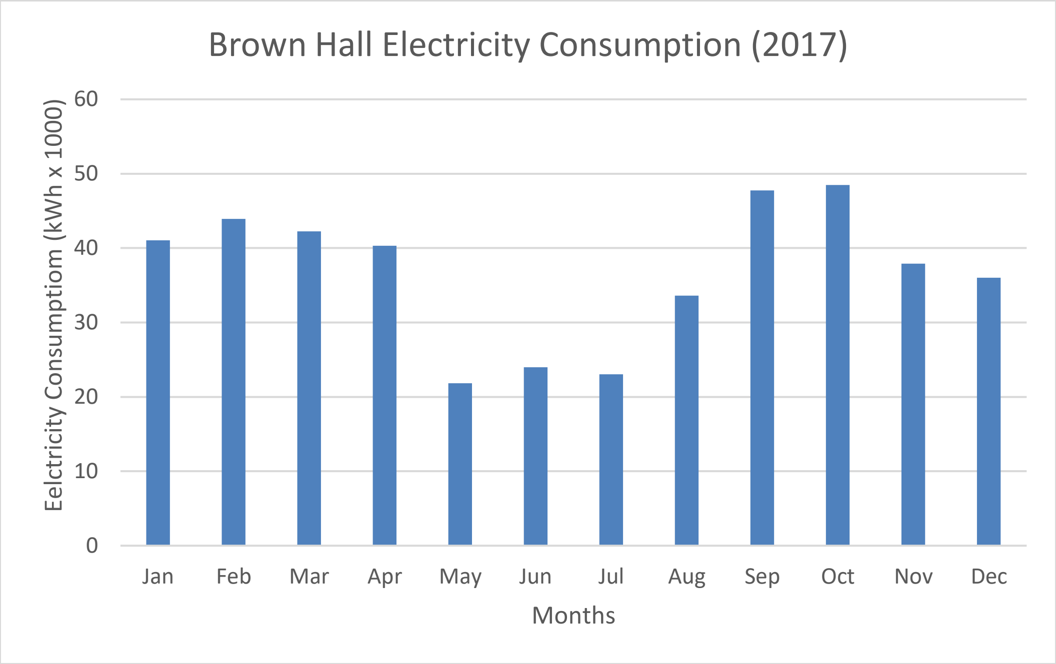


Figure 26: Brown Hall electricity consumption 2017

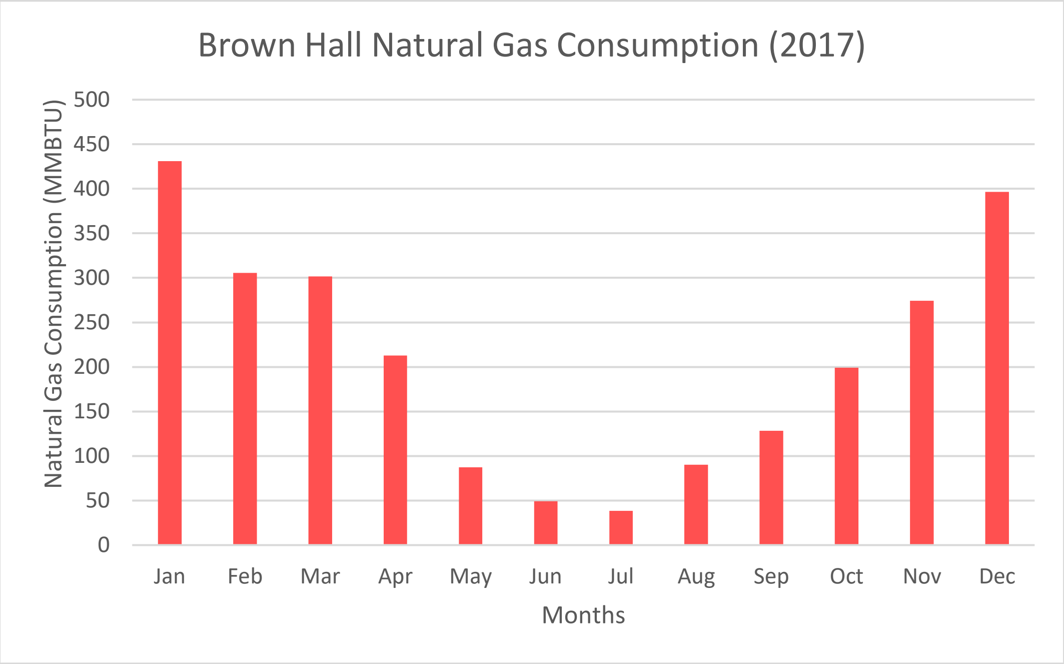


Figure 27: Brown Hall natural gas consumption 2017

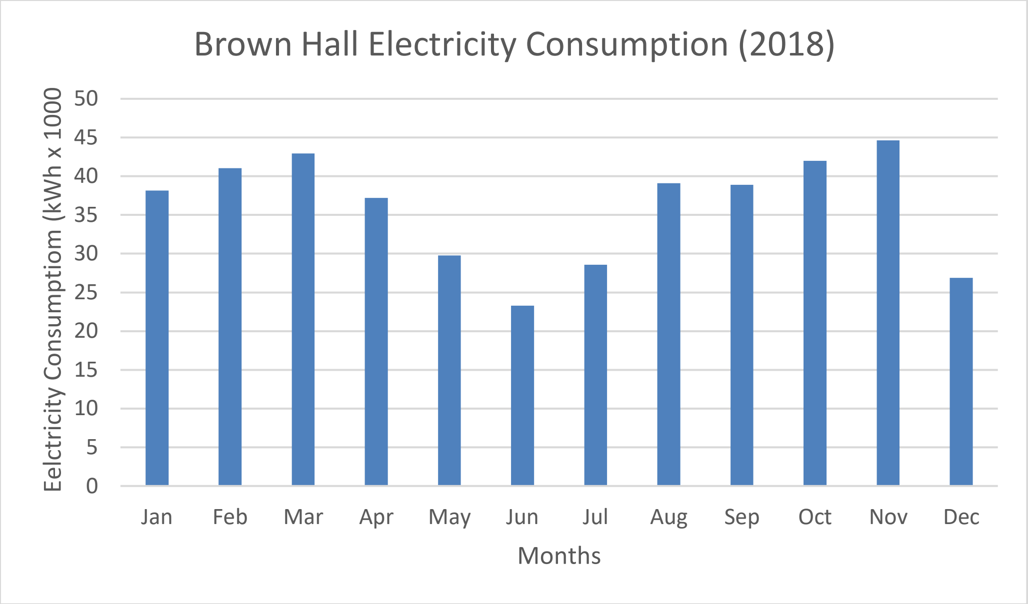


Figure 28: Brown Hall electricity consumption 2018

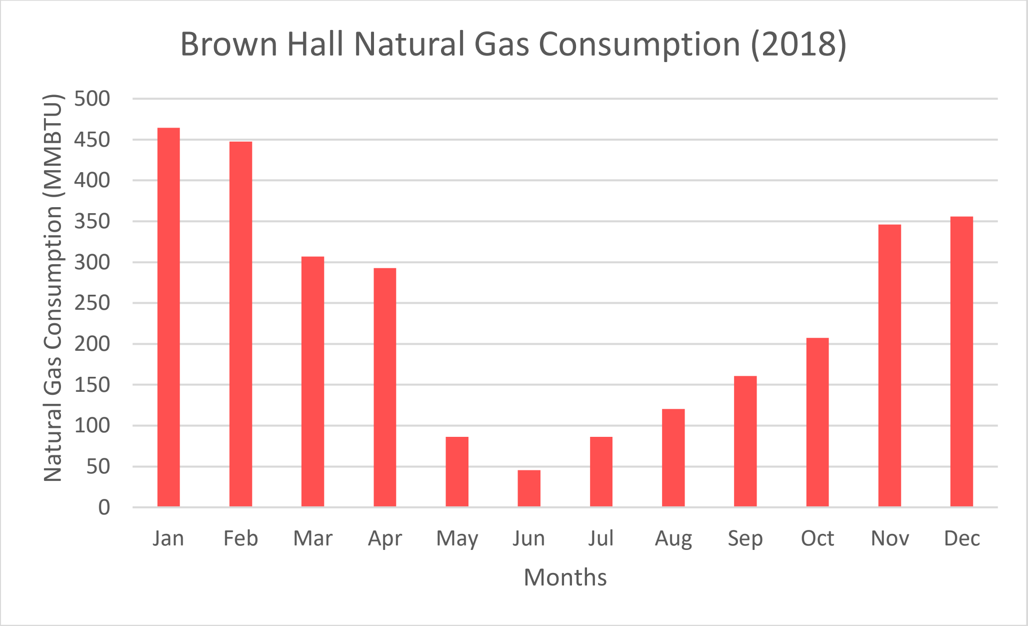


Figure 29: Brown Hall natural gas consumption 2018

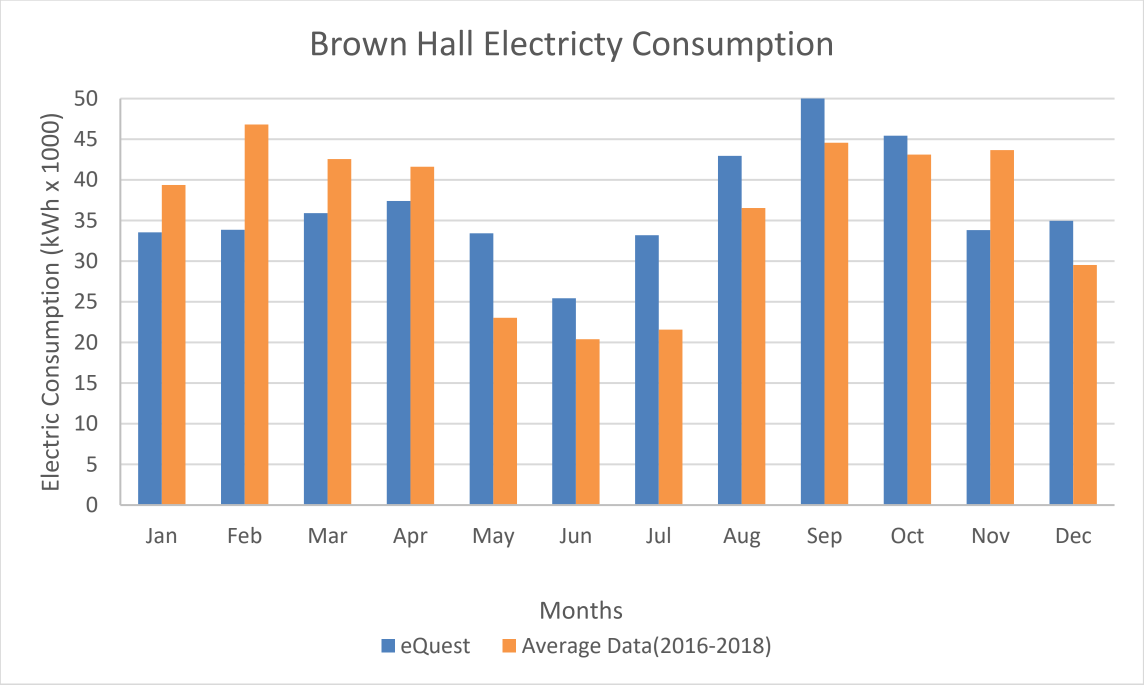


Figure 30: Brown Hall electricity consumption comparison

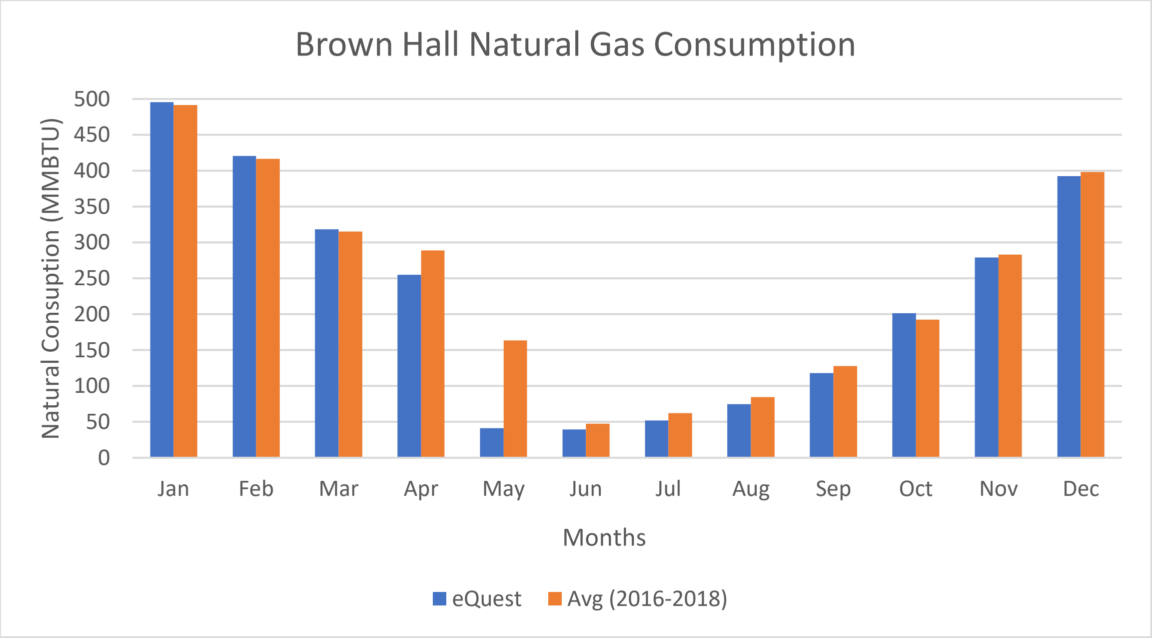


Figure 31: Brown Hall natural gas consumption comparison

The graphs in Figure 31 and Figure 32 show the results obtained from the simulation for electricity and natural gas consumption are similar to actual consumption. Since Brown Hall is a residential facility, its usage varies from year to year during summer months and hence, it is difficult to predict the exact operating conditions of the building. Another area of uncertainty in building usage is during winter break. The number of students living in the building during the break differs from year to year, which makes it difficult to set operating conditions for December and January. During 2016 - 2018, the number of cooling degree days (CDD) was 619, 534, and 590 respectively. When averaged, it comes out to be 580 CDD for the 2016-2018 period. eQuest estimated the number of CDD to be 541. Hence, some of the differences between simulation and actual data can be attributed to varying weather patterns.

AGRICULTURE (AG) ENGINEERING BUILDING

The Agriculture Engineering building is located on the north side of campus, east of Briggs Library. It was constructed in 1959 using a brick structure at a cost of $659,000. The building contains classrooms, labs, a shop area for the engineering department, and water resources institute. and the Office of Climatology as well. The building is connected to a central steam plant which is used during winters for heating. For cooling, most individual rooms are equipped with window air-conditioning units. One Air-Handling unit was installed in 2007 to cool the lecture hall room of Ag engineering room 100.

Floor Plan

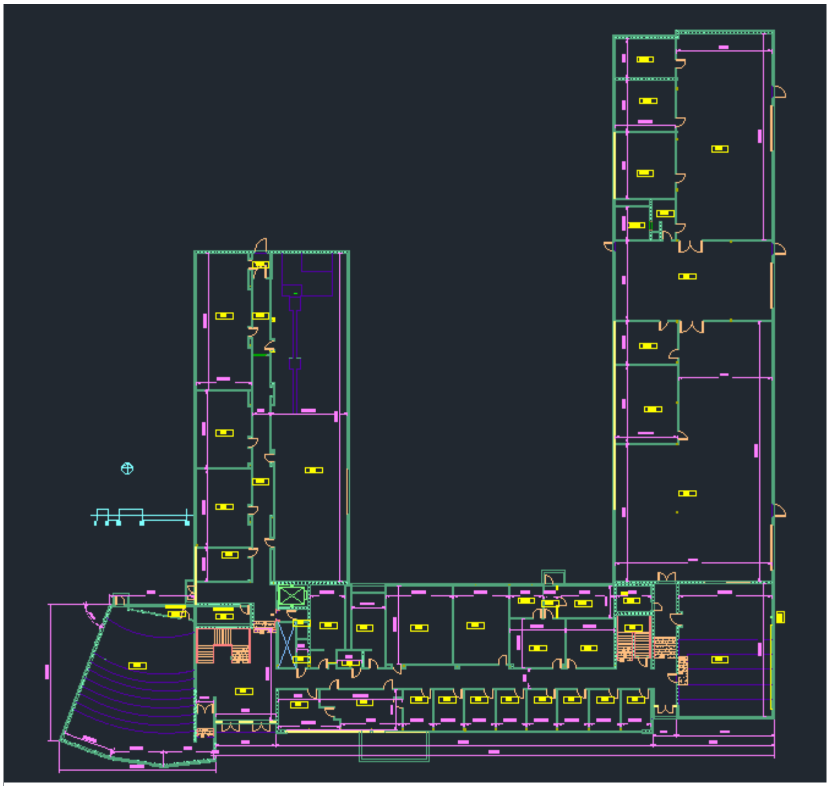
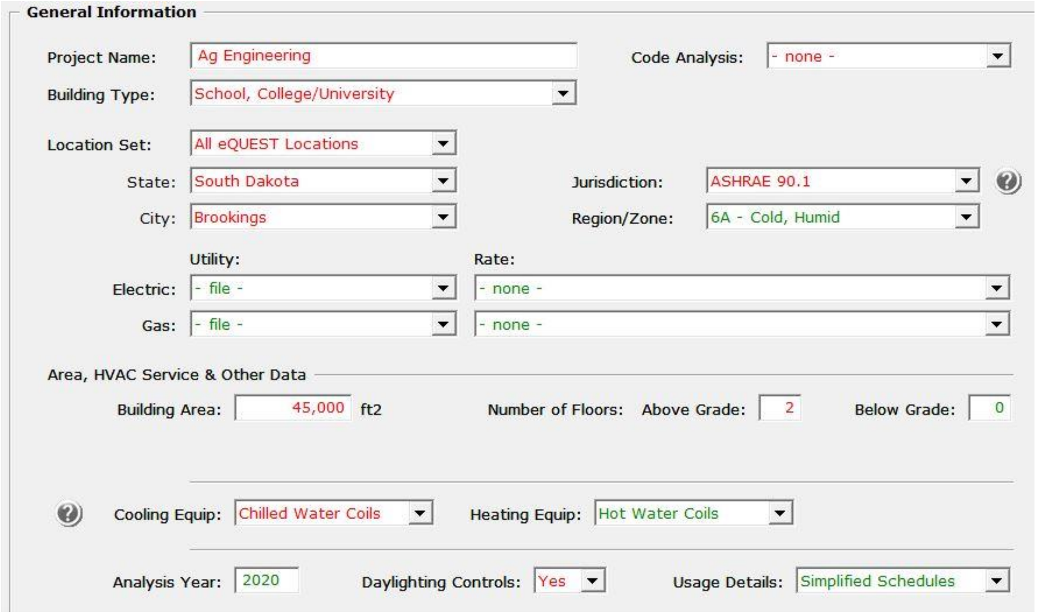


Figure 32: Ag Engineering floor plan

The above plan shows the first floor of the Ag Engineering building. Space consists of a couple of laboratories, classrooms, and a lecture hall. The building typically operates from 8 am to 5 pm during weekdays. During weekends, there may be some activity in the laboratory, but it is assumed minimal for the purpose of the simulation in eQuest. The second floor has a similar footprint but excludes the lecture auditorium. The mechanical room is located in the basement of the building.

eQuest Model

Energy modeling for the building was performed on eQuest to predict the energy savings in the Ag Engineering building. The following screenshots of the software show the changes that were made to accomplish the reduction in energy usage.



General Information

Project Name: Ag Engineering

Code Analysis: - none -

Building Type: School, College/University

Location Set: All eQUEST Locations

State: South Dakota

Jurisdiction: ASHRAE 90.1

City: Brookings

Region/Zone: 6A - Cold, Humid

Utility: / Rate:

Electric: - file - / - none -

Gas: - file - / - none -

Area, HVAC Service & Other Data

Building Area: 45,000 ft2

Number of Floors: Above Grade: 2 Below Grade: 0

Cooling Equip: Chilled Water Coils

Heating Equip: Hot Water Coils

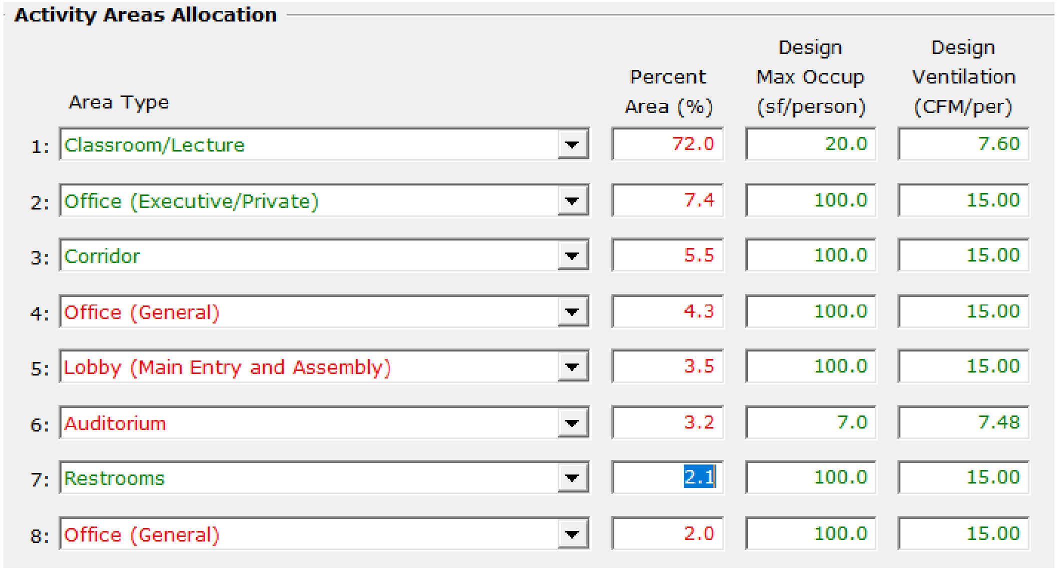
Analysis Year: 2020

Daylighting Controls: Yes

Usage Details: Simplified Schedules

Figure 33: Ag Engineering general information

Figure 34 provides general information that was entered to generate the model. Building type, geographic location, heating, and cooling equipment are selected on this screen.

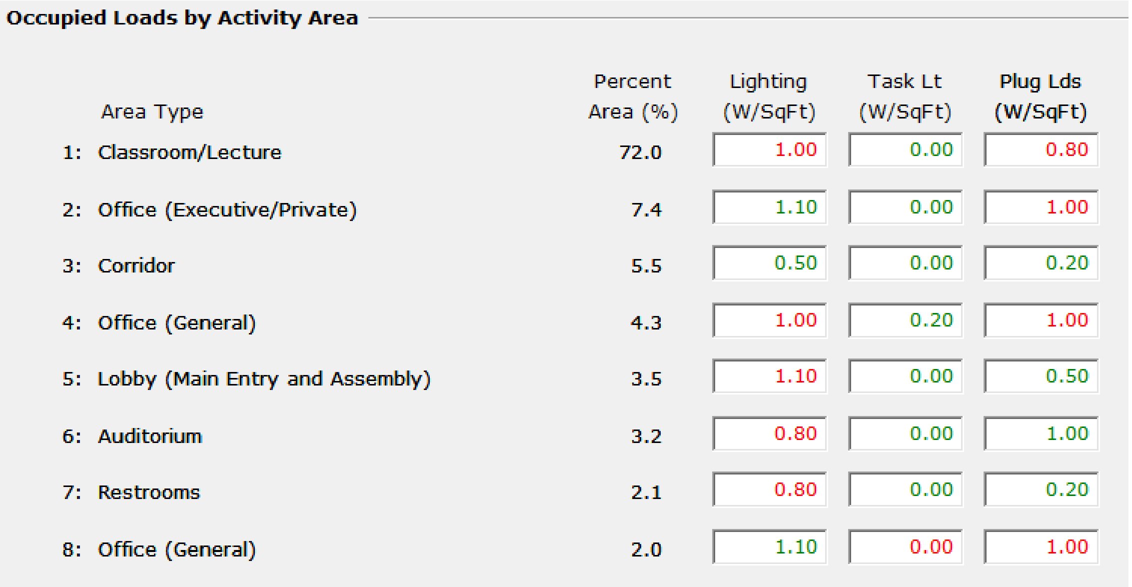


Activity Areas Allocation

	Area Type	Percent Area (%)	Design Max Occup (sf/person)	Design Ventilation (CFM/per)
1:	Classroom/Lecture	72.0	20.0	7.60
2:	Office (Executive/Private)	7.4	100.0	15.00
3:	Corridor	5.5	100.0	15.00
4:	Office (General)	4.3	100.0	15.00
5:	Lobby (Main Entry and Assembly)	3.5	100.0	15.00
6:	Auditorium	3.2	7.0	7.48
7:	Restrooms	2.1	100.0	15.00
8:	Office (General)	2.0	100.0	15.00

Figure 34: Ag Engineering activities area allocation

Activities area allocation (Figure 35) screen considers the max occupancy and design ventilation in a given space using ASHRAE standard 62.1-2019. The percentage area for each is type is utilized further to estimate the plug loads and lighting loads.

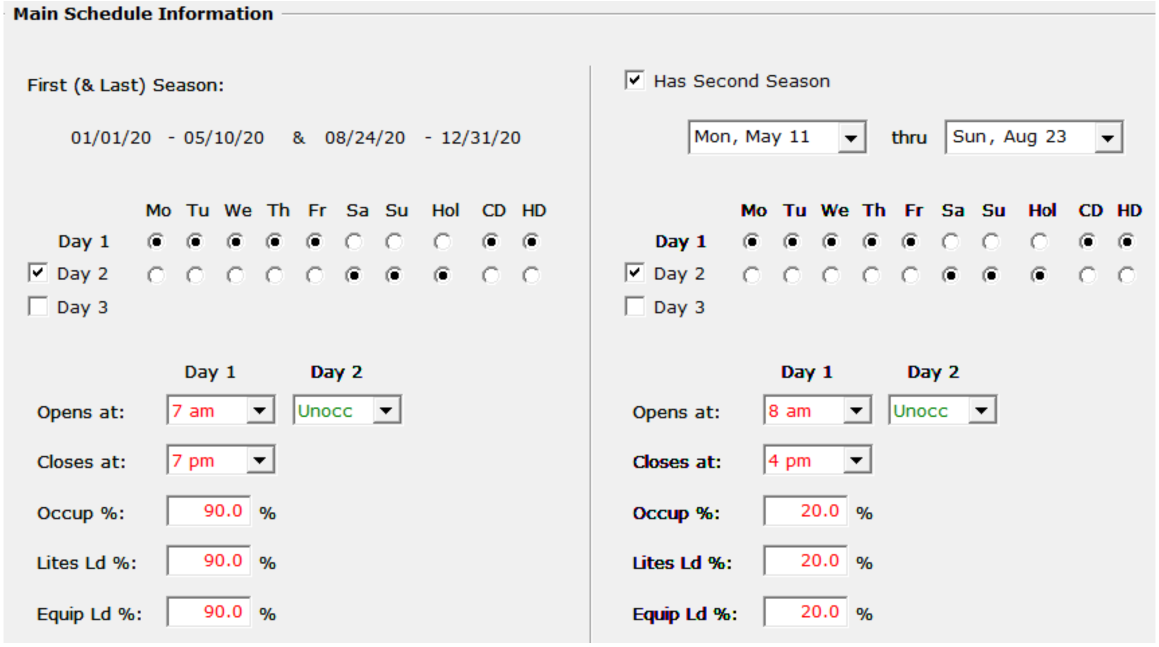


Occupied Loads by Activity Area

	Area Type	Percent Area (%)	Lighting (W/SqFt)	Task Lt (W/SqFt)	Plug Lds (W/SqFt)
1:	Classroom/Lecture	72.0	1.00	0.00	0.80
2:	Office (Executive/Private)	7.4	1.10	0.00	1.00
3:	Corridor	5.5	0.50	0.00	0.20
4:	Office (General)	4.3	1.00	0.20	1.00
5:	Lobby (Main Entry and Assembly)	3.5	1.10	0.00	0.50
6:	Auditorium	3.2	0.80	0.00	1.00
7:	Restrooms	2.1	0.80	0.00	0.20
8:	Office (General)	2.0	1.10	0.00	1.00

Figure 22: Ag Engineering occupied loads by activity area

ASHRAE Standard 90.1 was used to adjust the values for occupied loads in the building. Lighting and plug loads for classrooms, office was reduced from 1.50 W/sqft to 1.20 W/sqft and 1.10 W/sqft to 0.80 W/sqft respectively.



Main Schedule Information

First (& Last) Season:

01/01/20 - 05/10/20 & 08/24/20 - 12/31/20

	Mo	Tu	We	Th	Fr	Sa	Su	Hol	CD	HD
Day 1	●	●	●	●	●	○	○	○	●	●
☑ Day 2	○	○	○	○	○	●	●	●	○	○
☐ Day 3										

	Day 1	Day 2
Opens at:	7 am	Unocc
Closes at:	7 pm	
Occup %:	90.0 %	
Lites Ld %:	90.0 %	
Equip Ld %:	90.0 %	

☑ Has Second Season

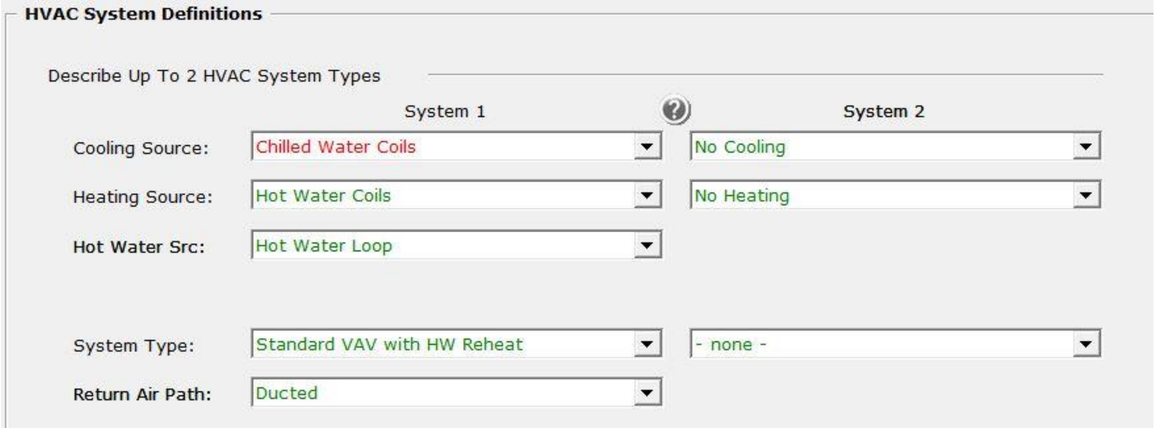
Mon, May 11 thru Sun, Aug 23

	Mo	Tu	We	Th	Fr	Sa	Su	Hol	CD	HD
Day 1	●	●	●	●	●	○	○	○	●	●
☑ Day 2	○	○	○	○	○	●	●	●	○	○
☐ Day 3										

	Day 1	Day 2
Opens at:	8 am	Unocc
Closes at:	4 pm	
Occup %:	20.0 %	
Lites Ld %:	20.0 %	
Equip Ld %:	20.0 %	

Figure 35: Ag Engineering main schedule information

The main schedule information wizard is used to input the information on how the building is used throughout the year. Building usage is divided into two seasons: spring/fall semester as one season and summer semester as the second season. For the first season, when the school is in session, the building is scheduled to be open from 7 am to 7 pm. For the second season, the building is scheduled to operate from 8 am to 4 pm as the school is not in session. These parameters are selected after consulting with facilities and services on how the building is currently operated.



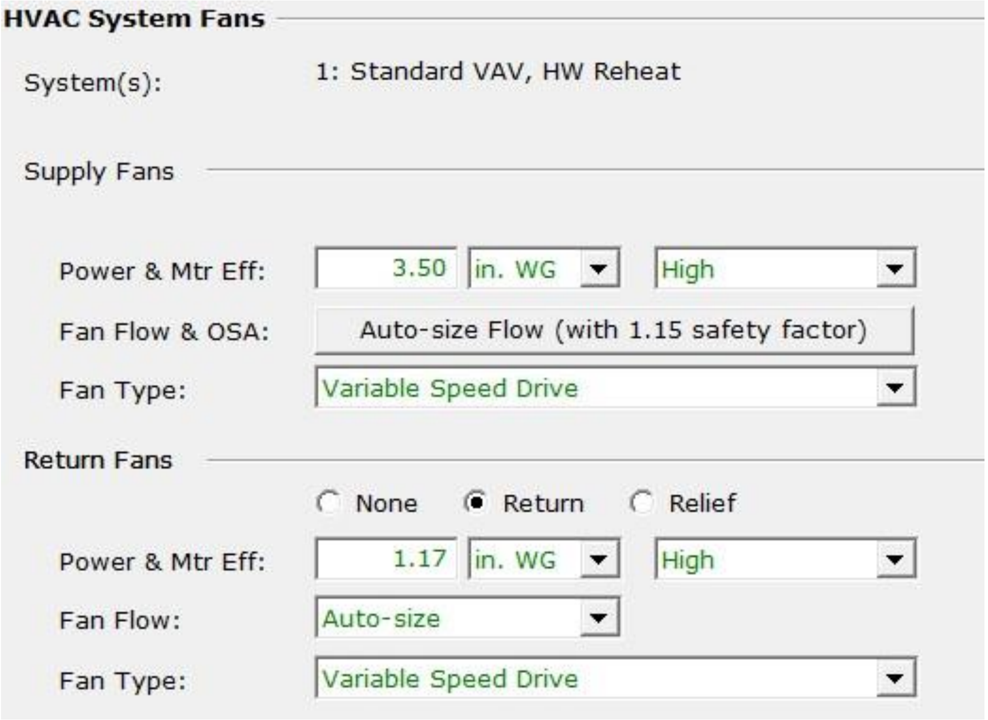
HVAC System Definitions

Describe Up To 2 HVAC System Types

	System 1	System 2
Cooling Source:	Chilled Water Coils	No Cooling
Heating Source:	Hot Water Coils	No Heating
Hot Water Src:	Hot Water Loop	
System Type:	Standard VAV with HW Reheat	- none -
Return Air Path:	Ducted	

Figure 36: Ag Engineering HVAC system definitions

The Ag Engineering building in the future will be cooled with chilled water-cooling coils and heated with hot water heating coils. Standard VAV terminal boxes with hot water reheat are used to serve the individual rooms. The fan specification for the VAV supply and return fans are shown below.



HVAC System Fans

System(s): 1: Standard VAV, HW Reheat

Supply Fans

Power & Mtr Eff: 3.50 in. WG High

Fan Flow & OSA: Auto-size Flow (with 1.15 safety factor)

Fan Type: Variable Speed Drive

Return Fans

○ None ● Return ○ Relief

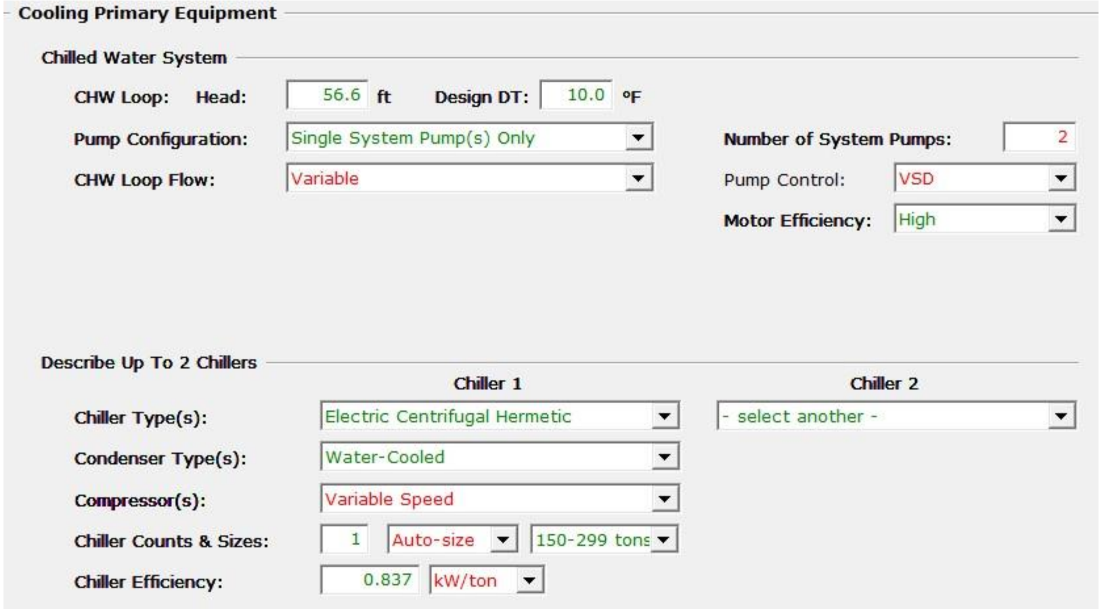
Power & Mtr Eff: 1.17 in. WG High

Fan Flow: Auto-size

Fan Type: Variable Speed Drive

Figure 37: Ag Engineering supply and return fans

The supply and return fans are selected with high motor efficiency with variable speed drives instead of constant speed so the fans can be modulated as the demand varies throughout the day.



Cooling Primary Equipment

Chilled Water System

CHW Loop: Head: 56.6 ft Design DT: 10.0 °F

Pump Configuration: Single System Pump(s) Only

Number of System Pumps: 2

CHW Loop Flow: Variable

Pump Control: VSD

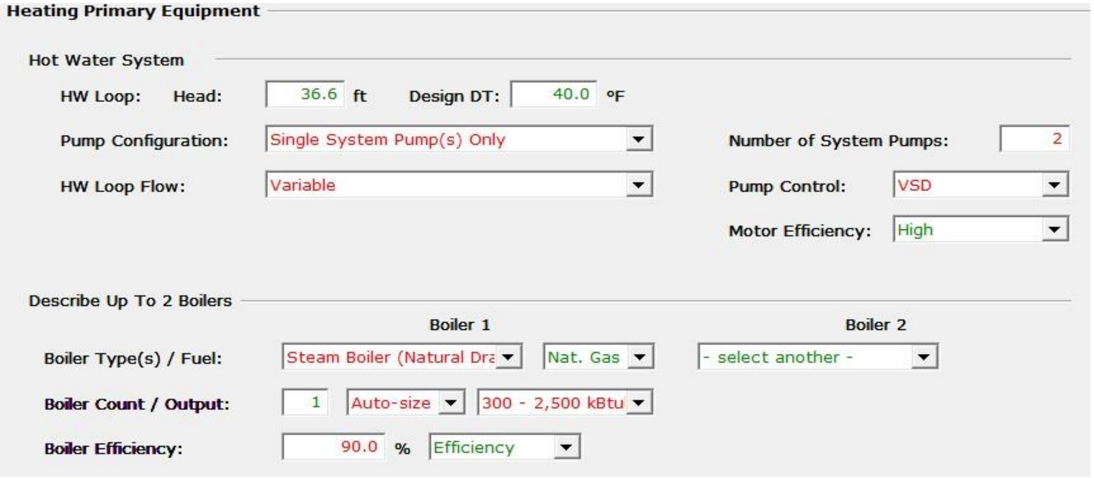
Motor Efficiency: High

Describe Up To 2 Chillers

	Chiller 1	Chiller 2
Chiller Type(s):	Electric Centrifugal Hermetic	- select another -
Condenser Type(s):	Water-Cooled	
Compressor(s):	Variable Speed	
Chiller Counts & Sizes:	1 Auto-size 150-299 tons	
Chiller Efficiency:	0.837 kW/ton	

Figure 38: Ag Engineering cooling primary equipment

The chilled water system is distributed in the building with the help of two high-efficiency system pumps controlled with variable speed drives to modulate the water as needed. The chilled Water system will be connected to the central chiller plant at SDSU to meet the cooling demand during the summer. The compressor type is changed from constant speed to variable speed which helps in reducing the electricity needed to run the compressor.



Heating Primary Equipment

Hot Water System

HW Loop: Head: 36.6 ft Design DT: 40.0 °F

Pump Configuration: Single System Pump(s) Only

Number of System Pumps: 2

HW Loop Flow: Variable

Pump Control: VSD

Motor Efficiency: High

Describe Up To 2 Boilers

	Boiler 1	Boiler 2
Boiler Type(s) / Fuel:	Steam Boiler (Natural Dra Nat. Gas	- select another -
Boiler Count / Output:	1 Auto-size 300 - 2,500 kBtu	
Boiler Efficiency:	90.0 % Efficiency	

Figure 39: Ag Engineering heating primary equipment

Similar to the chilled water system, the hot water system is connected to two high-efficiency pumps controlled with variable speed drives in the building. The hot water system will be connected to the central steam plant to meet the heating demand during the winter. Boiler efficiency is changed from 80% to 90% to reduce natural gas consumption. The results obtained with these changes are analyzed in the following section.

eQuest Simulation Results

The simulation was performed using eQuest to determine how much reduction in energy consumption can be obtained by upgrading to efficient mechanical systems for the building. Figures 29 and 30 and Table 4 display how the monthly usage of electricity and natural gas for building's electrical loads and HVAC loads. The cooling loads from the simulation is determined to be ~80,000 kWh. Gas consumption for the heating load is determined to be 1,987 MMBTU (~582,332 kWh).

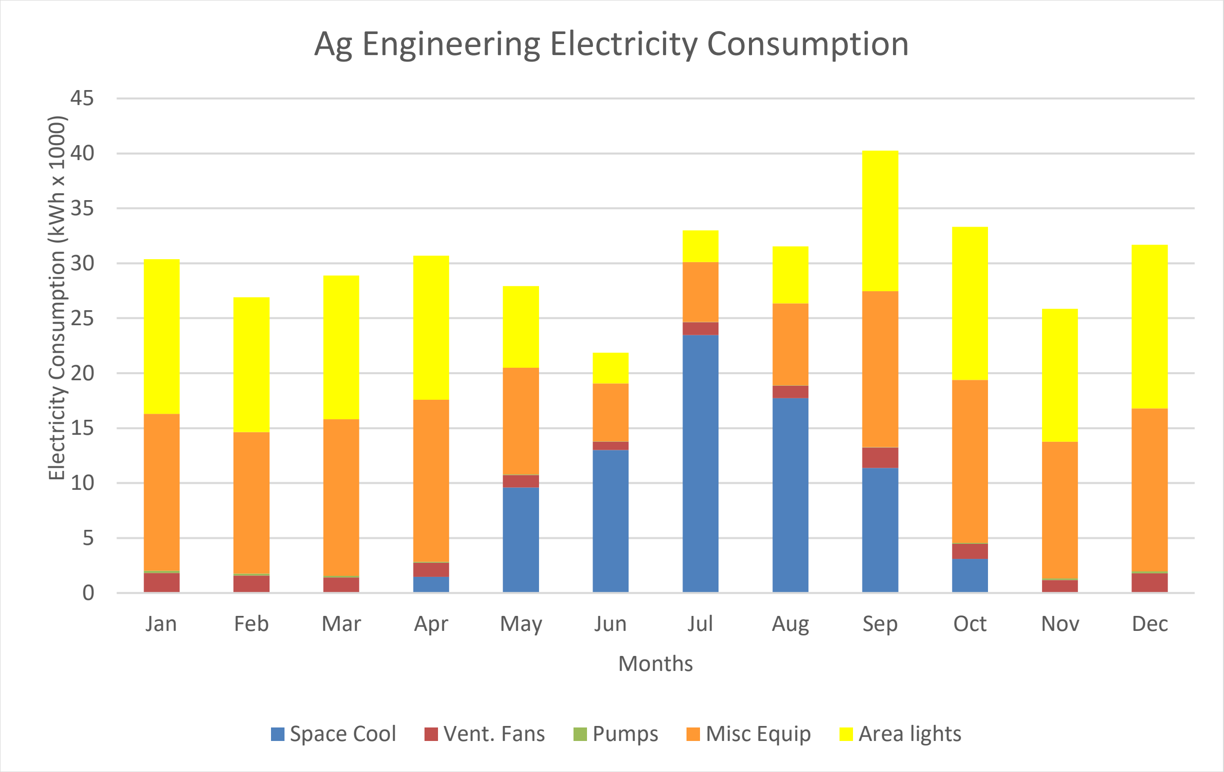


Figure 40: eQuest Ag Engineering electricity simulation

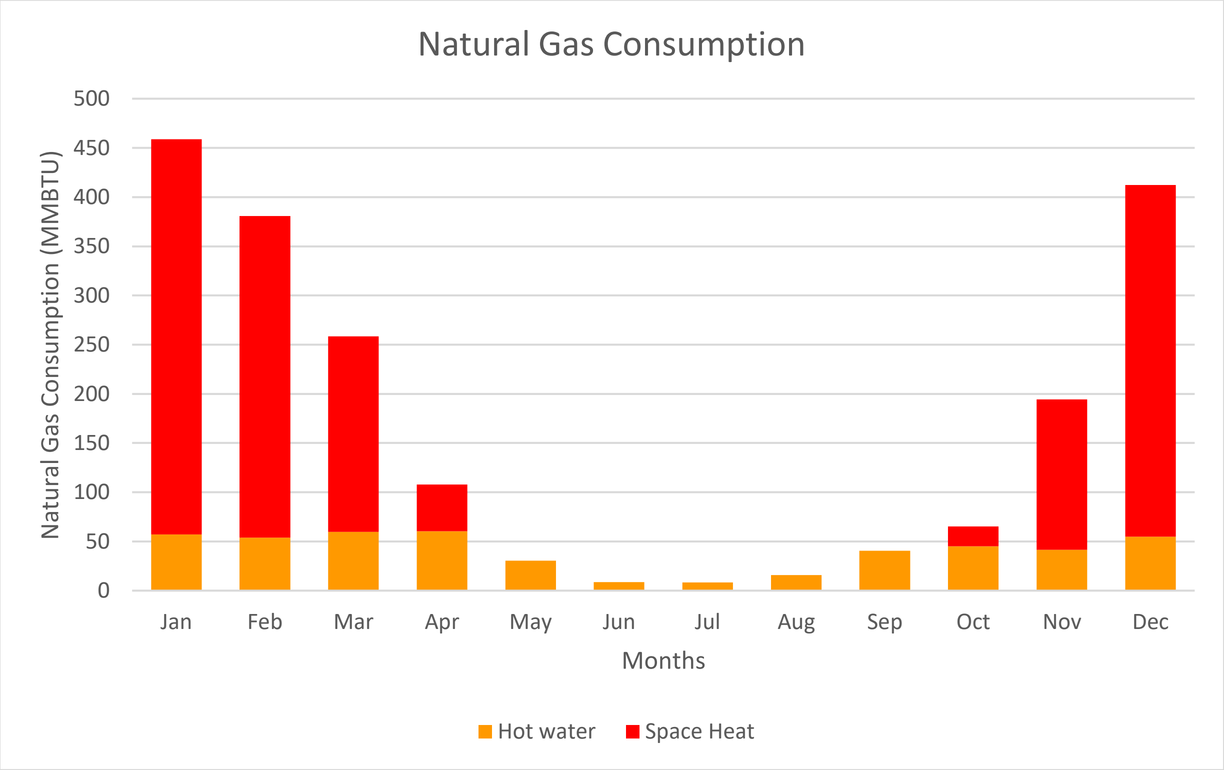
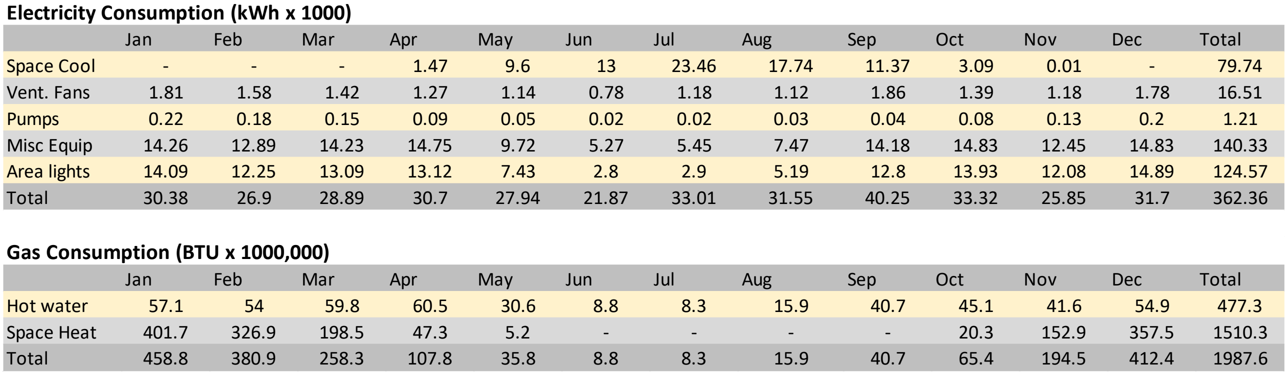


Figure 41: eQuest Ag Engineering natural gas consumption simulation

Table 4: Ag Engineering building electricity and gas consumption



Electricity Consumption (kWh x 1000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	1.47	9.6	13	23.46	17.74	11.37	3.09	0.01	-	79.74
Vent. Fans	1.81	1.58	1.42	1.27	1.14	0.78	1.18	1.12	1.86	1.39	1.18	1.78	16.51
Pumps	0.22	0.18	0.15	0.09	0.05	0.02	0.02	0.03	0.04	0.08	0.13	0.2	1.21
Misc Equip	14.26	12.89	14.23	14.75	9.72	5.27	5.45	7.47	14.18	14.83	12.45	14.83	140.33
Area lights	14.09	12.25	13.09	13.12	7.43	2.8	2.9	5.19	12.8	13.93	12.08	14.89	124.57
Total	30.38	26.9	28.89	30.7	27.94	21.87	33.01	31.55	40.25	33.32	25.85	31.7	362.36

Gas Consumption (BTU x 1000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Hot water	57.1	54	59.8	60.5	30.6	8.8	8.3	15.9	40.7	45.1	41.6	54.9	477.3
Space Heat	401.7	326.9	198.5	47.3	5.2	-	-	-	-	20.3	152.9	357.5	1510.3
Total	458.8	380.9	258.3	107.8	35.8	8.8	8.3	15.9	40.7	65.4	194.5	412.4	1987.6

Simulation Specifications

For this simulation, an Air Handling Unit (AHU) is used to get air transported to individual spaces in the building. Its main components are a supply fan with variable flow drive (VFD), return fan with VFD, economizer, energy recovery wheel, hot water heating coil, and chilled water-cooling coil. The air-handling unit will be controlled automatically using digital control methods through a local control panel and variable frequency drives. Sensing elements, dampers, valves, and actuators are electronic types. The supply fans are operated continuously during occupied periods and programmed to be shut off during unoccupied periods. A high limit pressure control will stop the supply fan if the static pressure at the fan discharge exceeds the set point. An airflow measuring station with its sensing elements in the fan inlet will continuously monitor the supply fan air volume required to meet the ASHRAE standard 62.1.

A duct static pressure sensor will provide a signal to maintain the supply air duct static pressure at the set point by signaling the variable frequency drive through the local control panel to vary supply fan rotational speed. The duct static pressure setpoint will be the minimum static pressure necessary to operate the most hydraulically remote variable air volume (VAV) unit. The duct static pressure setpoint within upper and lower limits can be reset by continuously monitoring all the VAV damper positions within the system by maintaining at least one VAV damper at 90 percent open. The supply fan will be soft started through the variable frequency drive. The normal position will be zero RPM. Fan acceleration and deceleration rates will be adjustable at the variable frequency drive. High limit duct static pressure switches with manual reset located close to the fan in the supply air ductwork will stop the AHU fans, index the system to its unoccupied cycle of operation, and send an alarm to the operator's workstation and BAS alarm printer if the duct static pressure exceeds 2.5" W.G.

A temperature sensor located in the supply air plenum (downstream of the final filters) will provide a signal to control the economizer outside air/return air/relief air dampers, the hot water heating coil, and the chilled water cooling coil in sequence to maintain an adjustable supply air temperature setpoint. The supply air temperature setpoint will be manually set at the Operator Workstation (or AHU control panel). Initial set point: 55 deg F (summer). The building automation system will automatically reset the supply air temperature setpoint within the range of 55- 65 deg F based on the VAV unit with the greatest cooling demand. The supply air temperature setpoint will be proportionally overridden (downward to 55 deg F limit) to provide dehumidification in response to return air relative humidity controls. The BAS monitors and controls return air temperature, return air relative humidity, outside air temperature, outside air temperature relative humidity, mixed air temperature, return air damper control signal, and outside air damper control signal.

Whenever the supply fan is started and the building is in occupied mode, the air flow measuring station damper will be proportionally positioned to maintain an adjustable minimum outside air quantity. Initial set point: 15 percent of maximum supply airflow. The minimum outside air setpoint will be proportionally increased to a maximum of 20 percent of design airflow in response to the return air CO2 sensor. The minimum outside air controls will provide the least minimum outside air that will maintain the space carbon dioxide below the maximum limit. Initial limit: 700 parts per million above outdoor air concentration. The outdoor air damper will be closed whenever the supply fans are stopped.

In response to supply air temperature controls, the economizer will control the outside air/return air/relief air dampers to be proportionally positioned away from the minimum outside air position and toward the full outside air position to provide cooling. The outside and relief air damper will normally stay open and the return air damper will normally stay closed. Above the minimum outside air position, the dampers will be proportionally positioned to maintain a mixed air temperature setpoint 2 deg F lower than the supply air temperature setpoint. The outside air/return air/relief air dampers will be returned to the minimum outside air position whenever the outside air temperature is greater than the return air temperature or the outside air temperature rises above 75 degrees F. The outside air/return air/relief air dampers will modulate to prevent the mixed air temperature from falling below 45 degrees F. The control of the return air damper will be proportionally overridden by a signal from a mixed air plenum static pressure sensor to maintain the mixed air plenum static pressure at a minimum set point.

An outside air temperature sensor located downstream of the wheel will modulate the energy recovery wheel speed through the variable frequency drive to maintain a maximum leaving wheel outside air temperature setpoint of 45˚F. An exhaust/relief air temperature sensor located downstream of the energy recovery wheel will modulate the wheel speed through the variable speed drive. The temperature data obtained is used to maintain a minimum leaving wheel exhaust/relief air temperature greater than the return air dewpoint plus 2˚F as calculated with the return air dry bulb temperature and return air humidity. As the exhaust/relief air temperature drops below its set point, the wheel will slow down. The exhaust/relief air temperature sensor control will override the outside air temperature control. When the outside air temperature leaving the wheel is between the leaving exhaust air temperature setpoint and the leaving wheel outside air setpoint, the heat wheel will rotate at full speed to maximize heat recovery. When the outside air temperature downstream of the heat wheel is greater than the temperature setpoint and the heat wheel is turning at its minimum speed, the system will be indexed to economizer mode and the wheel will stop rotating.

The hot water heating control valve will be proportionally positioned to maintain the coil leaving temperature 2˚F lower than the supply air temperature. The hot water control valve will be a two-way throttling valve, normally open. The heating coil controls will be operational regardless of the supply fan status. The heating coil controls will modulate to prevent the mixed air temperature from falling below 45˚F. A freeze protection thermostat located on the discharge side of the heating coil will send an alarm to the operator's workstation and BAS alarm printer. The auxiliary contacts of the freeze protection thermostat will shut off the fan motor, fully close the outside air damper, and open the heating coil valve to full flow through the coil whenever the coil outlet air temperature falls below its setting. The BAS monitors and controls heating coil entering air temperature, leaving air temperature, control valve signal, control valve position, and outside air temperature.

The chilled water coil is served from the central cooling plant hydronic loop. The cooling coil valve shall not be allowed to open when the system is in heating mode. The chilled water-cooling control valve shall be proportionally positioned to maintain the supply air temperature setpoint. The chilled water-cooling control valve shall be closed whenever the supply fan is stopped. The BAS monitors and controls the cooling coil entering air temperature, leaving air temperature, control valve signal, and control valve position.

A static pressure sensor located in the return air/relief air plenum will provide a signal to maintain the static pressure at an adjustable set point by signaling the variable frequency drive through the local control panel to modulate the return/relief fan rotational speed. The return/relief fan will be soft started through the variable frequency drive. The normal position will be zero RPM. Fan acceleration and deceleration rates will be adjustable at the variable frequency drive.

A building static pressure sensor will provide a signal to proportionally position the relief air damper to maintain the building static pressure relative to the outside air static pressure. The building static pressure sensor will have one pressure sensing element located in the ceiling and the other located in the outside air. A differential pressure sensor will provide a signal to the Operator Workstation when the air filter pressure drop reaches the set point of 0.02” of Water Gauge (W.G.) During occupied operation, the AHU fan will run continuously as determined by the Building Automation System (BAS). When the occupied cycle of operation is initiated, the BAS will prevent the AHU outside air damper from opening and open the heating valve to maintain 100˚F during morning warm-up. When the return air duct temperature sensor reaches 68˚F, the outside air damper will open to its minimum position and the heating valve will modulate to maintain discharge air temperature.

The VAV boxes will be indexed to the occupied or unoccupied mode by system according to the operator specified occupancy schedules. When the VAV box is in unoccupied mode, a switch on each VAV box space temperature sensor will allow an occupant to switch the VAV box to occupied mode. An occupant setpoint adjustment lever located at each VAV box space temperature sensor will allow occupants to raise or lower the space temperature setpoint for that VAV zone. VAV terminals with reheat coils are served by a common space temperature sensor separate control valves will be provided.

In Occupied Mode, the terminal fan will run continuously. The controller will modulate the variable air volume terminal unit to maintain the desired space temperature. As the space temperature rises above the cooling setpoint, the VAV box primary air damper will modulate from the minimum CFM set point toward the maximum CFM set point. When the VAV box damper is 100% open and the space still need cooling, a "cooling request" will be transmitted over the control module network to the Air Handling Unit. The air handling unit discharge air temperature setpoint will be reset depending on the number of cooling requests being received. When the space is satisfied and the demand for cooling is reduced, the primary air damper will be modulated toward the minimum CFM position. As the space temperature drops below the heating occupied set point, the zone control valve will open fully before opening the reheat coil control valve. The primary air damper will be positioned to minimum airflow. If the space temperature continues to be below the set point, the reheat valve will be proportionally positioned from fully closed to fully open to maintain the space temperature setpoint. When commanded by the BAS to change over to the unoccupied mode, the VAV controller will raise the cooling setpoint to 78˚F and decrease the heating setpoint to 50˚F to operator determined values.

In the Unoccupied Mode, when there is no call for heating to maintain the unoccupied space temperature set points, the reheat valve will be closed, and the terminal fan will be off. The "Cooling requests" from various zones are ignored by the system and no action is taken.

Current Use vs eQuest Data

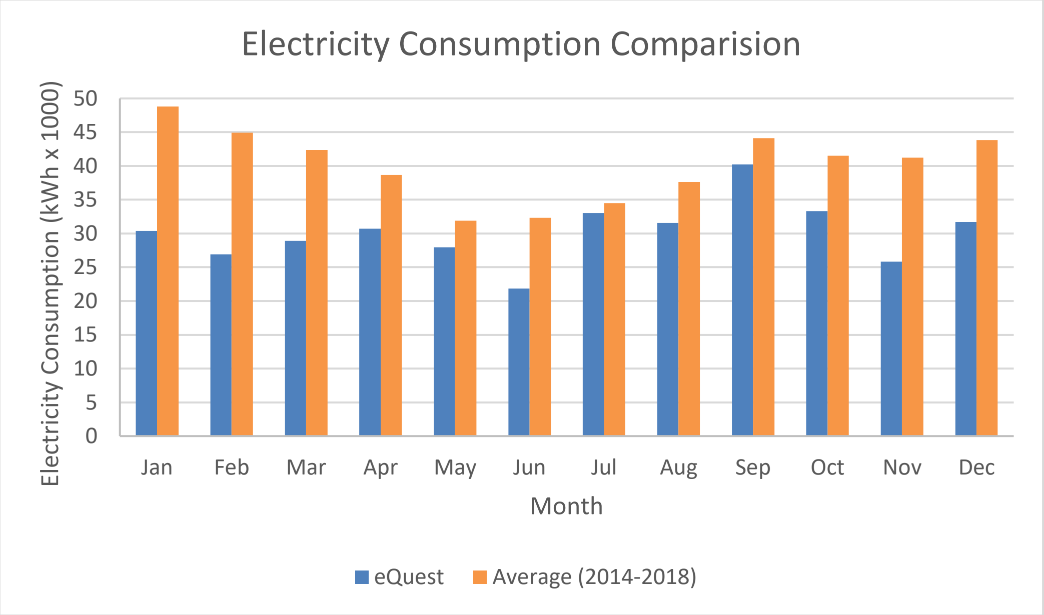


Figure 42: Ag Engineering electricity consumption comparison

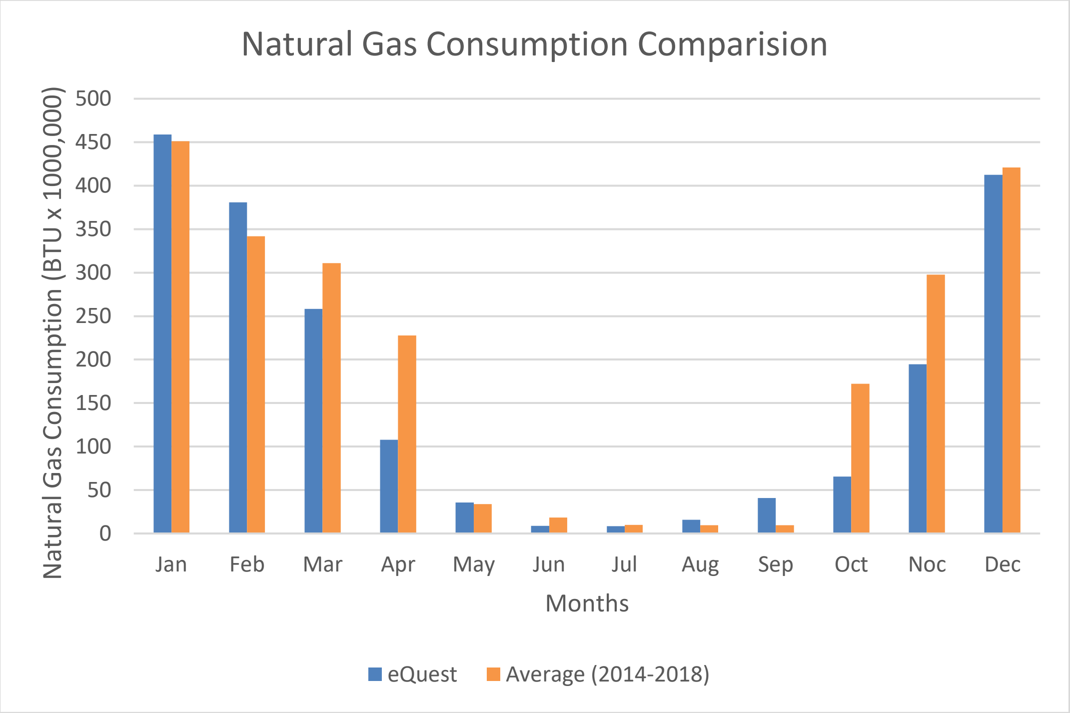


Figure 43: Ag Engineering natural gas consumption comparison

Above Figures 43 and 44 show the comparison between the eQuest simulation and the average electricity and natural gas consumption data for five years (2014 – 2018). It can be observed that simulation results follow a similar trend to the current electricity usage. By using efficient mechanical systems discussed above and daylight controls, electricity consumption could be reduced by 24% and natural gas consumption by 14% annually. One way to understand the reduction of energy use is to look at energy used per square foot before and after retrofitting. The current rate of energy can be reduced by 54%, from 134.83 kBTU/sf to 61.67 kBTU/sf. This can be put into perspective by comparing it to the average energy use of the campus buildings from 2014 to 2018, the campus building’s rate of energy was 146.83 kBTU/sf, resulting in only a 58% reduction in energy use.

Another factor that can have an impact is how hot or cold a year has been. This drives the need for heating or cooling in the building. To normalize the data across different years, degree days (DD) are used. EIA defines *“A degree day is a measure of how warm or cold a location is*” (EIA, 2020). The current energy use for the period 2014-2018 is 15.5 BTU/sf/DD which reduces to 6.48 BTU/sf/DD, resulting in a 58% decrease in energy use. When compared to a campus building, the average rate of energy use of 16.95 BTU/sf/DD results in a 61.75% decrease. This energy-saving translates to monetary savings of over $5,300 in electricity cost and $2,200 in natural gas cost annually. Importantly, during the winter months, Figure 22 shows there is a significant decline in energy consumption between the current operating conditions and simulated operating conditions. This is key for a geographical location like South Dakota because the heating load dominates for most of the academic year.

Solar Wall

Solar Wall and Photovoltaics (PV) panel array systems are two renewable energy systems considered for the Ag Engineering building to reduce the energy costs. SDSU has already employed a solar wall in Frost Arena to offset the heating load, which has provided a return of investment under 10 years. Another factor that should be considered is that maintenance staff are already familiar with this type of equipment. A solar wall heating system will be placed on the south wall of the building to reduce the heating loads during summer. This system will reduce the building heating load by using heat generated on the wall and an air handling unit to move air into space. The proposed wall dimensions are 175 feet in length and 25 feet in height which provides a total area of

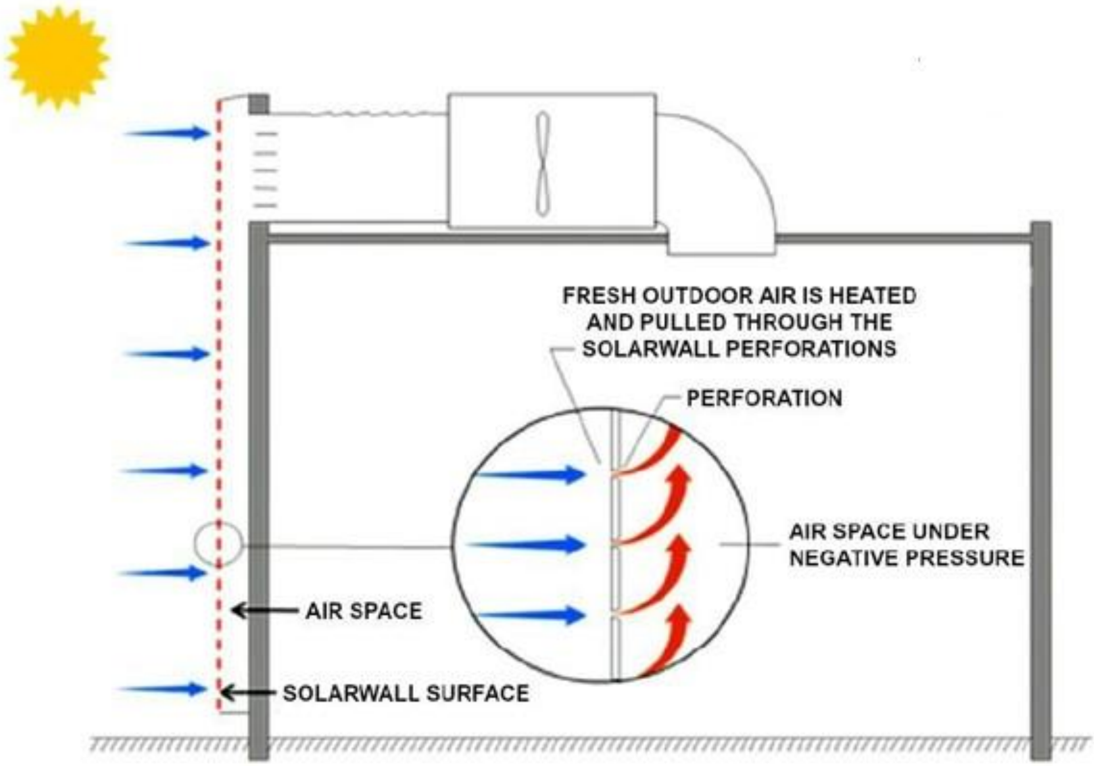


Figure 44: Solar wall heating schematic

4375 sq. feet (406m^2) for the panels. The solar wall energy model is simulated using RETScreen Expert, software developed by the government of Canada is a Clean Energy Management Software system for energy efficiency, renewable energy, and cogeneration project feasibility analysis as well as ongoing energy performance analysis (Natural resources Canada, 2019). The following assumptions are made for the system:

1. Indoor Air Temperature: 68˚F
2. Air Temperature: 160˚F
3. R-value: 12 ft^2-˚F/BTU-hr
4. Design flow rate: 12,000 cfm
5. Heating Requirement: 1,510 MMBTU
6. Solar Collector absorptivity: 0.95
7. Performance Factor: 1.05
8. Solar air heater efficiency: 24%

Perforated, metal panels are installed on the exterior of the building, which is heated by solar radiation from the sun. The air handling unit creates a negative pressure in the air space behind the wall and brings in heated, fresh air through panel perforations. During summer months, when heating is not required, a summer bypass damper is used to avoid the solar wall system and therefore bringing in cooler outdoor air. Figure 16 shows the proposed schematic of the solar wall. EPA recommends using central HVAC Air Handling Units (AHUs) when possible to maintain the required Indoor Air Quality (IAQ) standards (EPA, n.d.). According to ASHRAE standard 62.1-2001, if outside air is brought into space through a mechanical system in a classroom and other school spaces, “*then at least 15 cubic feet per minute (cfm) of outside air must be provided for each* *occupant*." To approximate the number of occupants per classroom, it is assumed there are 30 students in each classroom in the building.

$$Total\ Outside\ Air(OA) = \frac{15\ cfm}{student} \times \frac{30\ students}{classroom} \times 25\ classrooms$$

$$Total\ Outside\ Air(OA) = 11{,}250\ cfm$$

RetScreen Expert simulates the amount of solar energy that will be available each month. This value is then utilized to calculate how much of the heating loads can be offset every month. The following graph shows the amount of daily solar radiation (kWh/month) that can be utilized in Brookings, SD.

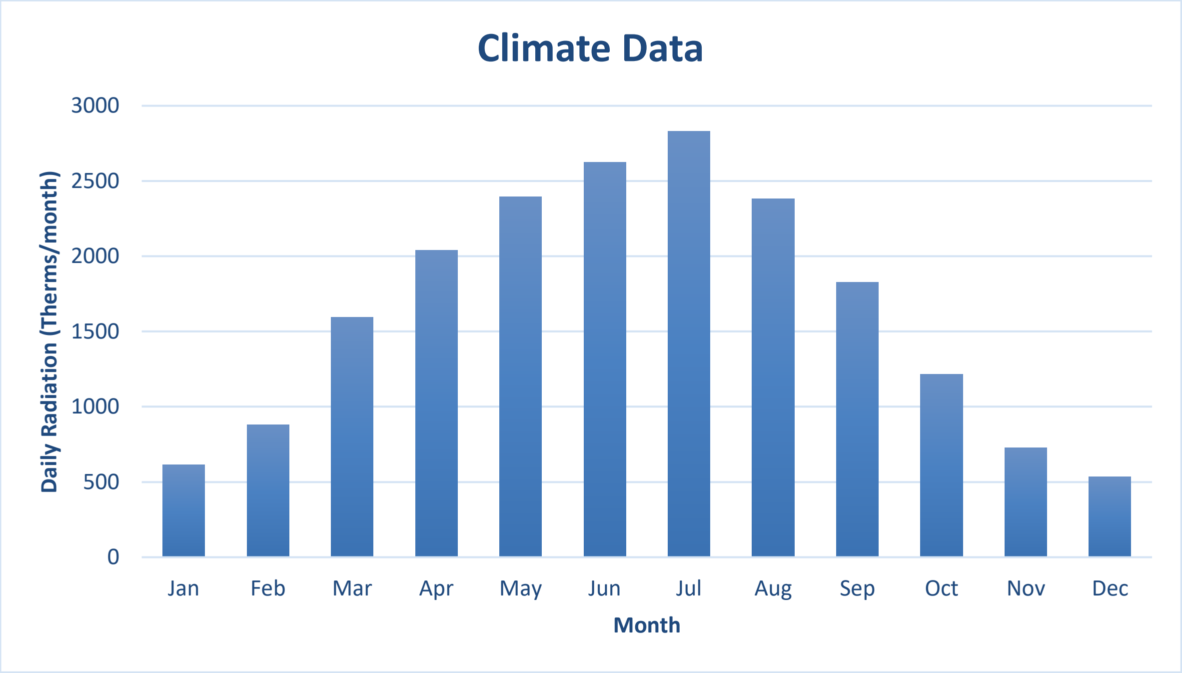


Figure 45: Brookings climate data

Table 5: Ag Engineering solar wall

Month	Solar Wall (therms)	Value ($)	Heating Load (therms)	Current Cost ($)	Future cost ($)
Jan	613.64	429.55	4,017	2,811.90	2,382.35
Feb	879.84	615.89	3,269	2,288.30	1,672.41
Mar	1,596.33	1,117.43	1,985	1,389.50	272.07
Apr	2,039.02	1,427.31	473	331.10	0
May	2,394.50	1,676.15	52	36.40	0
Jun	2,624.56	1,837.19	-	-	0
Jul	2,832.20	1,982.54	-	-	0
Aug	2,381.62	1,667.14	-	-	0
Sep	1,827.22	1,279.06	-	-	0
Oct	1,214.41	850.09	203	142.10	0
Nov	726.74	508.72	1,529	1,070.30	561.58
Dec	536.40	375.48	3,575	2,502.50	2,127.02
Total	**19,666.48**	**13,766.53**	**15,103**	**10,572.10**	**7,015.44**

Table 5 shows the energy generated by the Solar wall each month and its corresponding value in dollars. Space heating load demand and its corresponding cost are calculated in columns four and five. The last column shows during the months of April through October, the solar wall heating surpasses the heating demand in the building. Therefore, the cost of natural gas during these months is zero for the university. Annually, using solar wall results in a savings of $3,556 annually.

The solar wall heat gain is maximum during the month of July and least in December. The total capacity of the solar wall to generate heat is approximately 19,666 therms/year. When looked at macroscopically, this appears to meet the natural gas demand for heating, which is 15,103 therms/year. However, since the solar thermal heat is limited during the winter months, the system will only a fraction of the demand. The following graph reveals what percentage of demand is met each month.

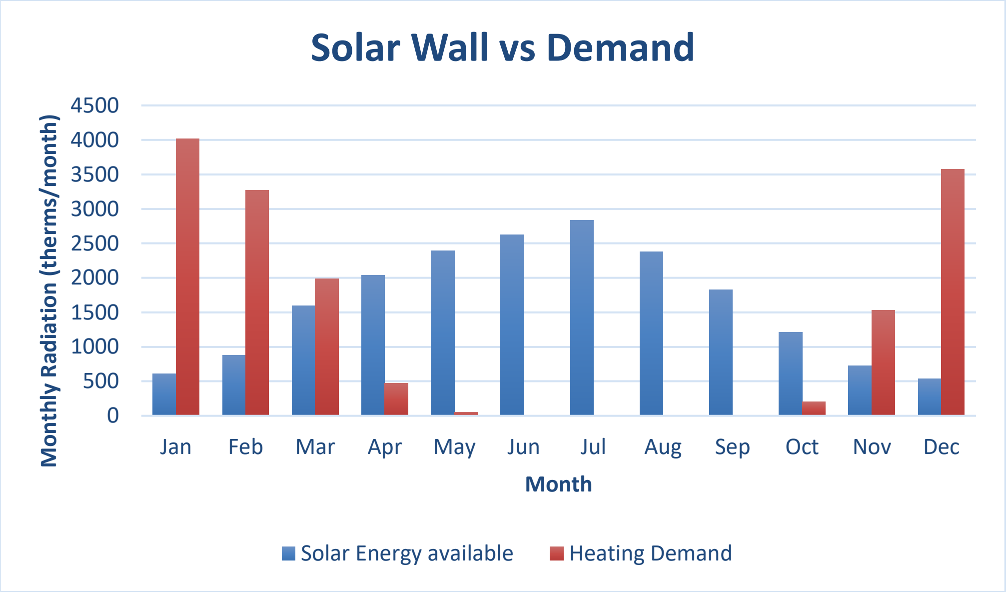


Figure 46: Comparison of solar energy available for heating vs demand

It can be observed that the net demand for space heating is met entirely from the month of April to October. During winter months, solar wall meets 10% to 40% of the heat required. The cost of heating the occupied space for a year without the use of a solar wall heating system is $10,572 for 15,100 therms. By using a solar wall for heating, the cost of natural gas per year is brought down to $7,015 for 10,022 therms.

Return on investment (Solar Wall)

To calculate the return on investment, it is important to understand what the net cost of the project, annual savings, and life cycle savings of the system will be. Table 6 below shows the total installed cost of the solar wall heating system.

Table 6: Cost of solar wall

Solar wall system	$28,560
Estimated cost of installation	$10,800
Estimated cost for supply and insulation ducting	$20,000
Automatic temperature controls	$5,000
Total installed cost	**$64,360**

The projected life of the solar wall is approximately 40 years. The projected cost savings from natural gas cost for space heating per year is $2,948. The table 7 shows the projected costs and savings:

Table 7: Cost and savings from solar wall heating system

Solar wall system cost	$64,360
Annual savings from energy cost	$3,556
Simple payback period	18.09 years

Once the cost of investment is gained back in 18.09 years, the solar wall system will generate revenue for the university in the form of dollars saved.

$$Total\ Revenue\ generated = 40\ years * \frac{\$3{,}556}{year} = \$142{,}240$$

$$Revenue\ genertaing\ years = (40 - 18.09)\ years = 21.91\ years$$

$$Net\ Revenue\ generated = 21.91 years * \frac{\$3,556}{year} = \$77,911$$

CO₂ Emissions

The emission analysis includes the amount of CO_2 emitted before and after the solar wall system is utilized. CO_2 is the primary gas emitted when natural gas is used. A total of 15,103 therms of energy is consumed annually, which equates to 88.1 tons of CO_2 emissions (EPA, 2014). Energy consumption when a solar wall is used reduces to 10,022 therms per year, which results in 58.5 tons of CO_2. This reduction in energy usage results in saving 29.6 tons of carbon dioxide emissions into the year. This is equivalent to 35.1 acres of U.S. forests sequestering carbon in one year or over 1000 incandescent lamps switched to LEDs.

Photovoltaics (PV) System

The PV system will be used to offset the electrical load generated due to lighting and equipment in the building. The lighting and equipment load in the building accounts for 124,000 kWh and 143,000 kWh and per year, respectively. National Renewable Energy Lab's (NREL) PVWatts simulator is used to identify the solar energy generation capacity on top of the building's roof (NREL, n.d.). A 184.2-kW system can be installed on the roof to maximize solar PV energy production. The output may range from 238,516 kWh to 262,061 kWh per year. The following assumptions are made to achieve the projected output:

1. Fixed type array
2. 14.08% system losses,
3. 20 degrees tilt, Azimuth angle at 180-degree,

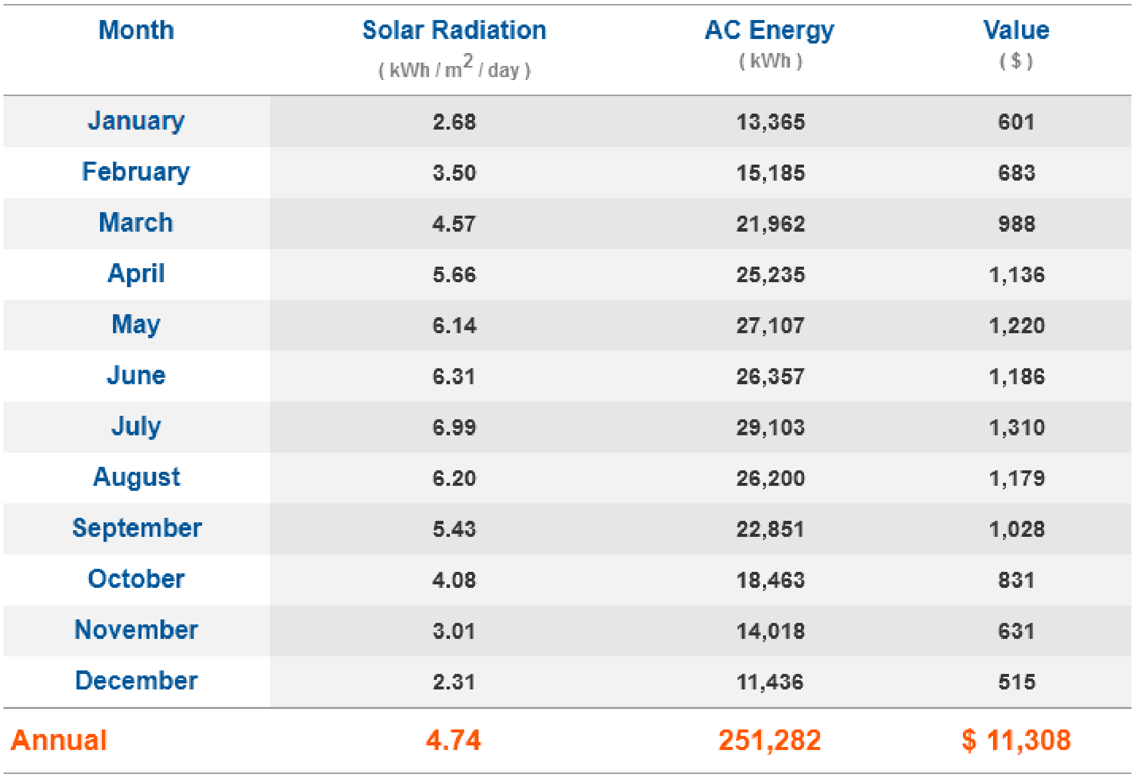
4. DC to AC size ratio = 1.2, inverter efficiency at 96%,
5. Ground coverage ratio of 0.4.
6. Rate of electricity for SDSU is \$ 0.045 per kWh.

The total area available on the roof of the building is 18,329 ft^2 (1,703 m^2). Ground Coverage Ratio (GCR) is the surface area of the module to the area of the ground or roof occupied by the array of solar panels. For a GCR value of 0.4, the area occupied by the

Figure 47: Solar PV location on Ag Engineering roof (NREL)

solar panels is approximately 7,330 ft^2 (680 m^2). PVWatts uses GCR value to calculate the losses associated due to shading of an adjacent solar PV array. Figure 48 above the proposed location of where the PV panels can be installed. Table 8 shows the projected electricity that can be generated using 184.2 kW of Solar PV Panels.

Table 8: NREL Projected monthly production through solar PV panels



Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	2.68	13,365	601
February	3.50	15,185	683
March	4.57	21,962	988
April	5.66	25,235	1,136
May	6.14	27,107	1,220
June	6.31	26,357	1,186
July	6.99	29,103	1,310
August	6.20	26,200	1,179
September	5.43	22,851	1,028
October	4.08	18,463	831
November	3.01	14,018	631
December	2.31	11,436	515
Annual	**4.74**	**251,282**	**$ 11,308**

**Solar output of a 182.4 kW PV array sized for maximum output based on the available roof area

The combined demand for lighting and equipment electrical load is approximately 265,000 kWh per year. When month to month demand and power generated is compared, electricity demand will not be met during the winter. Inversely, there is more electricity produced in the summer, but the demand is less than 50% of the winter months on average. If the system is optimally sized for the demand, excess electricity will not be generated. This reduces the capital cost of the system and thereby yields a faster simple payback period. The following Table 9 shows the energy and cost savings if the system is optimally designed.

Table 9: Optimum solar PV size calculation

System size	52.8 kW
Cost of the system	$96,624
Cost savings	$3,241/yr
Simple payback period	29.8 years
Energy Saved	72,029 kWh

A 52.8-kW solar PV system will require a capital cost investment of $96,624. By using this system, 72,029 kWh of energy can be saved annually. This results in dollar savings in electricity costs of $3,241 per year. Finally, the simple payback period is calculated to be 29.8 years. Alternatively, by maximizing the solar PV generation on the roof, initial capital investment will increase, therefore increasing the simple payback period by 7.36 years (37.16 yrs – 29.8 yrs). The calculation of the maximized solar PV system is shown in subsequent sections. This can be reduced by utilizing the excess electricity to power the neighboring buildings by negotiating a power purchase agreement in the future, which is discussed in future work sections.

Figure 49 compares the electricity produced versus the electrical loads. It also demonstrates the potential of using the excess electricity that is not utilized in Ag Engineering Hall. Table 17 below shows the calculation of a 184.2-kW solar PV system.

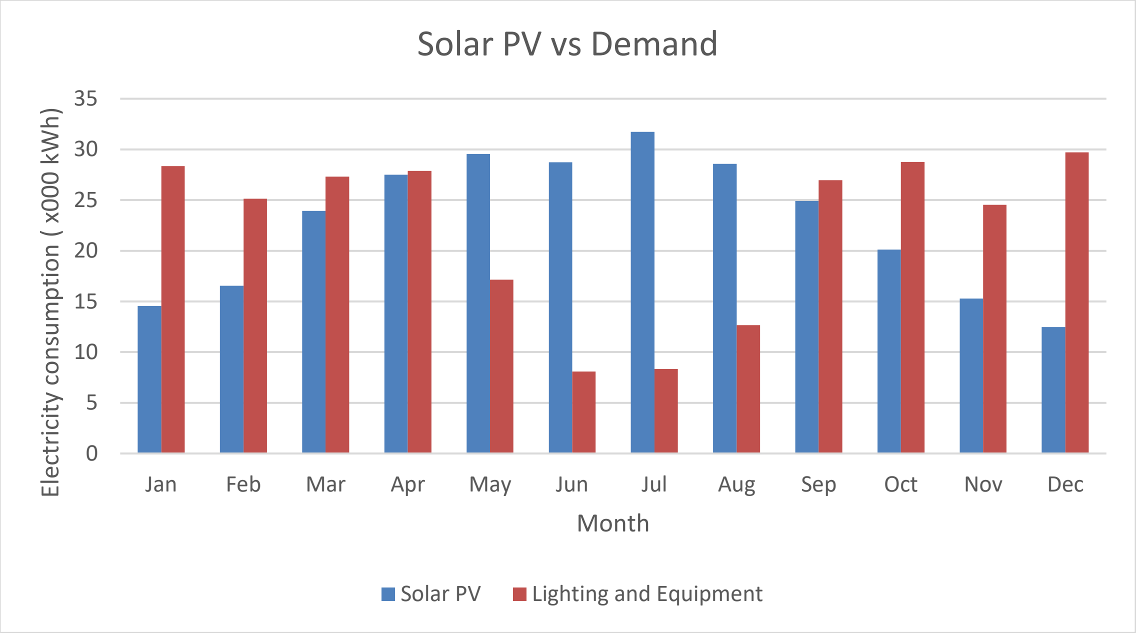


Figure 48: Comparison of electricity generated by PV and demand

Table 10: Ag Engineering solar PV calculation

Month	Solar PV (kWh)	Value ($)	Lighting & Equipment load (kWh)	Cost ($)	Metered Total (kWh)	Future Cost ($)
Jan	14,570	655.65	28,350	1,275.75	13,780	620.1
Feb	16,553	744.89	25,140	1,131.30	8,587	386.42
Mar	23,941	1,077.35	27,320	1,229.40	3,379	152.06
Apr	27,509	1,237.91	27,870	1,254.15	361	16.24
May	29,550	1,329.75	17,150	771.75	-12,400	-558
Jun	28,732	1,292.94	8,070	363.15	-20,662	-929.79
Jul	31,725	1,427.63	8,350	375.75	-23,375	-1,051.88
Aug	28,561	1,285.25	12,660	569.7	-15,901	-715.55
Sep	24,910	1,120.95	26,980	1,214.10	2,070	93.15
Oct	20,127	905.72	28,760	1,294.20	8,633	388.49
Nov	15,281	687.65	24,530	1,103.85	9,249	416.21
Dec	12,466	560.97	29,720	1,337.40	17,254	776.43
Total	**273,925**	**12,326.63**	**264,900**	**11,920.50**	**63,313**	**2,849.09**

The second and third column in Table 10 shows the electricity that can be generated using solar PV panels and its corresponding value in dollars, respectively. The fourth and fifth column lists the lighting and equipment loads and the utilities cost associated with it. The fifth column shows the electricity demand needed after the solar PV system offsets the original demand. The negative numbers during the months of May through August indicate the potential electricity that can be used to reduce the simple payback period as discussed earlier. The last column shows the projected monthly bill after using solar PV to offset the energy costs. During the months of May through June, more electricity can be produced than there is demand, hence the cost of the electricity bill is negative for those months. Therefore, when calculating the total electricity cost, those months are excluded from the calculation. The excess power capacity can be utilized to power neighboring buildings if the power purchase agreement between SDSU and the utility provider allows for it.

NREL study has estimated that the commercial cost of solar energy per Watt of production is $1.83 (Fu, Feldman, & Margolis, Nd, 2018). This value includes hardware costs (module), Inverter, structural and electrical components, labor costs, sales tax overhead, and net profit. The electricity bill for the building per year amounts to be $11,920 for 265,000 kWh. By using Solar PV to generate electricity, the projected electricity bill will be $2,849 per year for 63,313 kWh resulting in a savings of $9,071 per year.

Table 11: Ag Engineering solar PV ROI

Total Capital Cost	$337,086
Annual Savings	$9,071
Simple Payback Period	37.16 yrs

Return on Investment (PV)

To calculate the return on investment, it is important to investigate how the life span of the system. According to NREL, the average life of solar PV panels generating electricity at its peak performance is approximately 32.5 years (NREL, n.d.). With regular maintenance, the PV panels are projected to last additional 25-30 years. Solar panels have a degradation rate of 0.3% per year (Jordan & Kurtz, 2015). This means that production from a solar panel will decrease at a rate of 0.3% per year. At year 60, the solar panels will operate at 80% of its original capacity.

Once the payback period is completed, the system will start to generate net revenue. Once this value is known, revenue-generating years can be calculated which begins after the capital investment cost has been earned back from generating electricity. Finally, ROI can be calculated by multiplying the dollar amount saved per year and revenue-generating years.

$$Revenue\ generated = \frac{\$7{,}256}{year} \times 60\ years = \$435{,}508$$

$$Revenue\ generating\ years = (60 - 37.16) years = 22.84\ years$$

$$Net\ Revenue\ Generated = \frac{\$7{,}256}{year} * 22.84 = \$165{,}727$$

CO_2 Emissions

A total of 201,587 kWh of electricity can be saved by integrating the proposed solar PV system for the building. In addition to reducing the utility cost for the building, 157 tons of CO_2 emissions are saved from being entered into the environment. This is equivalent to CO_2 absorbed by 186 acres of U.S. forests in one year or 352,643 miles driven by an average passenger car (EPA, n.d.).

LINCOLN MUSIC HALL BUILDING

This building was constructed in 1927 and was known as the Lincoln Memorial Library. It became home to the Music Department when it was remodeled in 1979 with a budget of $254,200. The building consists of three floors. The first two floors are classroom spaces, and the third floor has an auditorium, which is used for musical performances and senior recitals. The building is heated using steam from a central steam plant. For cooling, the building relies on natural ventilation and some window air-conditioning systems.

Floor Plan

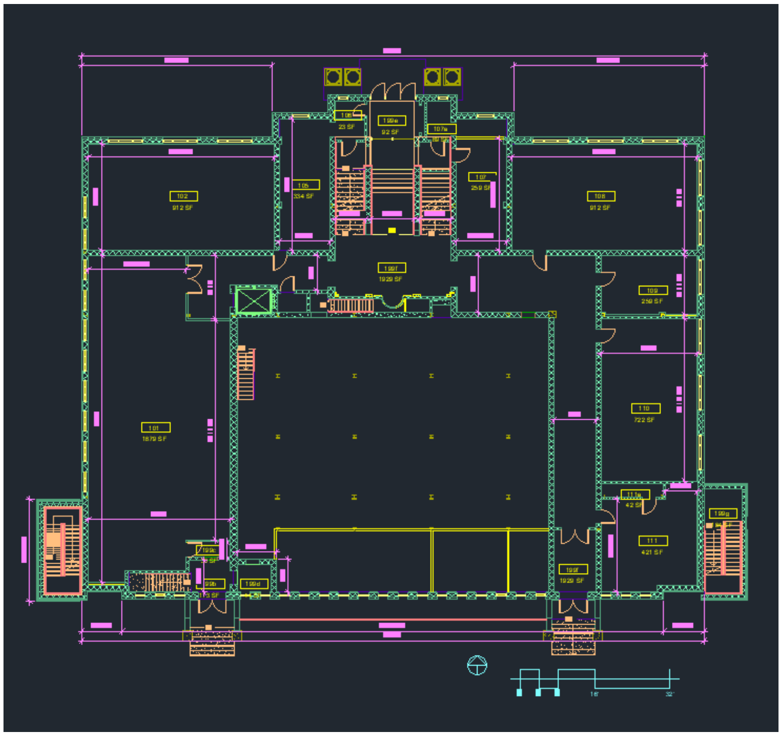
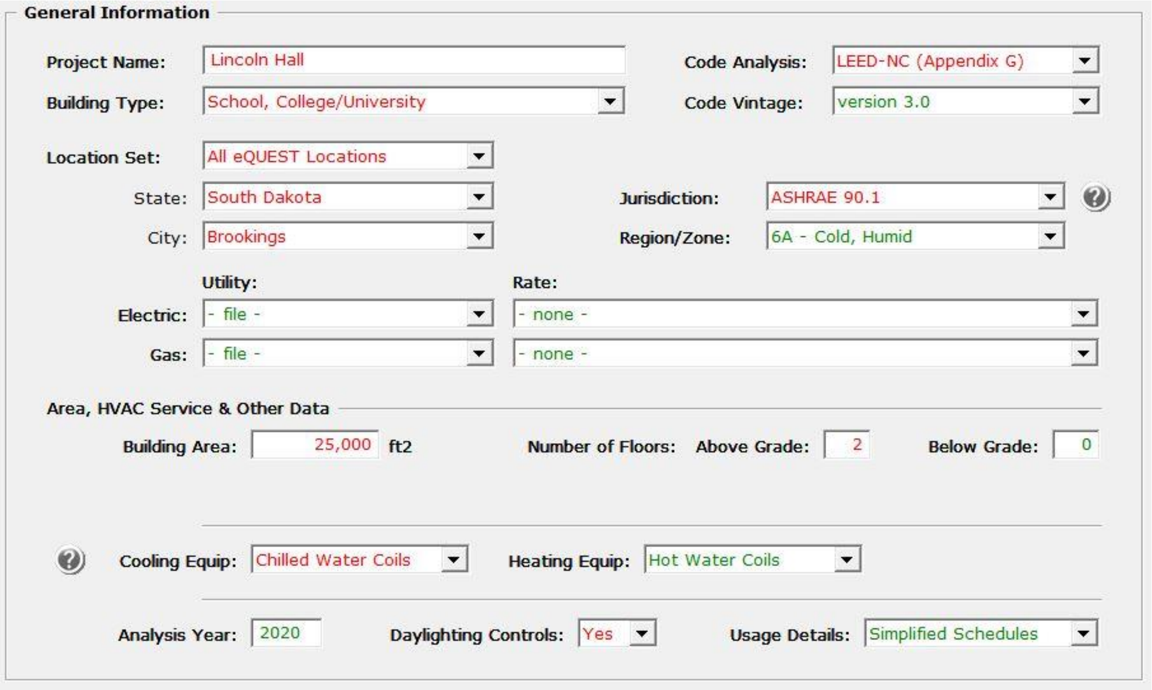


Figure 49: Lincoln Music Hall floor plan

The above floor plan in Figure 50 shows the first floor of Lincoln Music Hall. The building accommodates classrooms, community space, meeting rooms, and offices. It typically operates from 8 am to 5 pm during weekdays. During weekends, there may be some activity in the laboratory, but it is assumed minimal for the purpose of the simulation in eQuest. During summer, the space is used for different purposes, such as summer camps and other school activities regularly.

eQuest Model

Energy modeling for the building was performed on eQuest to predict the energy savings in the Lincoln Music Hall building. The following screenshots of the software show the changes that were made to accomplish the reduction in energy usage.



General Information

Project Name: Lincoln Hall
Code Analysis: LEED-NC (Appendix G)
Building Type: School, College/University
Code Vintage: version 3.0
Location Set: All eQUEST Locations
State: South Dakota
Jurisdiction: ASHRAE 90.1
City: Brookings
Region/Zone: 6A - Cold, Humid

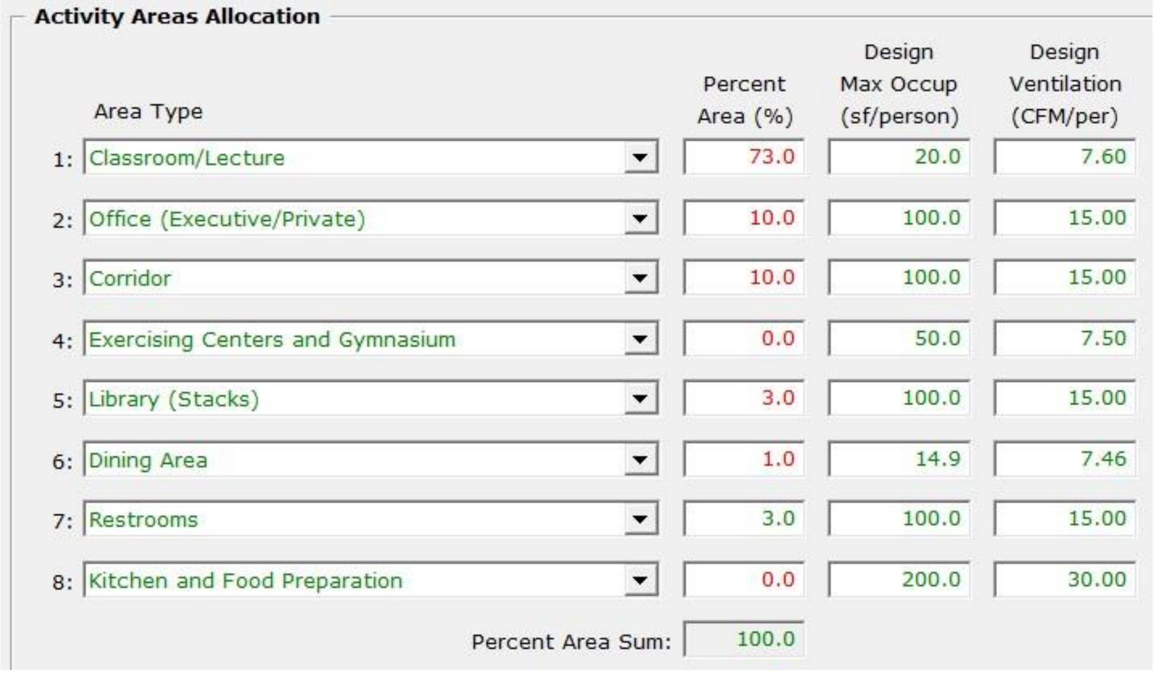
	Utility:	Rate:
Electric:	- file -	- none -
Gas:	- file -	- none -

Area, HVAC Service & Other Data

Building Area: 25,000 ft2
Number of Floors: Above Grade: 2
Below Grade: 0
Cooling Equip: Chilled Water Coils
Heating Equip: Hot Water Coils
Analysis Year: 2020
Daylighting Controls: Yes
Usage Details: Simplified Schedules

Figure 50: Lincoln Music Hall general information

Figure 51 provides general information that was entered to generate the model. Building type, geographic location, heating, and cooling equipment are selected on this screen.

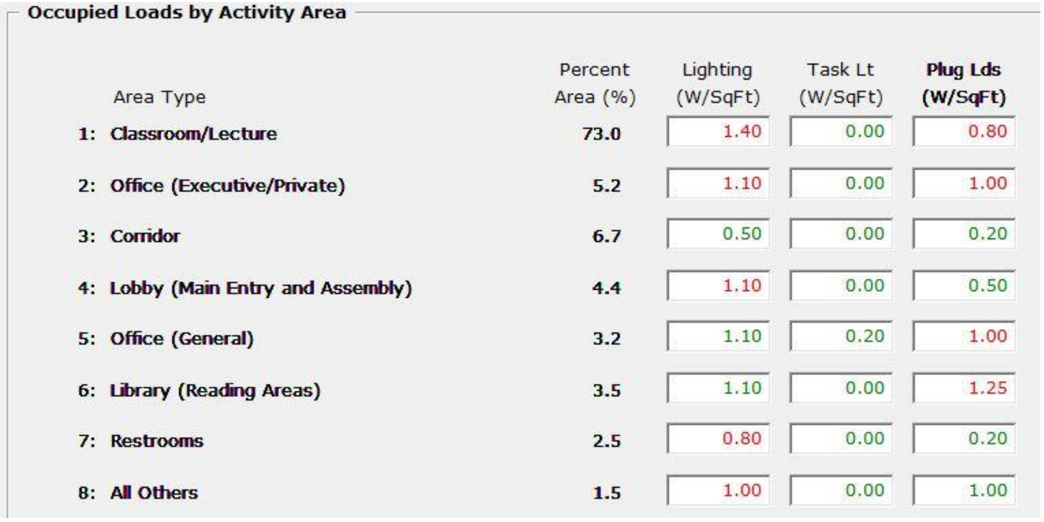


Activity Areas Allocation

	Area Type	Percent Area (%)	Design Max Occup (sf/person)	Design Ventilation (CFM/per)
1:	Classroom/Lecture	73.0	20.0	7.60
2:	Office (Executive/Private)	10.0	100.0	15.00
3:	Corridor	10.0	100.0	15.00
4:	Exercising Centers and Gymnasium	0.0	50.0	7.50
5:	Library (Stacks)	3.0	100.0	15.00
6:	Dining Area	1.0	14.9	7.46
7:	Restrooms	3.0	100.0	15.00
8:	Kitchen and Food Preparation	0.0	200.0	30.00
	Percent Area Sum:	100.0		

Figure 51: Lincoln Music Hall activities area allocation

Activities area allocation (Figure 52) screen considers the max occupancy and design ventilation in a given space using ASHRAE standard 62.1-2019. The percentage area for each type is utilized further to estimate the plug loads and lighting loads.

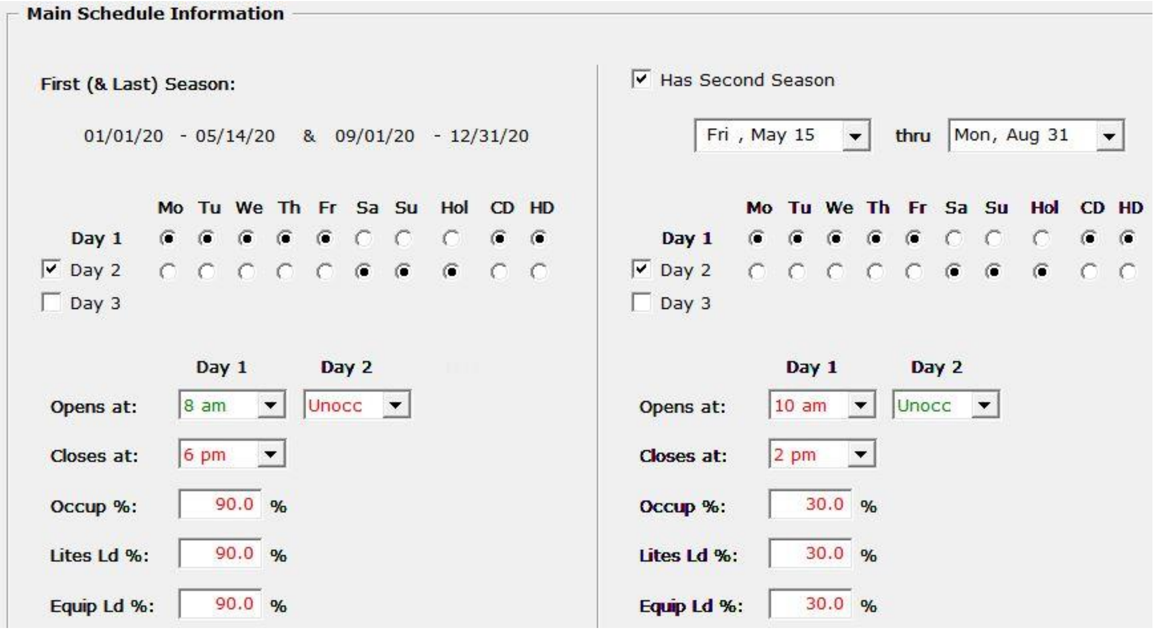


Occupied Loads by Activity Area

	Area Type	Percent Area (%)	Lighting (W/SqFt)	Task Lt (W/SqFt)	Plug Lds (W/SqFt)
1:	Classroom/Lecture	73.0	1.40	0.00	0.80
2:	Office (Executive/Private)	5.2	1.10	0.00	1.00
3:	Corridor	6.7	0.50	0.00	0.20
4:	Lobby (Main Entry and Assembly)	4.4	1.10	0.00	0.50
5:	Office (General)	3.2	1.10	0.20	1.00
6:	Library (Reading Areas)	3.5	1.10	0.00	1.25
7:	Restrooms	2.5	0.80	0.00	0.20
8:	All Others	1.5	1.00	0.00	1.00

Figure 52: Lincoln Music Hall occupied loads by activity area

ASHRAE Standard 90.1 was used to adjust the values for occupied loads in the building. Lighting and plug loads for classrooms, office was reduced from 1.50 W/sqft to 1.20 W/sqft and 1.10 W/sqft to 0.80 W/sqft respectively.



Main Schedule Information

First (& Last) Season:

01/01/20 - 05/14/20 & 09/01/20 - 12/31/20

	Mo	Tu	We	Th	Fr	Sa	Su	Hol	CD	HD
Day 1	●	●	●	●	●	○	○	○	●	●
☑ Day 2	○	○	○	○	○	●	●	●	○	○
☐ Day 3										

	Day 1	Day 2
Opens at:	8 am	Unocc
Closes at:	6 pm	
Occup %:	90.0 %	
Lites Ld %:	90.0 %	
Equip Ld %:	90.0 %	

☑ Has Second Season

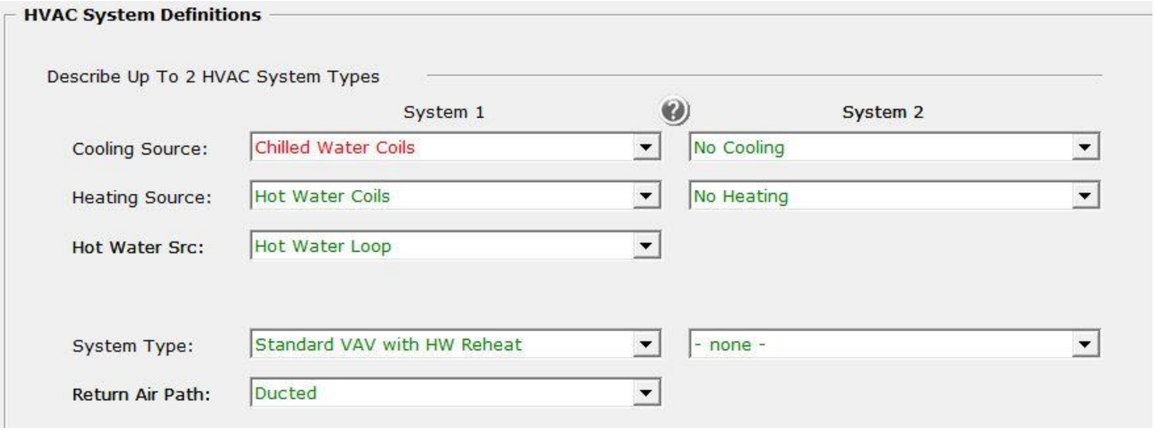
Fri , May 15 thru Mon, Aug 31

	Mo	Tu	We	Th	Fr	Sa	Su	Hol	CD	HD
Day 1	●	●	●	●	●	○	○	○	●	●
☑ Day 2	○	○	○	○	○	●	●	●	○	○
☐ Day 3										

	Day 1	Day 2
Opens at:	10 am	Unocc
Closes at:	2 pm	
Occup %:	30.0 %	
Lites Ld %:	30.0 %	
Equip Ld %:	30.0 %	

Figure 53: Lincoln Music Hall main schedule information

The main schedule information wizard is used to input the information on how the building is used throughout the year. Building usage is divided into two seasons: spring/fall semester as one season and summer semester as the second season. For the first season, when the school is in session, the building is scheduled to be open from 7 am to 7 pm. For the second season, the building is scheduled to operate from 8 am to 4 pm as the school is not in session. These parameters are selected after consulting with facilities and services on how the building is currently operated.

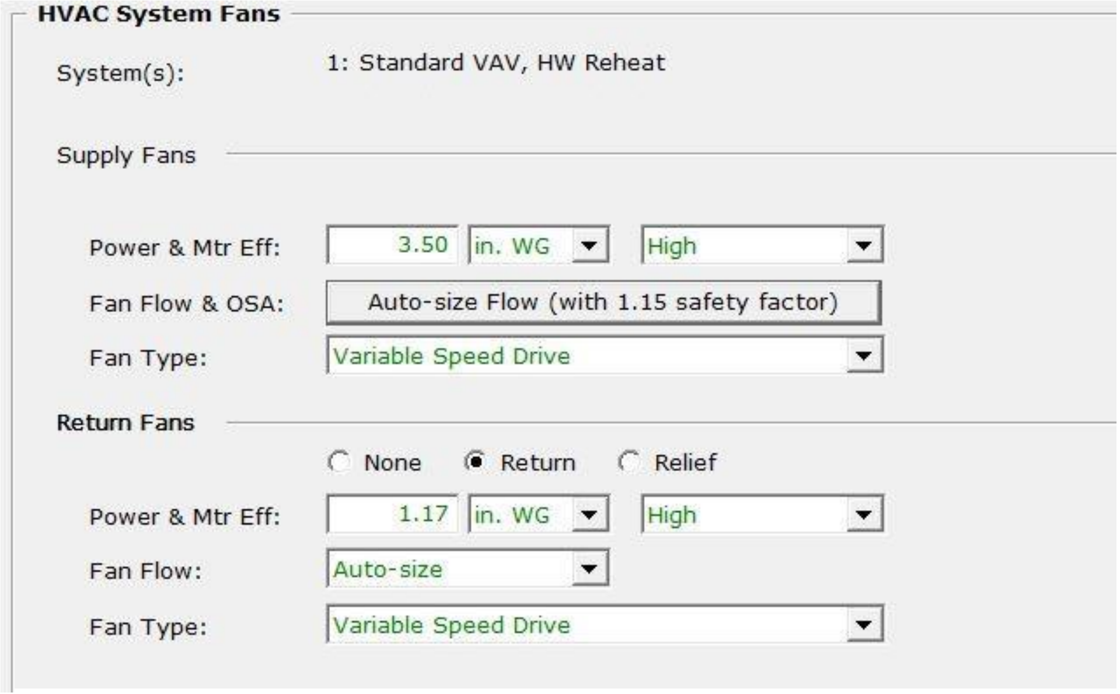

HVAC System Definitions

Describe Up To 2 HVAC System Types

	System 1	System 2
Cooling Source:	Chilled Water Coils	No Cooling
Heating Source:	Hot Water Coils	No Heating
Hot Water Src:	Hot Water Loop	
System Type:	Standard VAV with HW Reheat	- none -
Return Air Path:	Ducted	

Figure 54: Lincoln Music Hall HVAC system definition

The Ag Engineering building in the future will be cooled with chilled water-cooling coils and heated with hot water heating coils. Standard VAV terminal boxes with hot water reheat are used to serve the spaces in the buildings. The fan specification for the VAV supply and return fans are shown below.



HVAC System Fans

System(s): 1: Standard VAV, HW Reheat

Supply Fans

Power & Mtr Eff: 3.50 in. WG High

Fan Flow & OSA: Auto-size Flow (with 1.15 safety factor)

Fan Type: Variable Speed Drive

Return Fans

○ None ● Return ○ Relief

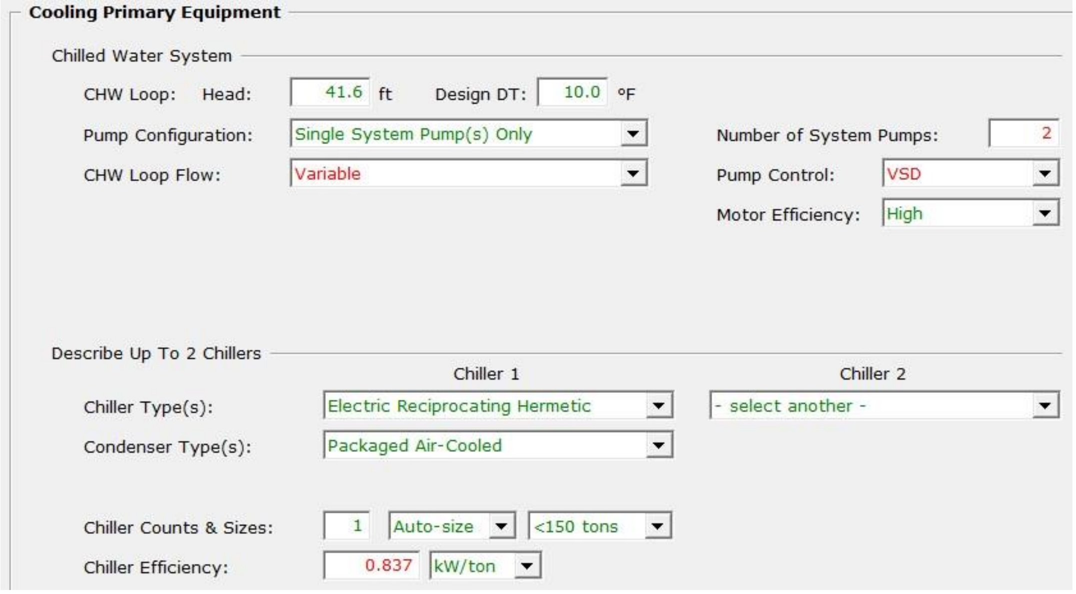
Power & Mtr Eff: 1.17 in. WG High

Fan Flow: Auto-size

Fan Type: Variable Speed Drive

Figure 55: Lincoln Music Hall HVAC system fans

The supply and return fans are selected with high motor efficiency with variable speed drives instead of constant speed so the fans can be modulated as the demand varies throughout the day.



Cooling Primary Equipment

Chilled Water System

CHW Loop: Head: 41.6 ft Design DT: 10.0 °F

Pump Configuration: Single System Pump(s) Only

Number of System Pumps: 2

CHW Loop Flow: Variable

Pump Control: VSD

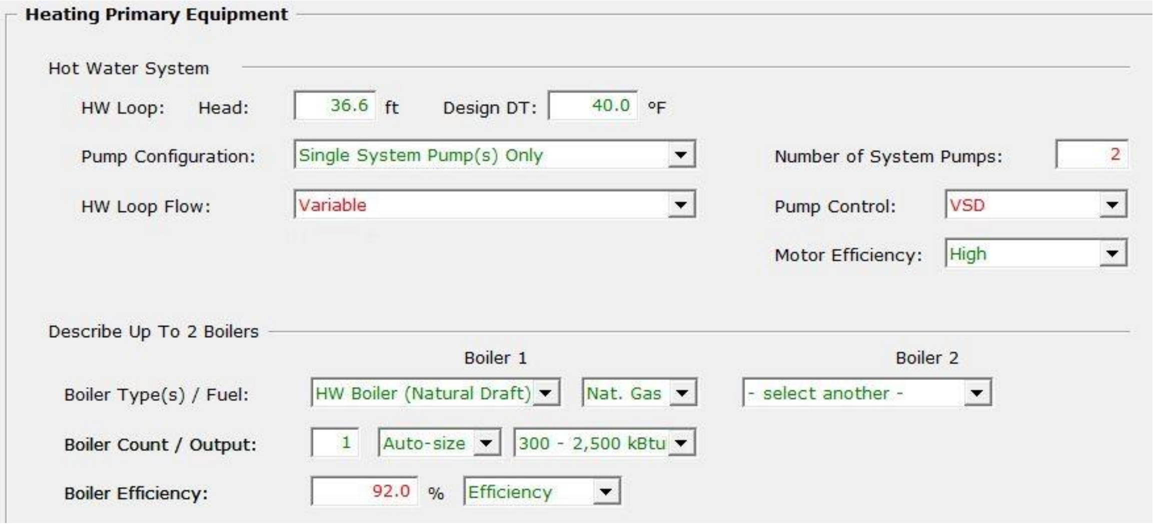
Motor Efficiency: High

Describe Up To 2 Chillers

	Chiller 1	Chiller 2
Chiller Type(s):	Electric Reciprocating Hermetic	- select another -
Condenser Type(s):	Packaged Air-Cooled	
Chiller Counts & Sizes:	1 Auto-size <150 tons	
Chiller Efficiency:	0.837 kW/ton	

Figure 56: Lincoln Music Hall cooling primary equipment

The chilled water system is distributed in the building with the help of two high-efficiency system pumps controlled with variable speed drives to modulate the water as needed. The chilled Water system will be connected to the central chiller plant at SDSU to meet the cooling demand during the summer. The compressor type is changed from constant speed to variable speed which helps in reducing the electricity needed to run the compressor.



Heating Primary Equipment

Hot Water System

HW Loop: Head: 36.6 ft Design DT: 40.0 °F

Pump Configuration: Single System Pump(s) Only

Number of System Pumps: 2

HW Loop Flow: Variable

Pump Control: VSD

Motor Efficiency: High

Describe Up To 2 Boilers

	Boiler 1			Boiler 2
Boiler Type(s) / Fuel:	HW Boiler (Natural Draft)	Nat. Gas		- select another -
Boiler Count / Output:	1	Auto-size	300 - 2,500 kBtu	
Boiler Efficiency:	92.0 %	Efficiency		

Figure 57: Lincoln Hall heating primary equipment

Similar to the chilled water system, the hot water system is connected to two high-efficiency pumps controlled with variable speed drives in the building. The hot water system will be connected to the central steam plant to meet the heating demand during the winter. Boiler efficiency is changed from 80% to 90% to reduce natural gas consumption. The results obtained with these changes are analyzed in the following section.

eQuest Simulation Results

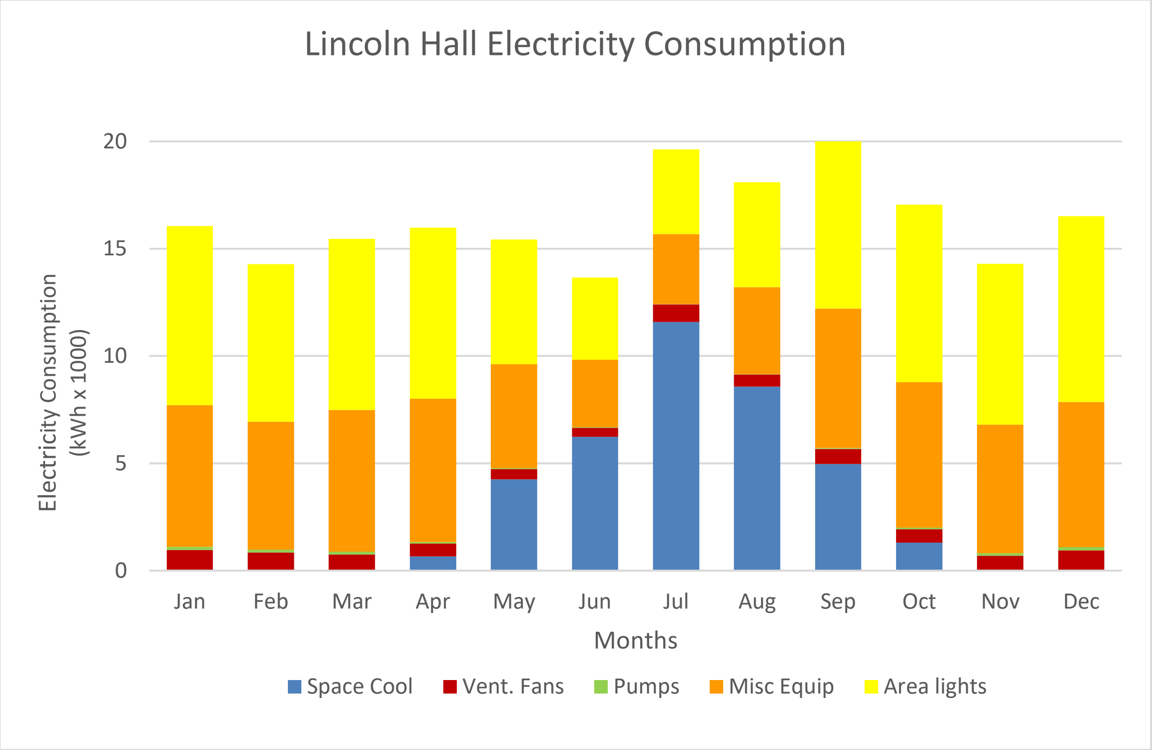


Figure 58: Lincoln Hall electricity consumption simulation

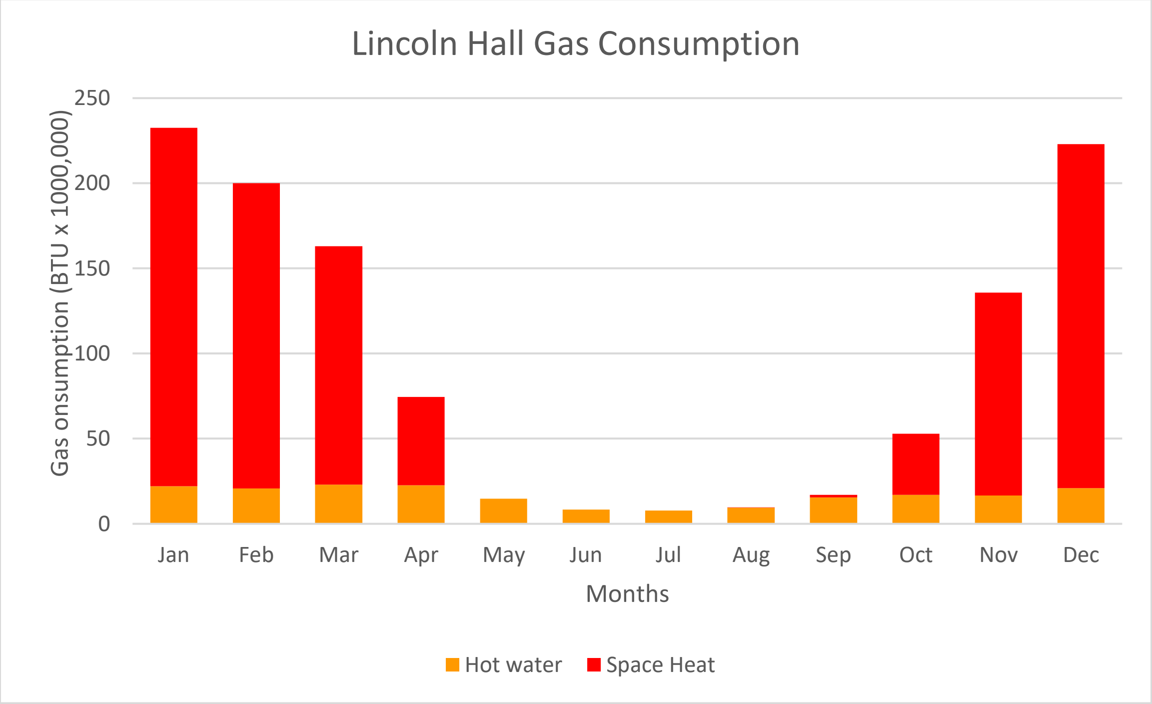


Figure 59: Lincoln Music Hall natural gas consumption simulation

The graphs in Figures 59 and 60 above shows the simulation of electricity and natural gas consumption at Lincoln Hall. Area lighting, plug loads, and ventilation remain almost constant throughout the academic year as the building is operated on a fixed schedule. However, the cooling load accounts for 38% of the total electricity consumption during the summer months. This includes the electricity required to power the AHU, pumps to circulate the chilled water, economizer, and energy recovery wheel. To reduce total electricity consumption was reduced to 196,450 kWh/yr from 295,159 kWh/yr by using daylight controls and efficient mechanical systems such as economizer and energy recovery wheel. The gas consumption is used for domestic hot water and space heating. The heating demand starts to rise in the fall and has a peak demand in January about 2,100 therms. The table below breaks down the electricity and natural gas monthly and how it is utilized.

Table 12: Monthly electricity & natural gas consumption

Electricity Consumption (kWh x 1000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	0.66	4.25	6.23	11.58	8.58	4.97	1.31	0.01	-	37.59
Vent. Fans	0.96	0.84	0.76	0.6	0.48	0.43	0.82	0.56	0.7	0.62	0.68	0.94	8.39
Pumps	0.15	0.13	0.13	0.08	0.04	0.02	0.02	0.02	0.04	0.08	0.12	0.15	0.98
Misc Equip	6.6	5.97	6.6	6.67	4.85	3.15	3.26	4.05	6.5	6.77	5.99	6.77	67.18
Area lights	8.35	7.34	7.97	7.97	5.81	3.82	3.95	4.88	7.8	8.27	7.5	8.65	82.31
Total	16.06	14.28	15.46	15.98	15.43	13.65	19.63	18.09	20.01	17.05	14.3	16.51	196.45

Gas Consumption (BTU x 1000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Hot water	22.1	20.8	23	22.7	14.7	8.3	7.8	9.4	15.5	17.1	16.6	20.9	198.9
Space Heat	210.4	179.3	140	51.8	-	-	-	0.1	1.6	35.8	119.2	202.1	940.3
Total	232.5	200.1	163	74.5	14.7	8.3	7.8	9.5	17.1	52.9	135.8	223	1139.2

Current Use vs eQuest Data

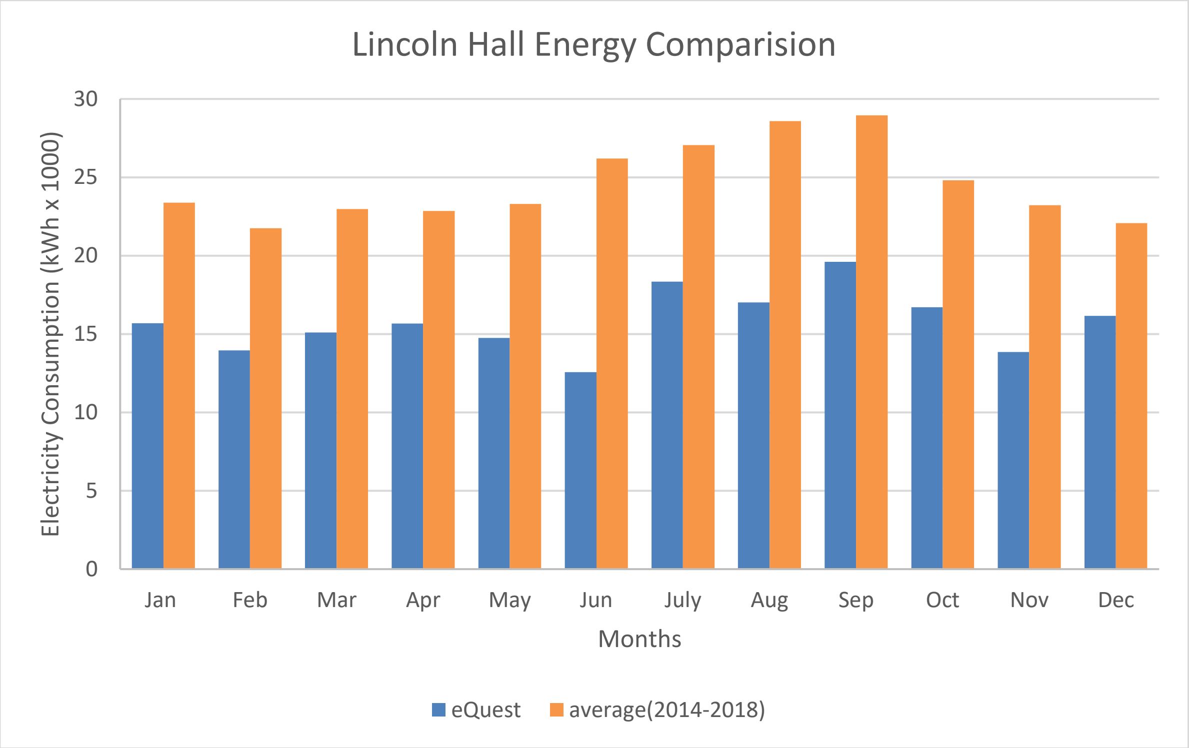


Figure 60: Lincoln Hall electricity consumption comparison

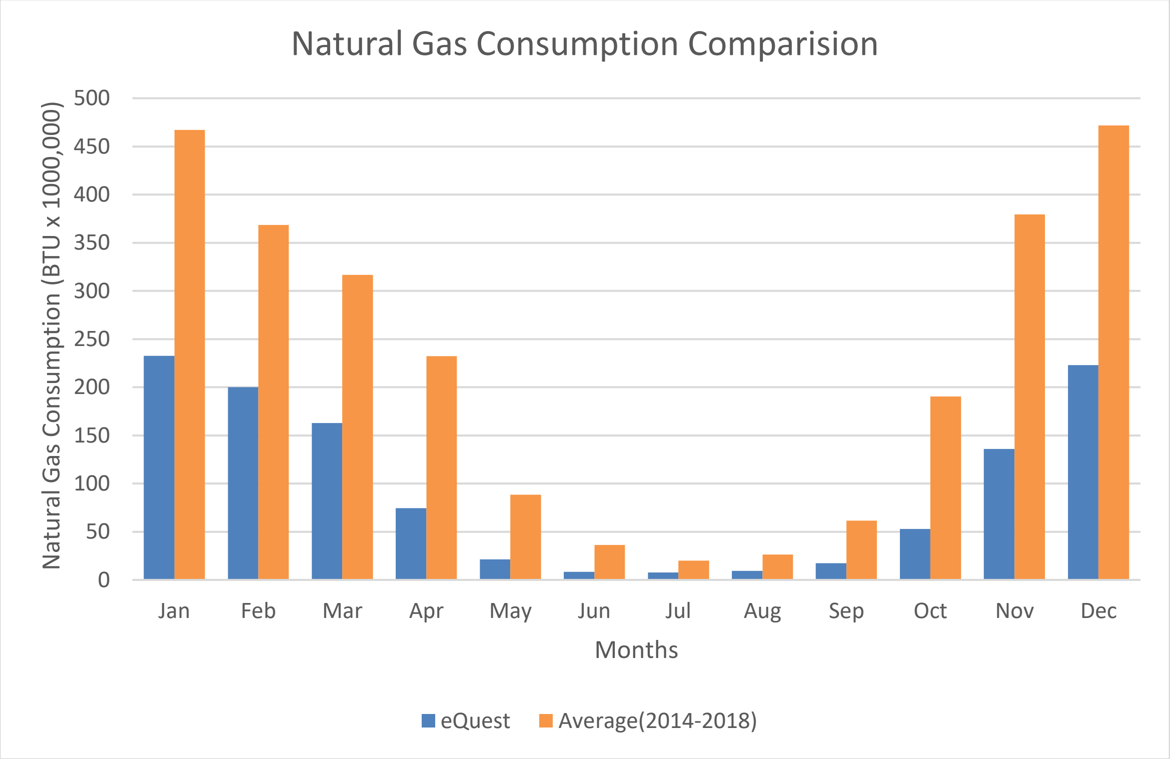


Figure 61: Lincoln Hall natural gas consumption comparison

Above Figures 61 and 62 show the reduction in electricity and natural gas consumption between 2014 to 2018. The simulation was performed using the same criteria as the Ag engineering building. This resulted in a reduction of electricity consumption by over 35% and natural gas consumption by 56%. The current rate of energy use is 151.96 kBTU/sf, which reduces to 54.4 kBTU/sf, a 64.2% decrease. This can be put into perspective by comparing it to the average energy use of the campus buildings for the period 2014-2018 which is 146.83 kBTU/sf. Another factor that can have an impact is how hot or cold a year has been. This drives the need for heating or cooling in the building. To normalize the data across different years, degree days (DD) are used. EIA defines "*A degree day is a measure of how warm or cold a location is*". The current energy use for the period 2014-2018 is 17.52 BTU/sf/DD which reduces to 5.72 BTU/sf/DD, resulting in a 67% decrease.

This energy saved translates to monetary savings of more than $4,700 in electricity cost and $8,000 in natural gas cost annually. The peak in electricity use can be seen to rise from June onwards as the cooling system is powered through electricity. One of the reasons why the existing building has higher electricity consumption is due to cooling individual spaces with window air conditioners. The eQuest model shows that the energy can be saved by efficiently conditioned using a central cooling system. Further reductions in energy consumption and costs are discussed in the section below.

Solar Wall

Lincoln Hall's space heating load can be offset using solar wall heating technology. Similar to the Ag Engineering building, the solar wall plates will be placed on the south wall to maximize the heat gain from solar energy. The proposed wall dimension is 180 feet in length and 25 feet in height to maximize the reduction in the heating load of the building. The following assumptions were made to simulate and gauge how much heating demand can be met using this system:

1. Indoor Air Temperature: 68˚F
2. Air Temperature: 160˚F
3. R-value: 12 ft^2-˚F/BTU-hr
4. Outside Design flow rate: 9,000 cfm
5. Heating Requirement: 9,800 therm
6. Solar Collector absorptivity: 0.95
7. Performance Factor: 1.05
8. Solar air heater efficiency: 24%

The building's Air Handling Unit (AHU) is used to move the heated air into the occupied spaces and serves the same role here as compared to the Ag Engineering building. The volume of outside air that will be brought into the AHU to supply the required outdoor air is calculated using ASHRAE standards. As per ASHRAE Standard 62.1-2001, if outside air is brought into space through a mechanical system in a classroom and other school spaces, "*then at least 15 cubic feet per minute (cfm) of outside air must be provided for each occupant.*" The total outside air is calculated by estimating the number of occupants in the building. Lincoln Music Hall has 20 classrooms and SDSU's average class occupancy is 30 students (U.S. News, n.d.).

$$Total\ Outside\ Air(OA) = \frac{15\ cfm}{student} \times \frac{30\ students}{classroom} \times 20\ classrooms$$

$$Total\ Outside\ Air(OA) = 9{,}000\ cfm$$

Table 13: Lincoln Music Hall solar wall calculation

Month	Solar Wall (therms generated)	Value ($)	Heating Load (therms)	Current Cost ($)	Future Cost ($)
Jan	454.94	318.46	2,104	1,472.80	1,154.34
Feb	652.29	456.60	1,793	1,255.10	798.50
Mar	1,183.49	828.44	1,400	980.00	151.56
Apr	1,511.68	1,058.18	518	362.60	0
May	1,775.23	1,242.66	65	45.50	0
Jun	1,945.79	1,362.06	-	-	0
Jul	2,099.73	1,469.81	-	-	0
Aug	1,765.68	1,235.98	1	0.70	0
Sep	1,354.67	948.27	16	11.20	0
Oct	900.34	630.24	358	250.60	0
Nov	538.79	377.15	1,192	834.40	457.25
Dec	397.68	278.37	2,021	1,414.70	1,136.33
Total	**14,580.32**	**10,206.22**	**9,468**	**6,627.6**	**3,697.97**

Table 13 shows the energy generated by a solar wall each month and its corresponding value in dollars. Space heating load demand and its corresponding cost are calculated in columns four and five. The last column shows that during the months of

April through October, the solar wall heating surpasses the outside air heating demand in the building. Therefore, the cost of natural gas during these months is zero for the university. Annually, using solar wall results in a savings of $2,930 annually.

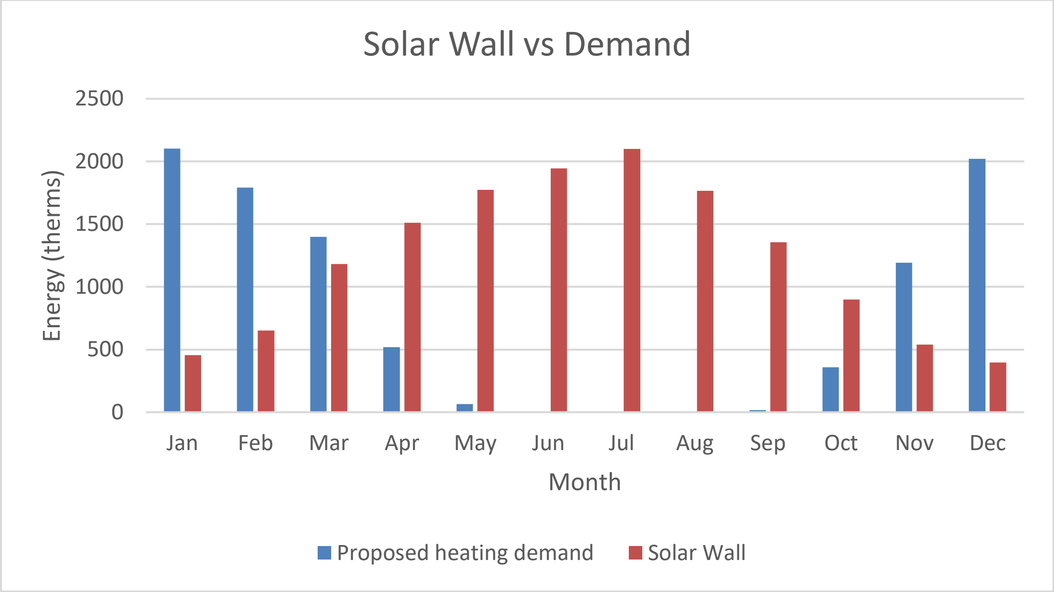


Figure 62: Comparison of proposed heating demand vs solar wall heating production

The graph in Figure 63 shows the solar thermal heat that is available each month and the demand for heating that is required by the building. As it can be expected in the northern hemisphere, the demand for heating starts to rise from October and reaches a peak of 2,104 therms in January. Heating generated from solar wall peaks at mid-summer in July and is capable of providing 2,099 therms of heating, but no heating is required this month. Ideally, to maximize the gain, the bars of the demand and the heat generated will be equal. The demand for heating during the month of March is 1,400 therms and solar energy can be harnessed to meet over 85% (1,200 therms) of the need.

During peak winter months (Nov, Dec, Jan, Feb), solar wall heat meets 20% to 36% of the heating demand. The annual cost of heating using natural gas without solar wall heat is $6,627 for 9,468 therms. By using solar wall heating technology, the consumption has been reduced to 5,282 therms/year, which reduces the bill to $3,697.

Return on Investment

The total cost of the solar wall system will be calculated by adding the cost of materials, installation costs, and mechanical costs which include temperature controls required to control the AHU. The following table shows the cost of adding this system:

Table 14: Lincoln Hall solar wall cost

Solar Wall System	$30,754
Estimated cost of installation	$14,280
Mechanical Costs	16,000
Automatic Temperature Controls	$5,000
Total installed cost	**$66,034**

The projected life of the solar wall is approximately 40 years. The projected cost savings from natural gas cost for space heating per year is $2,930. The table shows the projected costs and savings.

Table 15: Lincoln Hall solar wall ROI

Solar Wall System Cost	$66,034
Annual Savings from energy cost	$2,930
Simple Payback Period	22.5 years

Once the cost of investment is gained back in 22.5 years, the solar wall system will generate revenue for the university in the form of dollars saved.

$$Total\ Revenue\ generated = 40\ years * \frac{\$2{,}930}{year} = \$117{,}200$$

$$Revenue\ genertaing\ years = (40 - 22.5)\ years = 17.46\ years$$

$$Net\ Revenue\ generated = 17.46\ years * \frac{\$2{,}930}{year} = \$51{,}166$$

CO_2 Emissions

The emission analysis includes the amount of CO_2 emitted before and after the solar wall system is utilized. CO_2 is the primary gas emitted when natural gas is used. A total of 9,468 therms of energy is consumed annually which equates to 55.2 tons of CO_2 emissions (EPA, 2014). Energy consumption when a solar wall is used reduces to 5,282 per year, which results in 30.8 tons of CO_2. This reduction in energy usage results in saving 24.4 tons of carbon dioxide emissions into the year. This is equivalent to 28.9 acres of U.S. forests sequestering carbon in one year or over 841 incandescent lamps switched to LEDs.

Solar Photovoltaics (PV)

The PV system will be used to offset the electrical load generated due to lighting equipment in the building. The lighting and equipment loads in the building account for 67,190 kWh and 82,330 kWh per year respectively. National Renewable Energy Lab's (NREL) PWatts simulator is used to identify the solar energy generation capacity on top of the building's roof. A 110-kW system can be installed on the roof to maximize solar PV energy production. The system output may range from 141,271 kWh to 155,271 kWh per year. The following assumptions are made to achieve the projected output:

1. Fixed type array
2. 14.08% system losses,
3. 20 degrees tilt, Azimuth angle at 180-degree,
4. DC to AC size ratio = 1.2, inverter efficiency at 96%,
5. Ground coverage ratio of 0.4.
6. Rate of electricity for SDSU is $ 0.045 per kWh.

The total area available on the roof of the building is 12,369 ft^2 (m^2). Ground Coverage Ratio (GCR) is the surface area of the module to the area of the ground or roof occupied by the array of solar panels. For a GCR value of 0.3, the area occupied by the solar panels is approximately 3,710 ft^2 (m^2). Figure 63 below shows the proposed location of the PV panels on the roof.

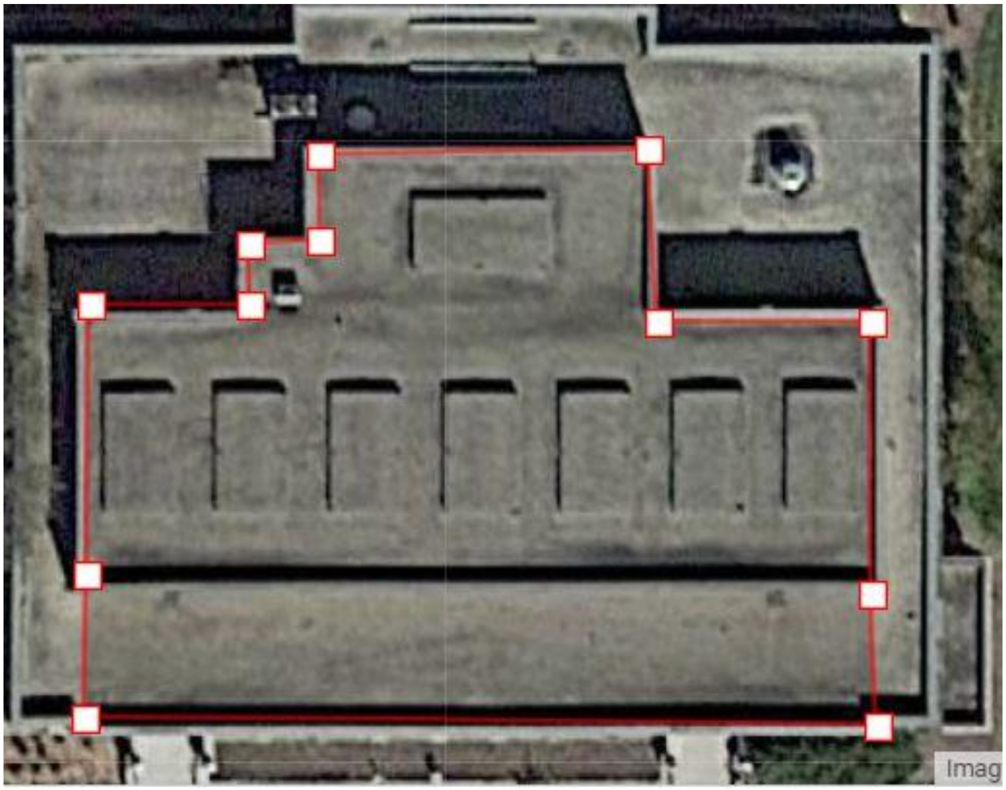
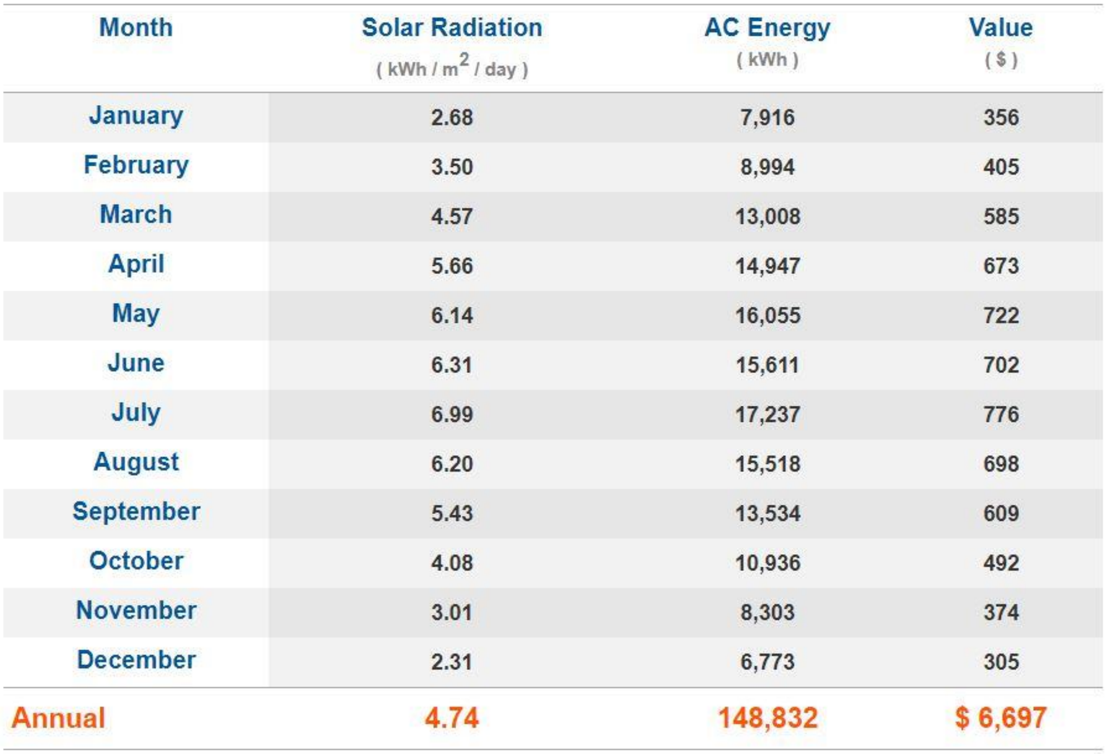


Figure 63: Solar PV location

PVWatts uses GCR value to calculate the losses associated due to shading of the adjacent solar PV array. Table 16 below shows the projected monthly electricity production from the PV panels that will offset the electricity loads.

Table 16: NREL projected electricity generation using solar PV panels



Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	2.68	7,916	356
February	3.50	8,994	405
March	4.57	13,008	585
April	5.66	14,947	673
May	6.14	16,055	722
June	6.31	15,611	702
July	6.99	17,237	776
August	6.20	15,518	698
September	5.43	13,534	609
October	4.08	10,936	492
November	3.01	8,303	374
December	2.31	6,773	305
Annual	4.74	148,832	$ 6,697

**Solar output of a 110 kW PV array sized for maximum output based on the available roof area

The combined demand for lighting and equipment electrical load is approximately 149,940 kWh per year. When month to month demand and power generated is compared, electricity demand will not be met during the winter solely by the PV system. Similar to the Ag Engineering building, there is more electricity produced by the PV system in the summer, but the demand is less than 50% of the winter months on average. If the system is optimally sized for the demand, excess electricity will not be generated. This reduces the capital cost of the system and thereby yields a faster simple payback period. The following Table 17 shows the energy and cost savings if the system is optimally designed.

Table 17: Lincoln Music Hall optimal Solar PV size

System size	45 kW
Cost of the system	$82,350
Cost savings	$2,762
Simple payback period	29.8 years
Energy Saved	61,388 kWh

A 45-kW solar PV system will require a capital cost investment of $82,350. By using this system, 61,388 kWh of energy can be saved annually. This results in dollar savings in electricity costs by $2,762 per year. Finally, the simple payback period is calculated to be 29.8 years. Alternatively, by maximizing the solar PV generation on the roof, initial capital investment will increase, therefore increasing the simple payback period by 7.92 years (37.72 yrs – 29.8 yrs). The calculation of the maximized solar PV system is shown in subsequent sections. This can be reduced by utilizing the excess electricity to power the neighboring buildings by negotiating a power purchase agreement in the future, which is discussed in future work sections.

The graph below in Figure 65 compares the electricity produced versus the electrical loads. It also demonstrates the potential of using the excess electricity that is not utilized in Lincoln Music Hall. Table 18 below shows the calculation of a 110-kW solar PV system.

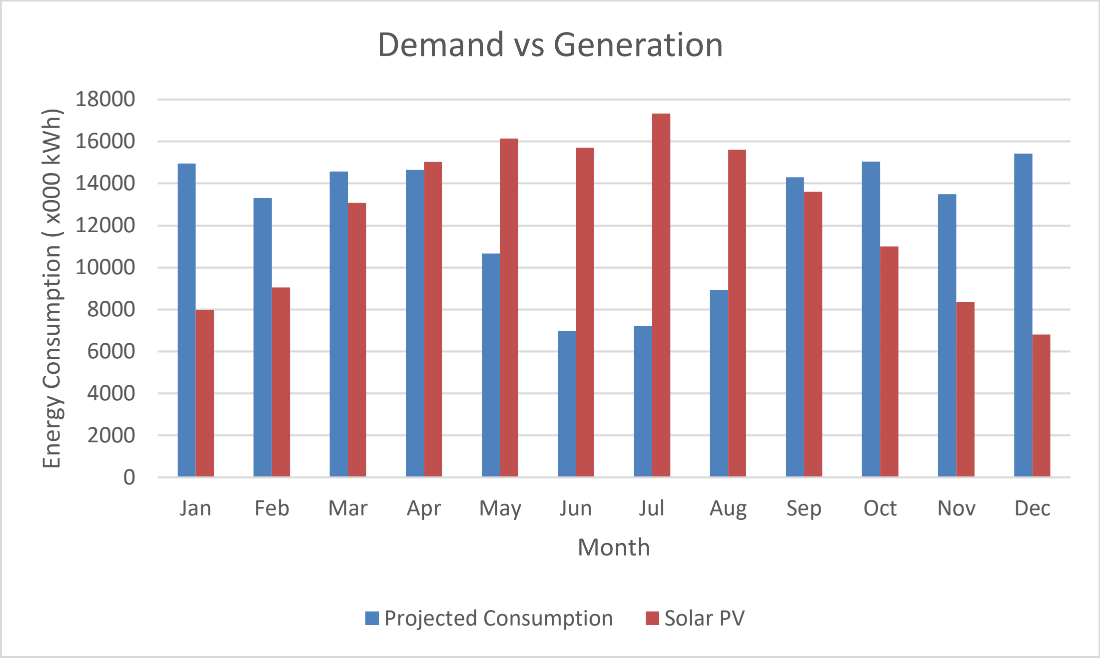


Figure 64: Electricity demand vs generation

Table 18: Lincoln Music Hall Solar PV calculation

Months	Solar PV Potenital (kWh)	Value ($)	Lighting & Equipment Load (kWh)	Current Cost ($)	Metered Total (kWh)	Future Cost ($)
Jan	7,960	358.2	14,950	672.75	6,990	314.55
Feb	9,043	406.94	13,310	598.95	4,267	192.02
Mar	13,079	588.56	14,570	655.65	1,491	67.1
Apr	15,029	676.31	14,640	658.8	-389	-17.51
May	16,144	726.48	10,660	479.7	-5,484	-246.78
Jun	15,697	706.37	6,970	313.65	-8,727	-392.72
Jul	17,332	779.94	7,210	324.45	-10,122	-455.49
Aug	15,603	702.14	8,930	401.85	-6,673	-300.29
Sep	13,609	612.41	14,300	643.5	691	31.1
Oct	10,996	494.82	15,040	676.8	4,044	181.98
Nov	8,348	375.66	13,490	607.05	5,142	231.39
Dec	6,810	306.45	15,420	693.9	8,610	387.45
Total	**149,650**	**6,734.25**	**149 ,490**	**6,727.05**	**31,235**	**1,405.58**

The second and third column in Table 18 shows the electricity that can be generated using solar PV panels and its corresponding value in dollars, respectively. The fourth and fifth column lists the lighting and equipment loads and the utilities cost associated with it. The fifth column shows the electricity demand needed after the solar PV system offsets the original demand. The negative numbers during the months of April through August indicate the potential electricity that can be used to reduce the simple payback period as discussed earlier. The last column shows the projected monthly bill after using solar PV to offset the energy costs. During the months of April through August, more electricity is produced than there is demand, hence the cost of lighting and equipment load is negative for those months. Therefore, when calculating the total electricity cost, those months are excluded from the calculation.

NREL study has estimated that the commercial cost of solar energy per Watt of production is $1.83. This value includes hardware costs (module), inverter, structural and electrical components, labor costs, sales tax overhead, and net profit. The electricity bill for the building per year amounts to be $6,727 for 149,490 kWh. By using Solar PV to generate electricity, the projected electricity bill will be reduced to $1,405 per year for 31,325 kWh resulting in a savings of $5,321 per year.

Table 19: Lincoln Music Hall - return on investment solar PV

Total Capital Cost	$200,751
Annual Savings	$5,321
Simple Payback Period	37.72 yrs

Return on Investment

To calculate the return on investment, it is important to investigate how the life span of the system. According to NREL, the average life of solar PV panels to generate electricity at its peak performance is approximately 32.5 years. With regular maintenance, the system is projected to last an additional 25-30 years. According to NREL, solar panels have a degradation rate of 0.3% per year. This means that production from a solar panel will decrease at a rate of 0.3% per year. At year 60, the solar panels will operate at 80% of its original capacity. Once the payback period is completed, the system will start to generate net revenue. Once this value is known, revenue-generating years can be calculated which begins after the capital investment cost has been earned back from generating electricity. Finally, ROI can be calculated by multiplying the dollar amount saved per year and revenue-generating years.

$$Total\ Revenue\ generated = \frac{\$4{,}256}{year} \times 60\ years = \$255{,}408$$

$$Revenue\ generating\ years = (60 - 37.72) years = 22.28\ years$$

$$Net\ Revenue\ Generated = \frac{\$4{,}256}{year} * 22.8 = \$97{,}036$$

CO_2 Emissions

A total of 118,165 kWh of electricity can be saved by integrating the proposed solar PV system for the building. In addition to reducing the utility cost for the building, 117 tons of CO_2 emissions are saved from being entered into the environment. This is equivalent to CO_2 absorbed by 138 acres of U.S. forests in one year or 262,324 miles driven by an average passenger car.

KEY RESULTS

The Ag Engineering building and Lincoln Music Hall energy consumption was modeled using eQuest to analyze the potential energy savings by upgrading the mechanical systems to reduce the energy demand. As seen in the Ag Engineering and Lincoln Hall section, results obtained from eQuest showed a reduction in energy consumption is attainable by 24% in the Ag Engineering building and 35% in Lincoln Music Hall. Additionally, the current natural gas usage is 15,100 therm/yr in Ag Engineering and 9,468 therms/yr in Lincoln Music Hall, but when a solar wall was used to provide an additional reduction in heating demand, it brings the natural gas consumption down to 10,022 therms/yr (42%) and 5,282 therms/yr (55%), respectively. The cost of installing solar wall technology is estimated to be $64,360 for the Ag Engineering building. The cost of heating is $10,572/yr without a solar wall and $7,015/yr by adding a solar wall. This yields a savings of $3,556/yr. The estimated simple payback period for this project is 18.09 years. Once the payback period is completed, the solar wall generates revenue of $77,911 for the rest of its life span of 21.91 years.

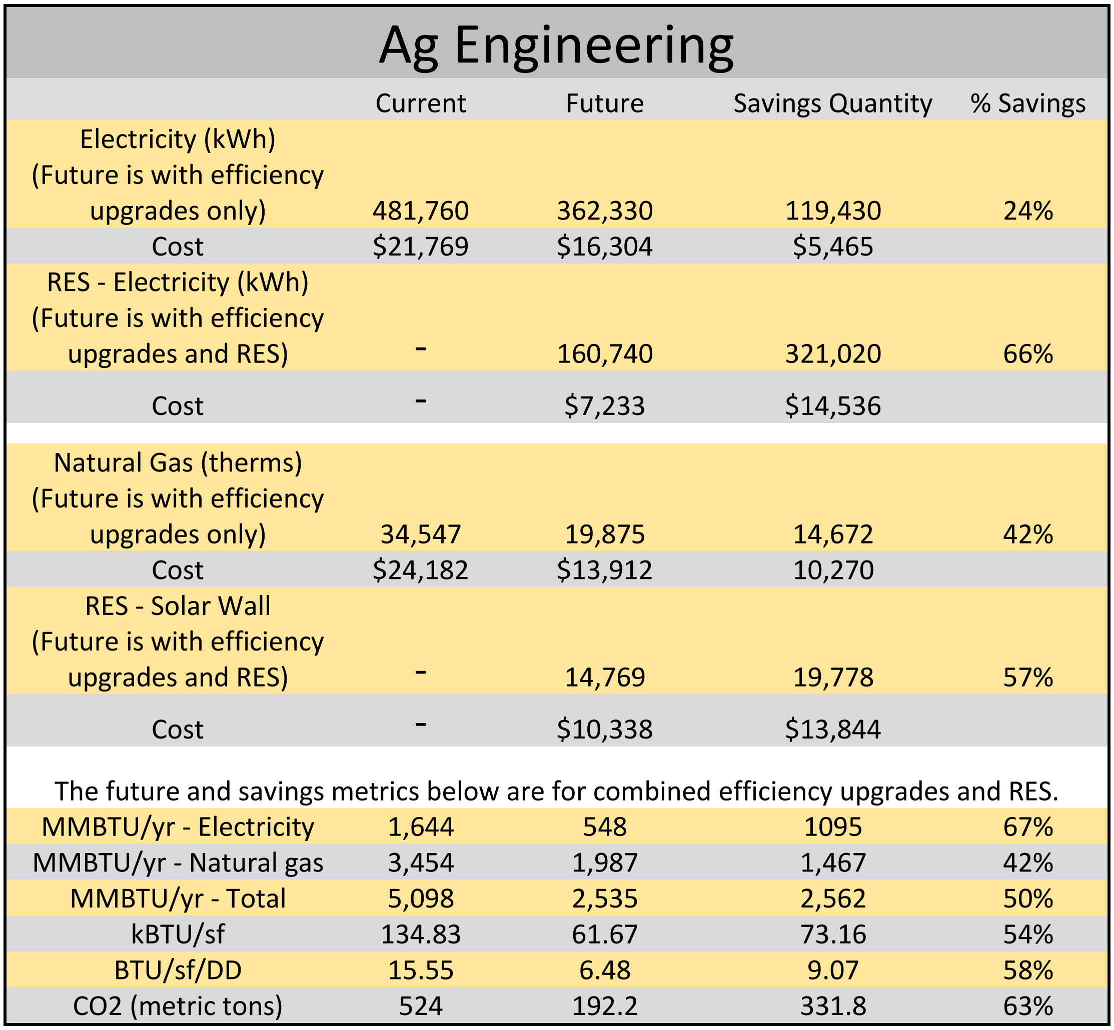
The cost of installing solar wall technology is estimated to be $66,034 for the Lincoln Music Hall building. The cost of heating is $6,627/yr without a solar wall and the cost of heating is brought down to $5,282/yr by adding a solar wall, yielding a savings of $2,930/yr. The estimated simple payback period for this project is 22.5 years. Once the payback period is completed, the solar wall generates revenue of $51,166 for the rest of its lifespan of 17.46 years. When Solar PV is utilized, electricity consumption is reduced from 265,000 kWh/yr to 63,000 kWh/yr in Ag Engineering and 149,490 kWh/yr to

31,325 kWh/yr in Lincoln Music Hall resulting in a net savings of 202,000 kWh/yr and 118,165 kWh/yr respectively. The cost of this PV system for Ag Engineering is proposed to be $337,086. The current cost of electricity consumption for lighting, equipment, and miscellaneous items is $11,920/yr which is reduced to $2,849/yr with the installation of a 184.2-kW PV system. This will yield a savings of $9,071 per year. A simple payback period for this investment can be obtained in 37.16 years. If the system is designed for a minimum load, compared to maximum PV output based on the roof area, the simple payback period is reduced by 7.36 years. The cost of installing a PV system for Lincoln Music Hall is proposed to be $200,751. The current cost of electricity consumption for lighting, equipment, and miscellaneous items is $6,727 which is reduced to $1,405/yr with the installation of a 110 kW PV system. This will yield a savings of $5,321 per year. A simple payback period on this investment can be obtained in 37.72 years. Lincoln Music Hall has a longer payback period due to its lower electricity demand and higher capital cost investment. One of the ways a simple payback period can be reduced is if the excess electricity generated is shared with a neighboring building. Alternatively, if the PV system is sized to the minimum load instead of maximum PV output, the simple payback period drops to 29.8 years.

Before and After Energy Use

The following Tables 20 and 21 summarizes the energy savings from implementing various upgrades. The first “After” segment refers to upgrading to more energy-efficient mechanical systems, such as adding an economizer and energy recovery wheel to reduce the need for mechanical cooling and heating. Next, a solar wall is integrated into the building design to offset the energy required to heat the building, and solar PV panels is used to lower the need for electricity consumed by the building for lights and miscellaneous items.

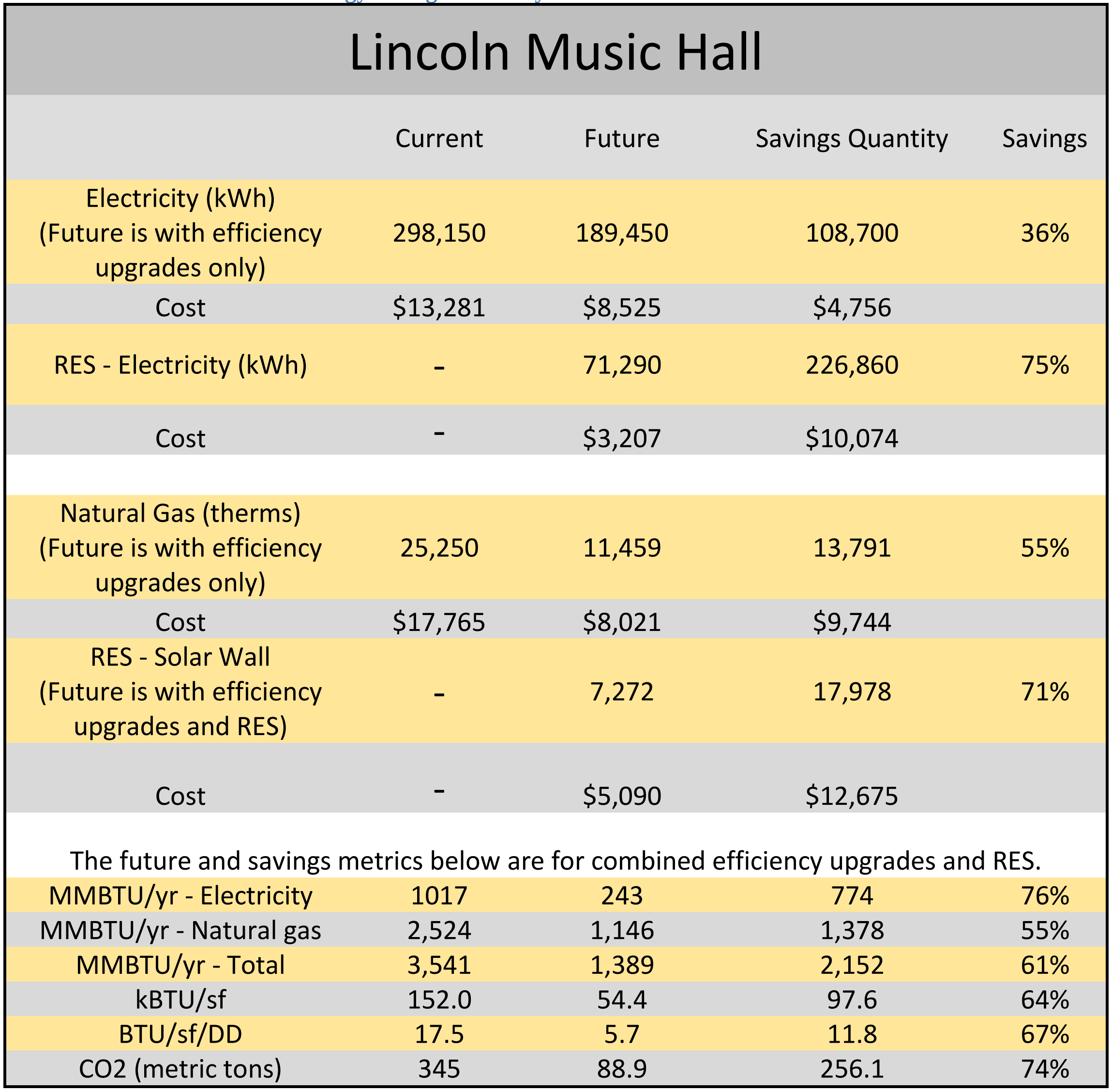
Table 20: Ag Engineering energy savings summary



Ag Engineering

	Current	Future	Savings Quantity	% Savings
Electricity (kWh) (Future is with efficiency upgrades only)	481,760	362,330	119,430	24%
Cost	$21,769	$16,304	$5,465	
RES - Electricity (kWh) (Future is with efficiency upgrades and RES)	-	160,740	321,020	66%
Cost	-	$7,233	$14,536	
Natural Gas (therms) (Future is with efficiency upgrades only)	34,547	19,875	14,672	42%
Cost	$24,182	$13,912	10,270	
RES - Solar Wall (Future is with efficiency upgrades and RES)	-	14,769	19,778	57%
Cost	-	$10,338	$13,844	
The future and savings metrics below are for combined efficiency upgrades and RES.				
MMBTU/yr - Electricity	1,644	548	1095	67%
MMBTU/yr - Natural gas	3,454	1,987	1,467	42%
MMBTU/yr - Total	5,098	2,535	2,562	50%
kBTU/sf	134.83	61.67	73.16	54%
BTU/sf/DD	15.55	6.48	9.07	58%
CO2 (metric tons)	524	192.2	331.8	63%

Table 21: Lincoln Music Hall energy savings summary



Lincoln Music Hall				
	Current	Future	Savings Quantity	Savings
Electricity (kWh) (Future is with efficiency upgrades only)	298,150	189,450	108,700	36%
Cost	$13,281	$8,525	$4,756	
RES - Electricity (kWh)	-	71,290	226,860	75%
Cost	-	$3,207	$10,074	
Natural Gas (therms) (Future is with efficiency upgrades only)	25,250	11,459	13,791	55%
Cost	$17,765	$8,021	$9,744	
RES - Solar Wall (Future is with efficiency upgrades and RES)	-	7,272	17,978	71%
Cost	-	$5,090	$12,675	
The future and savings metrics below are for combined efficiency upgrades and RES.				
MMBTU/yr - Electricity	1017	243	774	76%
MMBTU/yr - Natural gas	2,524	1,146	1,378	55%
MMBTU/yr - Total	3,541	1,389	2,152	61%
kBTU/sf	152.0	54.4	97.6	64%
BTU/sf/DD	17.5	5.7	11.8	67%
CO2 (metric tons)	345	88.9	256.1	74%

The analysis of both the buildings shows that there is significant potential in reducing the energy consumption in both buildings by integrating both energy efficiency measures and renewable energy solutions to offset the energy demand. The Ag Engineering building’s average electricity consumption for the years 2014-2018 was 481,760 kWh/yr. By utilizing efficient mechanical systems and integrating renewable energy systems to offset the lighting and equipment loads, a total of 218,670 kWh/yr of electricity consumption can be reduced from the average annual use which reduces the energy consumption by over 54%. Similarly, Lincoln Music Hall electricity consumption can be reduced from 295,158 kWh/yr to 158,215 kWh/yr by utilizing efficient mechanical systems and integrating renewable energy systems to offset the lighting and equipment loads.

When normalized for building area, both buildings demonstrated similar percent savings. The energy utilized in Ag Engineering is reduced from 135 kBTU/sf to 62 kBTU/sf resulting in savings of over 54%; whereas Lincoln Music Hall energy usage is reduced from 152 kBTU/sf to 54 kBTU/sf resulting in savings of 64%. The slightly higher energy savings in Lincoln Music Hall can be attributed to a smaller building footprint compared to Ag Engineering Hall. This not only results in saving dollars for the university but also helps in reducing GHG emissions. The total energy savings in Ag Engineering and Lincoln Music Hall translates to the carbon sequestered by 437 acres and 333 acres of forest in one year respectively.

The following Table 22 shows the potential of investing in energy efficiency measures and integrating renewable energy systems throughout campus. This study's findings were to be broadly extrapolated to all the buildings which encompass 3,943,924 square feet (as of 2019), hence further studies will be required to conclude more accurate results.

Table 22: Potential energy and cost savings at SDSU

SDSU		
	Current Use	Projected Use
MMBTU	585,730	322,151
kBTU/sf	149	88
Cost ($)	5,133,211	2,823,266
CO2 (metric tons)	133,788	91,645

SDSU could potentially reduce its overall energy use from 585,730 MMBTU to 322,151 MMBTU. This will result in savings of $2.3 million in annual utility costs. Overall energy use intensity can be decreased from 149 kBTU/sf to 88 kBTU/sf. Consequently, this energy and cost savings also translates to lowering CO_2 emissions by 42,143 metric tons. This is the equivalent of carbon sequestered by 158,505 acres of U.S. forests in one year.

CONCLUSION

SDSU is the largest land grant public university in the state of South Dakota. This translates to over 60 buildings which encompass an area of more than 4 million square feet. All the buildings need to be powered with electricity and maintained at optimum conditions for its occupants. The total cost of utilities (electricity and natural gas) to operate is over 5 million dollars every year. With more buildings being built to serve students and conduct research, more energy is required to operate these buildings which in turn will increase the cost of utilities. A small percentage reduction in energy consumption can yield savings of hundreds of thousands of dollars. As discussed in the literature review, there are multiple ways to make a building more efficient to reduce the energy it consumes. One is through minor upgrades and the other is through major upgrades. Minor upgrades are less expensive and yield a smaller reduction in costs whereas major upgrades cost more and yield a higher reduction in costs. Additionally, case studies show that making the minor and major upgrades and integrating renewable energy lowers the utilities and energy consumption the most. Also, the benefit of using renewable energy solutions is the reduction in GHG emissions that are released when traditional fossil fuel sources are used for energy consumption. The purpose of this thesis was to study the impact of energy efficiency and integrating renewable energy generation in existing buildings on a college campus. The conclusion of this study found that a typical SDSU building could benefit from a 54% reduction in kBTU/sf of energy. If this reduction in energy usage is extrapolated to all buildings on campus, energy usage can be reduced from 585,730 MMBTU to 322,151 MMBTU, saving SDSU potentially save over $2.3 million annually in energy costs.

FUTURE WORK

To better understand the implications of these results, future studies could explore the impacts of modifying existing Power Purchase Agreements so that SDSU could benefit from expanded RE power generation. Since SDSU is a public university, it is not able to take advantage of the federal solar investment tax credit, which would lower the investment cost and boost the number of years for a payback period. A follow-up study that explores the feasibility of using third parties or other alternatives to leverage these potential tax credits will help SDSU in the future. Additionally, the return on investment for renewable energy systems can also be improved by utilizing any excess electricity generated at one building to power adjacent buildings (but this is currently prevented by the existing PPA). This will increase the savings in electricity cost for the university and result in faster payback periods on the investment.

If renewable energy systems are integrated into the Ag Engineering Hall and Lincoln Music Hall in the future, the projected energy consumption performed in this thesis can be compared to the real-time energy consumption data, as well as comparing the actual renewable energy generation to the simulations. This will provide a better understanding of the building energy modeling software capabilities and verify the performance of the renewable energy systems. The projected return on investment and payback period can also be compared to the actual results to analyze the difference between simulated results and the real-time performance of these systems.

Currently, the state of South Dakota does not offer tax incentives to switch to renewable energy production. An analysis of neighboring states, which offer incentives for integrating renewable energy in buildings, could shed light on how similar incentives could enhance the attractiveness of similar investments in South Dakota. This study would need to take into consideration differences in utility rates, environmental regulations, payback period, etc.

A comparison study of SDSU's energy consumption analysis with its peer universities would provide an insight into where SDSU stands and identify its strengths and where it likely could improve in energy usage in buildings. This study could also help by exploring how different renewable energy sources can be integrated into a wider array of buildings. This thesis focused on onsite production of renewable energy; where-as a follow up future study could explore the potential for offsite renewable energy production.

LITERATURE CITED

1. Aaon Inc. (n.d.). Energy Recovery. Retrieved from https://aaon.com/Documents/Technical/AAONAire_110103.pdf
2. Abbott, S. (2014, December 3). Three reasons why universities are betting big on renewable energy | Greenbiz. Retrieved from https://www.greenbiz.com/article/3-reasons-why-universities-are-betting-big-renewable-energy
3. ASHRAE Journal. (2015, November). Benchmarking Building Energy Use. Retrieved from https://newbuildings.org/wp-content/uploads/2017/08/ASHRAE_Is-EUI-the-Best-Metric.pdf
4. ASHRAE Handbook 2010, *ANSI/ASHRAE Standard 62.1-2010. Ventilation for acceptable indoor air quality*. 2010, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.: Atlanta, GA.
5. ASHRAE Standard 90.1-2013. (2014, August). *Determination of Energy Savings: Quantitative Analysis*. Retrieved from https://www.energycodes.gov/sites/default/files/documents/901-2013_finalCommercialDeterminationQuantitativeAnalysis_TSD_0.pdf
6. Baczek, S. (2016, September 6). Wastewater heat recovery systems. Retrieved from https://www.jlconline.com/how-to/plumbing/wastewater-heat-recovery-systems_o
7. Boston University. (2018). Sustainability at Boston University. Retrieved from https://www.bu.edu/sustainability/what-were-doing/energy/

8. Butte College. (2011). Butte College Shines with 25,000 Solar Panels. Retrieved from https://www.butte.edu/feeds/2011/renewableEnergy.html
9. Cordill, B. (2020, July 3). Three advantages of going tankless in commercial buildings. Retrieved from https://www.pmmag.com/articles/102929-advantages-of-going-tankless-in-commercial-buildings
10. Coulston, S. (2019, July 8). Go green! Why universities are prizing sustainability. Retrieved from https://www.facilitiesnet.com/educationalfacilities/article/Go-Green-Why-Universities-Are-Prizing-Sustainability--18488
11. Cubick, R. (2017, April 24). Understanding energy recovery wheels. Retrieved from https://web.uponor.hk/radiant-cooling-blog/understanding-energy-recovery-wheels/
12. Dreyfus, M. (2016, December 15). People power: How communities and cities can help save the environment. Retrieved from https://theconversation.com/people-power-how-communities-and-cities-can-help-save-the-environment-70185
13. E source Companies. (2013). Retrieved from https://web.archive.org/web/20170922135424/https://bea.touchstoneenergy.com/sites/beabea/files/PDF/Sector/Colleges-Universities.pdf
14. EIA. (2017, September 14). EIA projects 28% increase in world energy use by 2040. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=32912

15. EIA. (2020, August 17). Degree-days. Retrieved from https://www.eia.gov/energyexplained/units-and-calculators/degree-days.php

16. EIA. (n.d.). Renewable energy explained. Retrieved from https://www.eia.gov/energyexplained/renewable-sources/

17. Energy Star. (n.d.). Air-side economizer. Retrieved from https://www.energystar.gov/products/low_carbon_it_campaign/12_ways_save_energy_data_center/air_side_economizer

18. Energy Star. (n.d.). State and local governments. Retrieved from https://www.energystar.gov/buildings/program-administrators/state-and-local-governments#_ftn1

19. EnergyStar. (n.d.). What is energy use intensity (EUI)? Retrieved from https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager/understand-metrics/what-energy

20. Environment America. (2017, October 2). Energy efficiency in campus buildings. Retrieved from https://environmentamerica.org/resources/amc/energy-efficiency-campus-buildings

21. Environmental and Energy Study Institute. (2011, September). What is District Energy? Retrieved from https://www.eesi.org/files/district_energy_factsheet_092311.pdf

22. Environmental Protection Agency. (2020, May 28). Overview of greenhouse gases. Retrieved from https://www.epa.gov/ghgemissions/overview-greenhouse-gases

23. EPA. (2014, April 4). Emission Factors for Greenhouse Gas Inventories. Retrieved from https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf
24. EPA. (2017). An office building occupants guide to indoor air quality. Retrieved from https://www.epa.gov/indoor-air-quality-iaq/office-building-occupants-guide-indoor-air-quality
25. EPA. (n.d.). Greenhouse gas equivalencies calculator. Retrieved from https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
26. EPA. (n.d.). Heating, ventilation, and air-conditioning systems, part of indoor air quality design tools for schools. Retrieved from https://www.epa.gov/iaq-schools/heating-ventilation-and-air-conditioning-systems-part-indoor-air-quality-design-tools
27. EPA. (6). Using cool roofs to reduce heat islands. Retrieved from https://www.epa.gov/heatislands/using-cool-roofs-reduce-heat-islands
28. Fisk et al. (2004, February 1). Economic benefits of an economizer system: Energy savings and reduced sick leave. Retrieved from https://digital.library.unt.edu/ark:/67531/metadc786837/#description-content-main
29. Fu, R., Feldman, D. A., & Margolis, Nd R. (2018). U.S. Solar Photovoltaic System Cost Benchmark: Q1 (2018). Retrieved from https://www.nrel.gov/docs/fy19osti/72399.pdf

30. Greenheck Inc. (1997). Energy Recovery Application Manual. Retrieved from https://content.greenheck.com/public/DAMProd/Original/10002/ERVApplManual_catalog.pdf

31. Hayter, S. J. (2011, August 5). Integrating Renewable Energy Systems in Buildings. Retrieved from https://www.nrel.gov/docs/fy11osti/52507.pdf

32. Housing Services Corporation. (2015, December 23). Developing an energy management plan. Retrieved from https://www.hscorp.ca/developing-an-energy-management-plan/

33. International Conference on Sustainable Building Asia. (210). Survey and Analysis of Energy Consumption in University Campuses. Retrieved from https://www.irbnet.de/daten/iconda/CIB17386.pdf

34. Jafary, M., Wright, M., Shephard, L., Gomez, J., & Nair, R. U. (2016). Understanding campus energy consumption -- People, buildings and technology - IEEE conference publication. Retrieved from https://ieeexplore.ieee.org/document/7462518/metrics#metrics

35. Jordan, D., & Kurtz, S. (2015, September 14). Overview of Field Experience Degradation Rates & Lifetimes. Retrieved from https://www.nrel.gov/docs/fy15osti/65040.pdf

36. Kim P. (2017, December 3). Average utility bills will shock you. Retrieved from https://www.creditdonkey.com/average-utility-bills.html

37. KMC Controls. Retrieved from https://www.kmccontrols.com/wp-content/uploads/kmc_documents/DCV_Benefits_White_Paper_KMC_RevB.pdf
38. Lawrence Berkeley National Laboratory. (n.d.). What is an economizer? Retrieved from https://svach.lbl.gov/what-is-an-economizer/
39. Legend Power Systems. (2019). The value of Conservation. Retrieved from https://www.legendpower.com/uncategorized/why-conserve-energy/
40. Lester, P. (2010, March 19). Ball state-building massive geothermal system. Retrieved from https://www.energy.gov/articles/ball-state-building-massive-geothermal-system
41. Madison Gas and Electric Company. (n.d.). Business energy advisor. Retrieved from https://www.mge.com/saving-energy/business/bea/article_detail.htm?nid=2390
42. Managing overhead expenses. (2019, February 6). Retrieved from https://universitybusiness.com/managing-overhead-expenses/?highlight=energy%20consumption%20data
43. Mechem, B. (2017, February 3). A quick look at ball state's geothermal system. Retrieved from https://www.ballstatedaily.com/article/2017/02/news-geothermal-project
44. Missouri State University. (2013, April 23). Top North American education institutions named for reducing carbon pollution. Retrieved from

https://www.missouristate.edu/assets/facilities/Top_North_American_education_institutions_named_for_reducing_carbon_pollution.pdf

45. Natural resources in Canada. (2019, December 18). RETScreen. Retrieved from https://www.nrcan.gc.ca/maps-tools-publications/tools/data-analysis-software-modelling/retscreen/7465
46. Natural Resources Canada. (2020, July 24). Energy benchmarking: The basics. Retrieved from https://www.nrcan.gc.ca/energy-efficiency/energy-star-canada/energy-star-buildings/energy-benchmarking-basics/18260
47. North Shore Community College. (n.d.). Our commitment to sustainability. Retrieved from https://www.northshore.edu/about/initiatives/sustainability/
48. NREL. (n.d.). PVWatts calculator. Retrieved from https://pvwatts.nrel.gov/pvwatts.php
49. NREL. (n.d.). Useful life. Retrieved from https://www.nrel.gov/analysis/tech-footprint.html
50. Page, E. (2011, September). A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings. Retrieved from https://energy.mo.gov/sites/energy/files/lbnl-metastudycontrols2011.pdf
51. Phoenix Energy Group. (2017, October 4). Why you should use renewable energy to power multi-story buildings. Retrieved from https://www.phoenixenergygroup.com/blog/why-you-should-use-renewable-energy-to-power-multi-story-buildings
52. Rolston, R. (2014, November 16). The economics of rooftop units (RTU). Energy efficiency depends on your choices. Retrieved from

https://blog.builtspace.com/2014/11/16/the-economics-of-rooftop-units-rtu-energy-efficiency-depends-on-your-choices/

53. Rosone, M. (2017, December 12). Looking to reduce energy costs? Get an HVAC economizer. Retrieved from https://aristair.com/blog/looking-to-reduce-energy-costs-get-an-hvac-economizer/
54. Schneider Electric. (n.d.). Leading Techniques for energy Savings in Colleges and Universities. Retrieved from http://www2.schneider-electric.com/documents/buildings/lleading_techniques_for_energy_savings_in_colleges_and_universities.pdf
55. Shiminski, J. (2012, January 16). Energy recovery wheels | What is an enthalpy wheel? Retrieved from https://www.dac-hvac.com/energy-recovery-wheels-what-is-an-enthalpy-wheel/
56. Sullivan, C. C. (2010, October 1). Heat recovery wheels for energy savings. Retrieved from https://www.buildings.com/article-details/articleid/10812/title/heat-recovery-wheels-for-energy-savings
57. Therma Inc. (2018, October 29). The benefits of upgrading to high-efficiency commercial HVAC equipment. Retrieved from https://www.therma.com/the-benefits-of-upgrading-to-high-efficiency-commercial-hvac-equipment/
58. Township of Scugog. (2014, June). Retrieved from http://www.scugog.ca/en/township-office/resources/Documents/Energy-Management-Plan.pdf

59. U.S. DOE. (2017, October). Energy Savings Analysis. Retrieved from https://www.energycodes.gov/sites/default/files/documents/02202018_Standard_90.1-2016_Determination_TSD.pdf

60. U.S. DOE. (n.d.). Tankless or demand-type water heaters. Retrieved from https://www.energy.gov/energysaver/heat-and-cool/water-heating/tankless-or-demand-type-water-heaters

61. U.S. Energy Information Administration. (2016). Industrial sector energy consumption. Retrieved from https://www.eia.gov/outlooks/ieo/pdf/industrial.pdf

62. U.S. News. (n.d.). South Dakota State University. Retrieved from https://www.usnews.com/best-colleges/south-dakota-state-3471

63. University of Notre Dame. (2017). Going geothermal. Retrieved from https://www.nd.edu/stories//going-geothermal/

64. Wind Power. (2006). Carleton College, Northfield, MN: Community wind project. Retrieved from https://www.windustry.org/resources/carleton-college-northfield-mn-community-wind-project

65. Yorkland Controls. (2011). Demand control ventilation. Retrieved from https://www.yorkland.net/applications/87-demand-control-ventilation