Energy Efficient at NAU Campus

Final Report

(Project team 8)
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1 BACKGROUND

1.1 Introduction

Energy efficiency refers to the methods utilized to reduce energy use while providing the same level of service. There is a sweeping worldwide movement to reduce energy use and greenhouse gas emissions through improving current building systems or by adding new systems to the already existing one. The United States Green Building Council (USGBC) developed a "green-building" rating system known as Leadership in Energy and Environmental Design (LEED) Certification. The USGBC's mission statement on their website is "to transform the way buildings and communities are designed, built and operated, enabling an environmentally and socially responsible, healthy, and prosperous environment that improves the quality of life.". LEED is a certification accredited to buildings that meet certain criteria or level of energy efficiency; however, having a building being LEED certified does not necessarily mean that the building in energy efficient [1].

Some of the items that are taken into consideration when measuring the building's energy efficiency is analyzing its current energy usage, water efficiency, material of building, air quality, thermal energy losses and insulation, and lighting (amount of natural light versus indoor bulbs and whether the bulbs use high or low voltage). This project will require the team to apply thermal fluid principals (thermodynamics, fluid mechanics, and heat transfer) as well as engineering economics. Increasing any system's energy efficiency is often costly at first and an analysis needs to be done to determine the system payback period compared to its cost. The team will conduct energy savings and cost analysis with the help of mentors so that a certain budget is not exceeded when determining measures to improve the system.

The building our team was assigned was the Student Academic Services (SAS) building. This four-level building is located on a one-acre site at Central Campus and houses a large auditorium for student events and offices for various student services. Additionally, the building has a study area and The Lumberjack Mathematics center that has many computers to be used for various math courses. According to the Architect's website (DWL Architect + Planners), the building is certified LEED GOLD and is constructed out of structural steel and an Aluminum Composite Material (ACM) exterior system. The building's offsite utilities include steam, reclaimed water, and chilled water. Reclaimed water is recycled water from the output of chilled water. This water is undrinkable and is used for irrigation of gardens and other needs.

1.2 Project Description

NAU is committed to lowering our impact on the local and global environment. One of the most impactful ways NAU can reduce our greenhouse gas and air pollutant emissions is through the reduction of energy use either through student/employee behaviors (energy conservation) or through the implementation of energy saving designs (energy efficiency). The goal of this project is to identify locations on campus, or campus wide efforts that could benefit from energy efficiency savings and to design or redesign a system to realize these energy savings. In short, you are tasked to develop energy efficiency designs for the Flagstaff Mountain campus.

The work in this project will primarily be analytical in nature, requiring you to investigate the thermal and electrical energy loads used by campus and/or individual buildings on campus. From this information you will want to identify locations were improvements can be gained and identify or create technologies to realize these savings. You will need to size the systems and estimate what the energy savings will be. This project requires that you apply thermal fluid principals (thermodynamics, fluid mechanics, heat transfer) to your analyses as well as engineering economics – all topics that are evaluated on engineering in training exam. Further, the project will expose you to building energy use, central boiler and chiller operations, and sustainable energy systems. Some monitoring and baseline testing may be possible depending on your proposed design/redesign strategies. To obtain funds for testing and experimentation you must apply to the NAU Greenfund.

1.3 Original System

This is an original design project. There is no original system.

2 REQUIREMENTS

Based on the project description given by Dr. Oman, the following Customer Requirements (CRs) were derived. Each customer requirement will be addressed and analyzed in order to find the proper solution for it. Each solution idea considered will require a certain amount of engineering considerations in order for the solution to be viable. Customer Requirements (CRs) are non-quantifiable and need to be translated into a quantifiable measurement (cost, amount, payback period, etc.). These quantifiable measurements will be discussed under the Engineering Requirements (ERs) section. The Engineering Requirements (ERs) will determine our testing procedures to test the final proposed design.

2.1 Customer Requirements (CRs)

The client (NAU represented by Dr. Wade and Dr. Brent) gave Customer Requirements (CRs) to the team. Each CR considered was given a weighted value based on its rank of importance. Four major requirements will be given a weighted value that represents a percentage. Thus, the weighted total of all CRs will be 100 percent.

2.1.1 Energy Efficient (30)

The client required that the new system must improve on its current energy efficiency measures. As discussed in the introduction, the building's offsite utilities include electricity, steam, reclaimed water, and chilled water. Current utility usage pattern will be analyzed to determine which utility needs an increase in efficiency the most compared to the others. The new system to be designed will satisfy these requirements in increase of efficiency.

2.1.2 Affordable (30)

In addition to an increase in efficiency, the system must also be affordable or help reduce the monthly usage cost for the SAS building. Typically, it will cost the client a certain amount of money for a new system to be installed. A payback period will have to be determined to make sure that the proposed system is sufficient for the client's need. The payback period will be determined based on the reduction of monthly cost due to the increase in efficiency.

2.1.3 Reduce Green House Gas (GHG) Emission (30)

In an effort to reduce NAU's carbon footprint, it is important for the client that the new system will reduce the current HVAC's environmental impact by decreasing the amount of GHG emissions.

2.1.4 Ease of Maintenance (10)

Occasional maintenance of HVAC systems is required to ensure the system is working adequately. The new system must perform sufficiently and must require less frequent inspection and maintenance to reduce the overall cost for the client.

2.2 Engineering Requirements (ERs)

Occasional maintenance of HVAC systems is required to ensure the system is working adequately. The new system must perform sufficiently and must require less frequent inspection and maintenance to reduce the overall cost for the client.

Table 1 – Summary of Engineering Requirements

Requirement	Unit	Target	Tolerance	Range
Reduce Energy Usage	kWh	10%	±1	9% - 11%
Reduce Peak Demand	kW	5%	±0.5	4.5% - 5.5%
Reduce Chilled Water	10^6 Btu	10%	±1	9% - 11%
Reduce Steam	kBtu	10%	±1	9% - 11%
Reduce Natural Gas	ft^3	10%	±1	9% - 11%
Reduce GHG	Ton of CO_2	10%	±1	9% - 11%
Reduce Maintenance Frequency	Times per year	2	±1	1-3
Implementation Time	Days	90	±14	76 – 104
Annual Cost	$	$8400/Year	-$2000	$6400 - $8400
Payback Period	years	5	±1	4 - 6

2.2.1 Reduce Energy Usage (kWh) / Peak Demand (kW)

Our goal is to reduce overall electricity consumption by 10% and peak power consumption by 5%. The overall energy consumption will be given a 1% degree of tolerance while Peak Power will be allowed a 0.5% degree of tolerance for a range of 9% to 11% and 4.5% to 5% consecutively.

2.2.2 Reduce Chilled Water

Our goal is reduce chilled water consumption by 10% with an allowable degree of freedom of 1% for an acceptable range of 9% to 11%.

2.2.3 Reduce Steam

Our goal is reduce overall steam consumption by 10% with an allowable degree of freedom of 1% for an acceptable range of 9% to 11%.

2.2.4 Reduce Natural Gas

Our goal is reduce overall natural gas consumption by 10% with an allowable degree of freedom of 1% for an acceptable range of 9% to 11%.

2.2.5 Reduce Green House Gas (GHG) Emissions

Our goal is reduce overall Green House Gas (GHG) Emissions by 10% with an allowable degree of freedom of 1% for an acceptable range of 9% to 11%.

2.2.6 Maintenance Frequency

HVAC utilities are typically inspected and maintained on quarterly or semi-annual basis. Our goal is to reduce frequency of maintenance to once every two years.

2.2.7 Implementation Time

Our goal is to install and implement the new system within 90 days with an allowable degree of freedom of 2 weeks (14 days) for an acceptable range of 76 to 104 days.

2.2.8 Annual Cost

An increase of energy efficiency of 10% overall will result in an average annual saving of $8400. Thus the target is to meet that amount of money or possibly more, hence allowing a tolerance of -$2000 for an average annual savings range from $6400 - $8400.

2.2.9 Payback Period

Our goal is for the new system to have a payback period of 5 years with an allowable degree of freedom of 1 year, for an acceptable range of 4-6 years.

2.3 Testing Procedures (TPs)

The following testing procedures showcase how analyses were conducted in order to achieve the engineering requirements needed for the new system to deliver at the given allowable ranges.

2.3.1 Run Simulation through eQuest

The team used eQuest to run a simulation of the SAS building to determine it's utility usage and maintenance frequency as well as other miscellaneous information. eQuest is an energy simulation software with an easy interface to help analyze any building's current energy consumption. The software allows team members to conduct an in-depth analysis of the SAS building energy use by going through the buildings design elements and features such as the HVAC equipment installed, lighting system, construction materials, area usage and occupancy, etc.

To use the simulation software, you need to identify the building data in details. This includes the exact location of the building, square footage of the entire building, number of levels, which side the building is facing (SAS is facing north), the type of construction material used for the building, ventilation, HVAC system used for the building, etc.

Multiple simulations can be run using eQuest to simulate various proposed designs and compare the output data simultaneously. The output data is given in graphical formats either in annual or monthly basis. The output graphs include the proposed simulation's electricity usage (monthly for one full year), peak hourly demand (per month), chilled water usage, steam usage, natural gas consumption, and Green House Gas Emissions.

2.3.2 Perform Cost Analysis

To obtain the data needed for energy consumption and cost-analysis, Alerton Compass software (by Alerton Building Automation Resource) is used. Alerton Compass is an energy management software to manage, monitor and control HVAC systems remotely anytime and at anywhere. The software displays detailed monthly utility usages of all campus facilities (including the Student Academic Services building which is the project's focus) as well as the rate of usage for these utilities. Data is collected from March of 2017 through March of 2018. The regular electric usage rate was given by Dr. Wade (the client) to be \$0.067 per kWh. Additionally, peak demand charge is given to be \$23 per kW. Gas consumption rate for chilled water was given by Mr. Heitzinger (Associate Director of Utility Services) to be \$12.86/10^6 kBTU and for steam is \$7.84/10^6 kBTU. To calculate the cost of utilities based on the building energy consumption data, the following equations were used:

$$Real\ Energy = \left(E_{end} - E_{beg}\right) \times \$0.067 \times kWh + \left(P_{max} \times \frac{\$23}{KW}\right) \tag{1}$$

Where E_{end} is the end of month meter reading in kWh
E_{beg} is the beginning of the month meter reading in kWh

$$Chilled\ Water = \left(Chilled\ Water_{end} - Chilled\ Water_{beg}\right) \times \frac{\$12.86}{10^6\ BTU} \qquad (2)$$

Where $Chilled\ Water_{end}$ is the end of month meter reading in therms
And $Chilled\ Water_{beg}$ is the beginning of the month meter reading in therms

$$Steam = \left(Steam\ Meter_{end} - Steam\ Meter_{beg}\right) \times \frac{\$7.84}{10^6\ BTU} \qquad (3)$$

Where $Steam_{end}$ is the end of month meter reading in therms
And $Steam_{end}$ is the beginning of month meter reading in therms

2.3.3 Perform Maintenance and Construction Scheduling

Implementation Time will require an extensive research to test for such a massive building as the SAS. Thus, testing Implementation Time of the proposed system will have to be done during the summer semester. As for the maintenance frequency, the pattern could be determined by observing the warnings triggered in the Alerton Compass software in the last year. And then after everything has been implemented, we will have to count the number of warning that indicate maintenance needed. This number should be less than or equal to twice a year for our proposed model. There aren't actual ways to predict how the new system will behave or if it will trigger these warning. The only test that this analysis requires is the test of time. The system has to be implemented for a whole year and monitored to see if such warnings will be triggered to suggest maintenance would be required.

2.4 House of Quality (HoQ)

House of Quality (HoQ) refers to the methods of relating the Customer Requirements (CRs) to the Engineering Requirements (ERs). Based on the weighted rank given to the CRs, a new weighted system is included in the HoQ table (as shown in Appendix 8.1) to relate these two requirements together based on importance. Since energy efficiency, affordability, and GHG emission reduction are all ranked equally, their weight in the HoQ table will be 5 on the 5-scale. The Ease of maintenance was given a weight of 2 since it ranked at 10% of priority.

3 EXISTING DESIGNS

This chapter will focus on the research done on the current design of the building and how the design research was conducted, what information was sought out, and how the information obtained was used for analysis of existing and proposed systems.

3.1 Design Research

When analyzing any system, one must research a system that has a similar or of equivalent capabilities to understand how the system operates in existing designs. Similar existing designed were researched through various online sources. First research done was on LEED Certifications to understand the requirement for the ranking (silver, gold, and platinum) and to further understand what makes a building to be considered energy efficient. Later, research on current campus buildings was done to see their LEED rating as well as compare them to the building that is in question. The Client helped the team locate the buildings on campus that are LEED certified.

3.2 System Level

The following three examples of system-level existing designs are explained thoroughly. These designs showcase how the system work and also their relevancy to the proposed design model.

3.2.1 Existing Design #1: The Student Academic Services Building

The building which was designed to function as a one-stop-shop houses Admissions, Office of the Registrar, Student Accounts, Financial Aid, faculty offices, Lumberjack Mathematics Center, and a 154-seat auditorium for student events. The building was able to achieve LEED Gold for adoption of energy efficient methods. For instance, it uses energy saving elements like green power, low-E insulated glazing, and the utilization of remote HVAC controls. There is use of renewable energy sources to provide electricity. In addition, the building has made use of high reflective roofing material that is used to cool the building hence reducing the impact on the surrounding environment. However, smaller windows have been used on the western side to minimize heat gain whereas in the northern and southern sides they are maximized to maximize entry of light [3].

Figure 1: The Student Academic Services Building

3.2.2 Existing Design #2: The International Pavilion

It was designed to be NAU's first Net Zero building. It is able to create more energy than it consumes. It was able to achieve LEED platinum by adopting of energy efficient methods. For instance, 54 % energy demands reduction for the whole building due to sustainable design elements. There is also use of motion lighting, solar lighting, and energy efficient light bulbs so as to reduce energy waste from leaving lights on. Also, it has energy efficient windows due to use of argon gas between window panes to keep the heat in and the cold out, and vice versa. In addition, there is radiant heating which is provided through hot water flowing through the pipes [4].

Figure 2: The International Pavilion

3.2.3 Existing Design #3: Hotel and Restaurant Management Complex

The building houses one of the largest and most respected HRM programs in the nation. The building was able to achieve LEED silver for applying energy efficient methods. For instance, large windows have been cut into the original masonry structure, supplemented by rooftop skylights so as to maximize amount of light entering the building. There is also the use of certified wood products for the whole wood roof structure including all of the wood trusses. In addition, there is use of special low-profile mats for collecting particulates. The mats do not require expensive replacement of the concrete slab, which is generally necessary with standard recessed mats [5].

Figure 3: Hotel and Restaurant Management complex

3.3 Functional Decomposition

Each new system will have to be decomposed to simpler forms in order to figure out how to accomplish the proposed designs and understand what the design specifically demand to function. To accomplish this decomposition, two models are needed: Black Box Model and Functional Model. The following sections further explain how these models were developed.

3.3.1 Black Box Model

Every system is made up of simpler components that make it perform the functions it is designed for. To understand these components that make the system work, one must break down the system to its simplest forms and create a Black Box Model to help understand the simple mechanics of the system. A graph is generally done to visually showcase the components of Black Box Model (as shown in Appendix 8.2). As shown in the diagram, the materials input into the model are air, gas, water, and duct. The materials output from the model are air, hot steam, cold water, and filtered duct. The system acts as a thermal energy control to convert the input materials into the output aforementioned earlier.

3.3.2 Functional Model

A functional model is a visual representation of the structure of operations for any given system. The functional model further breaks down each function, action, and operation in the entire system. The functional model helps derive relations between the different operations and assist in further showcasing the independent operations that have to exist simultaneously to make the system work. Appendix 8.3 shows the functional model for this project.

3.4 Subsystem Level

The subsystems discussed in this section are derived from the Functional Model explained earlier. The model requires material input (air, natural gas, and water), electricity usage, and the signals used to manipulate or control the system (turn it on and off as needed). The following subsystems will explain how the inputs are converted to the outputs shown in through the usage of the system itself.

3.4.1 Subsystem #1: Electricity

Electricity is an integral part for the functionality of the system. The electricity provided to the system helps with lighting, push air, provide chilled water, cool air, heated air, and is useful for the operations of any electrical equipment at the SAS building.

3.4.1.1 Existing Design #1: HVAC System

The HVAC system demands electrical power input in order to operate. The HVAC system converts the air input into hot and cool air. So for the HVAC system to act as a thermal energy control system for the pushed air through the ducts, (as shown in the Black Box Model) it requires electrical power input.

3.4.1.2 Existing Design #2: Steam

Water is heated in the boilers using natural gas; however, electricity is used to push the steam produced by boiling the water. As explained in the first existing design (HVAC System) electricity is used to push the air through the ducts. Air pushed through the steam control units will be converted to hot air exiting the HVAC system.

3.4.1.3 Existing Design #3: Chilled Water

Electricity is used to push the air through the chilled water control duct. Electricity is also used to cool the water (chilled water) that is used for this operation in order to provide cool air.

3.4.2 Subsystem #2: Natural Gas

Natural gas is another essential power resource for the complete operation of the thermal control unit. Natural gas is used to power the boilers in order to boil the water, which in turn provides steam. Natural gas is a fossil fuel so when used it will result in Green House Gas Emissions such as Carbon Dioxide (CO_2) and Nitrogen (N_2). The following sections will explain Natural Gas uses in the system.

3.4.2.1 Existing Design #1: Boilers

Boilers are used to boil the input water. The water is boiled in order to provide steam that is used to provide hot air. The boilers require Natural Gas energy source in order to operate.

3.4.2.2 Existing Design #2: Green House Gas Emissions

As explained in the introduction of Subsystem #2, natural gas decomposes to other gases when burnt to provide heat for the boilers. These Green House Gas Emissions include Carbon Dioxide (CO_2) and Nitrogen (N_2). These emissions need to be measured and controlled in order to lessen our environmental impact.

3.4.2.3 Existing Design #3: Steam

As explained earlier, steam is used to provide hot air output. The steam is generated through the boiler system that requires the natural gas power input in order to heat the water into steam.

3.4.3 Subsystem #3: Water

In order to hear or cool air input into the thermal control unit, water is used and is manipulated using the operations detailed and explained in section 3.4. When water is inputted to the system it is passed through two separate units. The following existing designs further explain these units as well as the usage of output water.

3.4.3.1 Existing Design #1: Chilled Water

The water that is passed to the unit controlled by electrical power source is cooled down to reach the chilled water level. As explained earlier, chilled water is used to provide cool air output.

3.4.3.2 Existing Design #2: Boilers

The water that is passed to the boilers (units controlled by natural gas power source) is heated up to reach the boiling water level. As explained earlier, boiled water provides the steam that is used to generate hot air output.

3.4.3.3 Existing Design #3: Recycled Water for Irrigation

Condensation is created when chilled water passes through the coils in order to create the cool air output. In most building this condensation is discarded. The current HVAC system at the SAS building harvests that condensation to provide irrigation water for the surrounding landscape. This process reduces the amount of water imported and used by the campus.

4 DESIGNS CONSIDERED

In this section, ten designs will be considered which will ensure that there is energy efficient. This will be accomplished by analyzing some of the energy efficient methods that have been used in the International Pavilion building (LEED PLATINUM) so as to apply them in the Student Academic Services building (LEED GOLD). The description of the designs considered has been given plus sketches that can be find in Appendix 8.4.

4.1 Design #1: Use of Insulation

This design entails the use of effective and improved use of insulation so as to ensure that even temperatures are achieved throughout the house while using less energy. This is effective since there are lower utility costs and the interior of the building becomes quieter and more comfortable [2] (Figure: 8.4.1).

4.2 Design #2: Motion Lighting

The motion lighting system has sensors which facilitate turning on lights automatically when they detect motion and then turn them off a short while later. They save energy since they are only on when they detect movement. They are also able to rotate at an angle of 360 degrees hence highly effective (Figure: 8.4.2).

4.3 Design #3: Energy Efficient Light Bulbs

Use of energy efficient light bulbs such as compact fluorescent lamps (CFLs), halogen incandescent, and light-emitting diodes (LEDs) will help to save a lot of energy since lights will be left on most of the time. These bulbs will help to reduce energy cost by 25%-80% less energy compared to the traditional ones. Also they last longer by 3-25 times longer (Figure: 8.4.3)

4.4 Design #4: Tight Construction and Tight Ducts

This design entails use of tight ducts and tight construction so as to eliminate dust, drafts, moisture, pollen and pests. This is very crucial since it helps to improve the quality of indoor air and hence comfort and eventually lowering the maintenance costs [3] (Figure: 8.4.4).

4.5 Design #5: Use of Argon Gas Windows

When windows, which are filled with argon gas in between window panes are used, they will increase energy efficiency since heat exchange is minimized though the window. Other additional benefits are increasing the soundproofing characteristics, reducing the possibility of condensation. However, the argon gas is environmentally friendly since it is non-toxic [2] (Figure: 8.4.5).

4.6 Design #6: Use of Solar Tubes

This design entails the installation of solar tubes to act as a natural lighting source in the various rooms of the building. The solar tubes will be very effective since they will help to reduce the amount of energy that is used for artificial lighting (Figure: 8.4.6).

4.7 Design #7: Radiant Heating

This design entails provision of radiant heating through piping which runs under all flooring. When hot water flows through those pipes it provides enough heat. This is very crucial since it ensures that less energy will be used, as there will be no need of using heating devices in the rooms [3] (Figure: 8.4.8).

4.8 Design #8: Use of Large Windows

This design entails the use of large windows so as to maximize amount of light entering a building. This will facilitate the building to become energy efficient since there will be less use of lighting bulbs. Figure 8.4.8

4.9 Design #9: Cool Roofs

This design entails the use of use highly reflective materials that are able to reflect a lot of light and at the same time absorb less heat from sunlight. This is crucial since it will help to lower the interior temperatures during the hot weather. This design enhances energy efficiency by reducing the use of air conditioners and fans (Figure: 8.4.9).

4.10 Design #10: Use of Remote Temperature Controls

This design entails use of a remote sensor to control water and air temperature in ducts and tanks and similar applications. The remote senses the increase and decrease of temperature and adjust them accordingly. This is crucial since it helps to reduce unnecessary use of energy thus increasing energy efficiency (Figure: 8.4.10).

5 DESIGN SELECTED

After going through the analytical procedure of analyzing existing designs, how they operate, how they relate to out proposed designs, and what can be learnt or applied to our system, the following sections describe how the final design was selected for our project.

5.1 Rationale for Design Selection

In the beginning of the semester the team was given few options to look at and consider for the project of increasing energy efficiency. These buildings were North Plant and Social and Behavioral Science (SBS) Castro Building, SBS West Building, Walkup Skydome, Student Academic Services (SAS) building, or any other building on campus. All of these buildings have some efficiency measures that make it ideal for analyzing for this project's purpose. After discussing the buildings with the client (Dr. Wade) the team chose to focus their analysis on the SAS buildings.

Since NAU already considered it for further energy efficiency improvements (as discussed with Dr. Wade), it was clear to see why SAS would be a good candidate for this project. All other buildings mentioned earlier have already been audited by NAU so most solutions have already been taken into consideration to improve their energy efficiency. The team wanted to look at the buildings that have already been energy-audited and use that information to make the SAS building more energy efficient. NAU has paid for professionals to do the energy audits so it could be beneficiary to look at those buildings and apply their solutions (or similar solutions) to our proposed designs. Dr. Wade also communicated with the Director of Utility on campus (Jon Heitzinger) that shared with her more information on energy efficiency of these buildings and discussed his concerns with the SAS building particularly due to its high energy consumption.

The Director of Utility was interested in seeing a thermal energy model of the SAS building. The amount of heat going into the building is known since it receives steam from North Campus boilers. The amount of electricity consumed by the SAS building is also known. Thus a baseline model could easily be done to mimic the current condition of the SAS building then general separate models that may help improve on these energy consumption patterns. The director also expressed his concern with the current condition of the heating and ventilation systems, adding that those two have not yet been optimized and thee is potential to make these two operate at a better level and making the system overall more energy efficient.

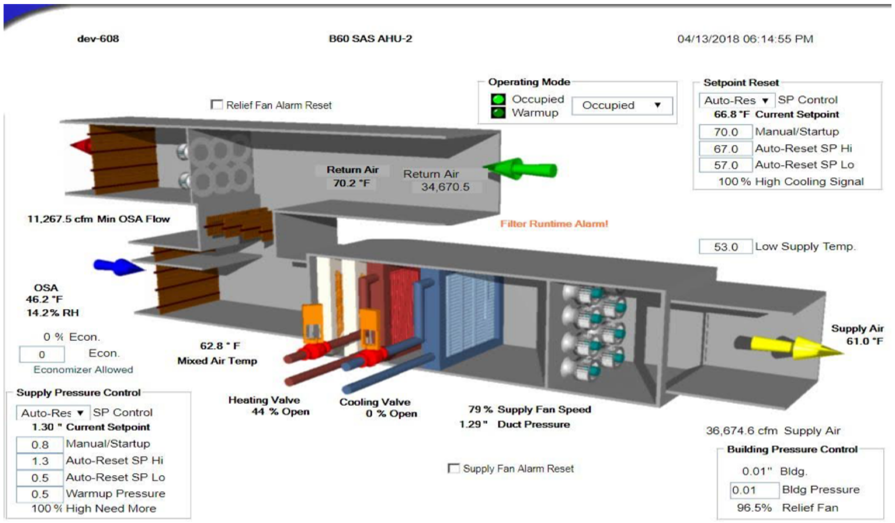
There is a lot of information that can be found about the SAS building that makes it the ideal candidate for this project. There are numerous meters and sensors and other data sources that allows the team to easily analyze the given data and see where the holes are to fix [5].

5.2 Design Description

Major area of energy use at NAU campus is from energy. Second highest energy source consumed on campus comes from Natural Gas, where it is pumped to the south and north campus boilers, burnt in the boiler, and used to heat water in a heat exchanger, and that hot water is piped to all buildings on campus. The hot water get coiled into other systems which brings out the warm air needed to keep the buildings are acceptable room temperature during the cold season. This energy consumption information tells us that the three major variables the team needed to consider for the final design are electricity, natural gas, and water.

To obtain the data needed to create the thermal model of the SAS building, Alerton Compass software (by Alerton Building Automation Resource) was used. Alerton Compass is an energy management software to manage, monitor and control HVAC systems remotely anytime and at anywhere. The software displays detailed monthly utility usages of all campus facilities (including the Student Academic Services building which is the project's focus) as well as the rate of usage for these utilities.

Data is collected from March of 2017 through March of 2018. See figure 5.1 below to see what Alerton Compass software looks like and how the data is displayed [6].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04/13/2018 06:14:55 PM

Operating Mode
● Occupied
● Warmup
Occupied ▾

Setpoint Reset
Auto-Res ▾ SP Control
66.8 °F Current Setpoint
70.0 Manual/Startup
67.0 Auto-Reset SP Hi
57.0 Auto-Reset SP Lo
100 % High Cooling Signal

☐ Relief Fan Alarm Reset

Return Air 70.2 °F
Return Air 34,670.5
11,267.5 cfm Min OSA Flow
Filter Runtime Alarm!
53.0 Low Supply Temp.
OSA 46.2 °F 14.2% RH
0 % Econ.
0 Econ.
Economizer Allowed
62.8 °F Mixed Air Temp
Supply Air 61.0 °F
Heating Valve 44 % Open
Cooling Valve 0 % Open
79 % Supply Fan Speed
1.29" Duct Pressure
36,674.6 cfm Supply Air

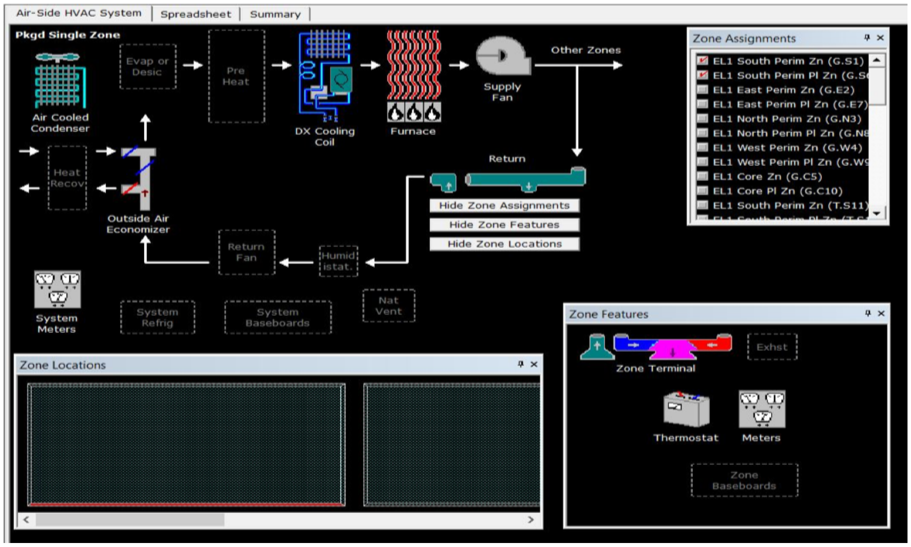
Supply Pressure Control
Auto-Res ▾ SP Control
1.30 " Current Setpoint
0.8 Manual/Startup
1.3 Auto-Reset SP Hi
0.5 Auto-Reset SP Lo
0.5 Warmup Pressure
100 % High Need More

☐ Supply Fan Alarm Reset

Building Pressure Control
0.01" Bldg.
0.01 Bldg Pressure
96.5% Relief Fan

Figure 5.1: Alerton Model

With the wealth of information the team has, it wasn't too difficult to create a thermal model of the current SAS building using eQuest. Detailed explanation of how eQuest software was used to create the separate models can be found in section 2.3.1 of this report. There were many model variations done produce a system that provides the same level of services with lower energy consumption while also reducing GHG emissions. See the figure 5.2 below for one of the models done on eQuest [7].



☒ EL1 South Perim Zn (G.S1)
☒ EL1 South Perim Pl Zn (G.S
☐ EL1 East Perim Zn (G.E2)
☐ EL1 East Perim Pl Zn (G.E7)
☐ EL1 North Perim Zn (G.N3)
☐ EL1 North Perim Pl Zn (G.N
☐ EL1 West Perim Zn (G.W4)
☐ EL1 West Perim Pl Zn (G.W
☐ EL1 Core Zn (G.C5)
☐ EL1 Core Pl Zn (G.C10)
☐ EL1 South Perim Zn (T.S11)

Figure 5.2: eQuest Model

One of the models used a different sequence of operations (known as load shifting). Load shifting means instead of consuming electricity in the middle of the day when it is more costly, we can shift the usage to the middle of the night when it is least costly. When doing so the team realized that this method only saves on cost but it does not reduce energy consumption, ruling it out as the solution for this project. Although saving on cost is important to our project, it is more important to save on energy consumption while also cutting down on cost and GHG emissions. Other models created were concerned with the condition under which we need to cool or heat the building to create a more optimized system.

The Director of Utility of NAU campus expressed his concern with the heating, cooling, and ventilation system currently in place at SAS building. The Director suggested that since we have all the information regarding these elements, we can model them but optimize each item by creating separate model and finding out which model will provide highest energy efficiency while lowing cost and GHG.

6 PROPOSED DESIGN

There is a logic system that the current Air Handling Unit (AHU) follows for its operations at the SAS building. The building gets cooling from chilled water and heating from steam though the heat exchanger. AHU pulls outside air (OSA) in and then mix it with air that is coming up through ventilation in the building (there is constant circulation of air). Some of the air goes out and some is circulated back in. How much heat to be supplied depends on the amount of supply air being provided and what the room temperature is. When room temperature is really low, supply air is really high to get a lot more heat into the room. Room temperature is controlled through those valves. This logical flow of operations is fully explained in the Appendix 8.5.1 (Cooling Valve) and Appendix 8.5.2 (Heating Valve).

The Director of Utility wanted the team to understand how these valves work, at what percentage each valve operate at what time, fully grasp how the logic of the system flows, know (based on the room temperature) when the valves are opening and closing, and then propose changes to the control logic by changing the percentage of valve opening. Looking at the cooling valve logic, at the far left you can see “Manual Allow Clg Valve” labeled “BV-37”. This valve can be manipulated to trigger the ON/OFF switches in the logic control system. The current cool valve is operating at 34.6%. However, even when the BI-8-N switch is triggered to switch off, the valve is still operating at the same level. This is clearly not efficient and the valve needs to be reduced so that when the switch is off, less electricity is used to cool the air and push the cool air through. The team suggests reducing the operation level of the valve by 10% so that the valve is still operating at

Looking at the heat valve logic, at the far left you can see “Low Temp Limit” labeled “BI-8”. Room temperature triggers the ON/OFF switches in the logic control system. The current heating valve is operating at 100% through the first switch, suggesting that the room is at temperature lower than the one set by the heating system requiring hot air to be supplied. The heated air goes through three logical tests. The top one is called “COMPARTOR” which is an electronic circuit comparing two electrical signals to determine if steam is needed to heat the air. The bottom one is the “INPUT SCALER” where the hot air in and hot air out is balanced. The first input is pumping air at 0% but the first output is pumping air at 20%. The second input is pumping air at 100% and the second output is pumping air at 100% as well. The team proposes to shut off the first output valve to reduce the amount of hot air being bumped out, which consequently saves the amount of natural gas being burnt to heat the steam that heats the air being wasted [8].

Now that the team decided on what valves to manipulate and by how much, an implementation schedule will be done during the summer semester to determine how long the new system will need to be installed. Then, the team will monitor the proposed model in the summer and record the response, then compare the findings with what initially was predicted. The team will continue to discuss the operations of the proposed system with the Director of Utility and with the SAS facility manager.

7 REFERENCES

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[7] "eQUEST", Doe2.com, 2018. [Online]. Available: http://www.doe2.com/equest/. [Accessed: 04- Apr- 2018].

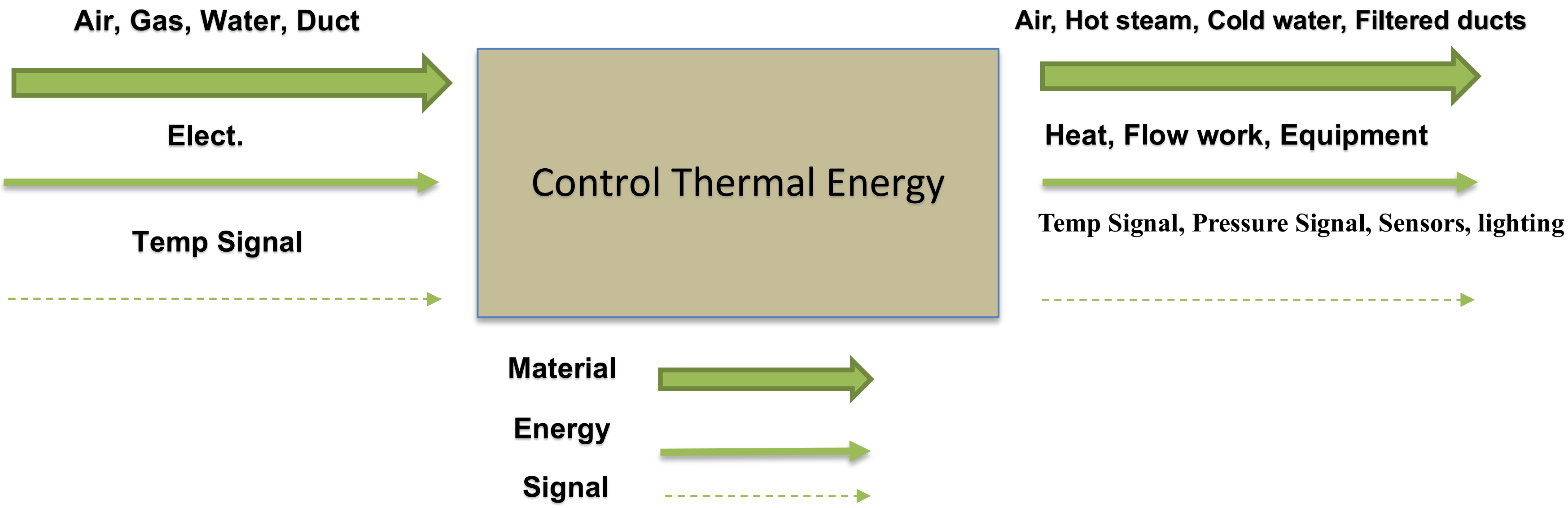
[8]]SAS AHU-2. Flagstaff: Dr. Wade, 2018, pp. 6,7.

8 APPENDICES

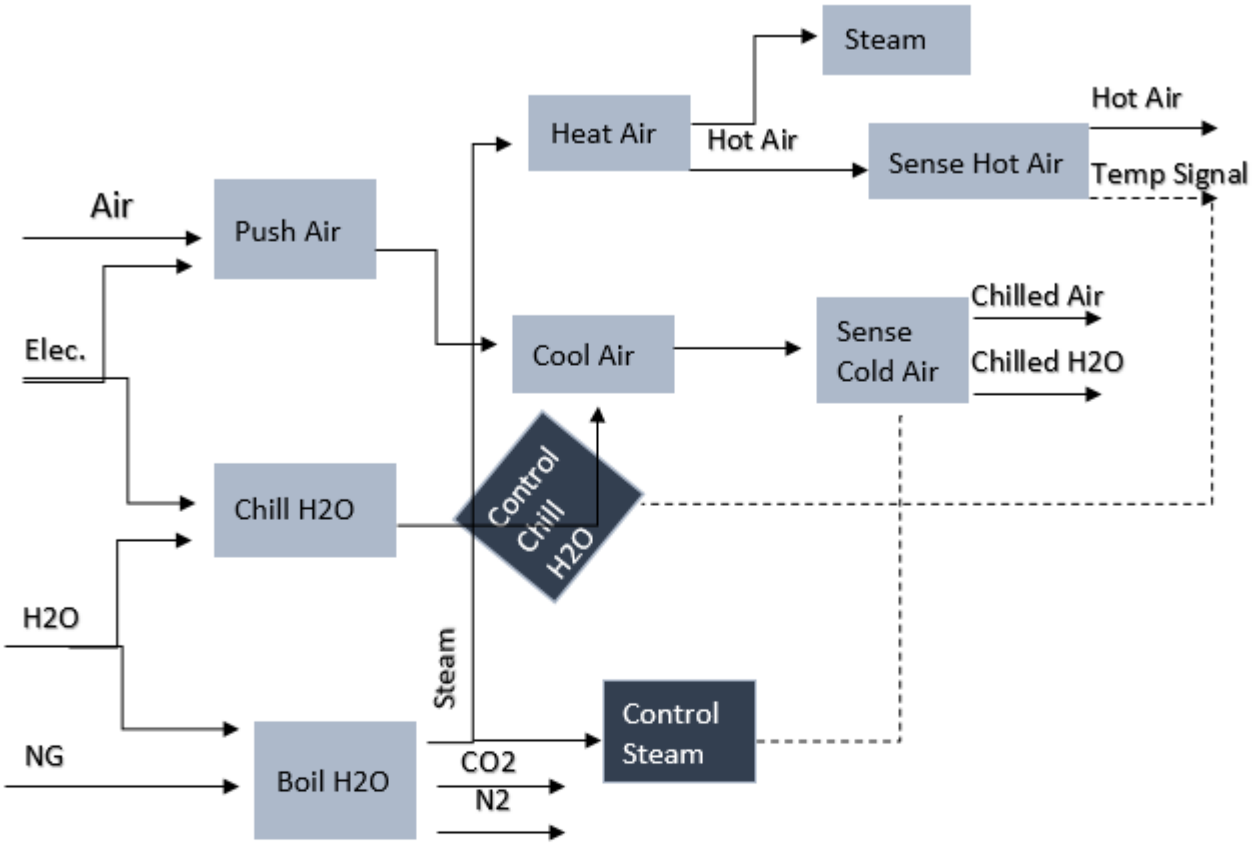
8.1 House of Quality (HoQ)

Customer Requirement	**Weight**	**Engineering Requirement**	Reduce Energy Usage	Reduce Peak Demand	Reduce Chilled Water	Reduce Steam	Reduce Natural Gas	Reduce GHG	Reduce Maintenance Frequency	Implementation Time	Annual Cost	Payback Period
			kWh	kW	1E6 BTU	kBTU	ft^3	tons of CO2	times/year	days	$	years
1. Energy Efficient	5		9	9	9	9	9	3	1	1	3	3
2. Affordable	5		3	3	1	1	1	1	1	1	3	9
3. Reduce GHG Emission	5		9	9	1	3	9	9	1	1	9	3
4. Ease of Maintenance	2		3	3	1	1	3	1	9	1	9	3
Absolute Technical Importance (ATI)			111	111	57	67	101	67	33	17	93	81
Relative Technical Importance (RTI)			1	1	8	6	3	6	9	10	4	5
Target ER values			10%	5%	10%	10%	10%	10%	2	90	$8,400	5
Tolerances of Ers			± 1%	± 0.5%	± 1%	± 1%	± 1%	± 1%	± 1	± 14	- $2,000	± 1
Testing Procedure (TP#)												

8.2 Black Box


Air, Gas, Water, Duct
Elect.
Temp Signal
Control Thermal Energy
Air, Hot steam, Cold water, Filtered ducts
Heat, Flow work, Equipment
Temp Signal, Pressure Signal, Sensors, lighting
Material
Energy
Signal

8.3 Functional Model



8.4 Design Considered

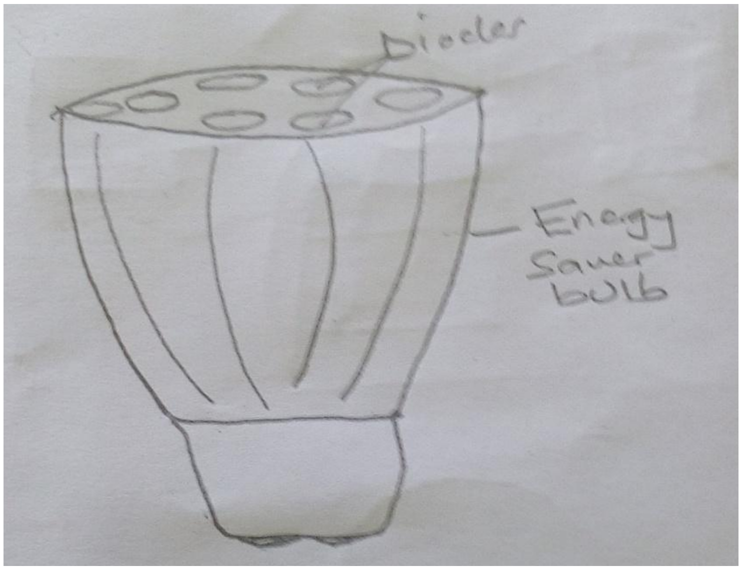


Figure 8.4.1: Energy efficient light bulb

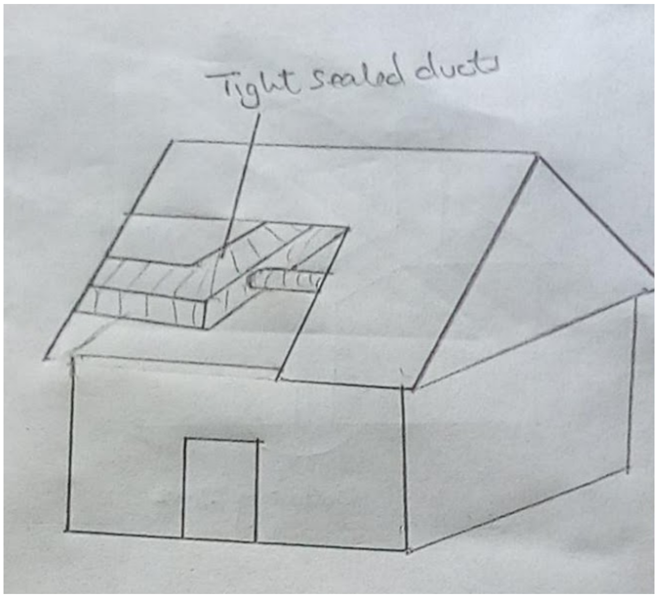


Figure 8.4.2: Tight construction and tight ducts

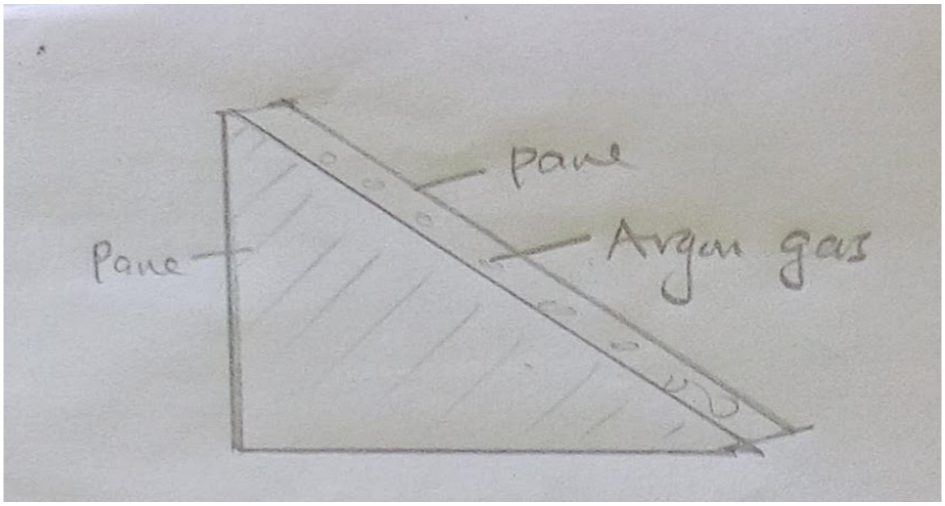


Figure 8.4.3: Argon gas windows

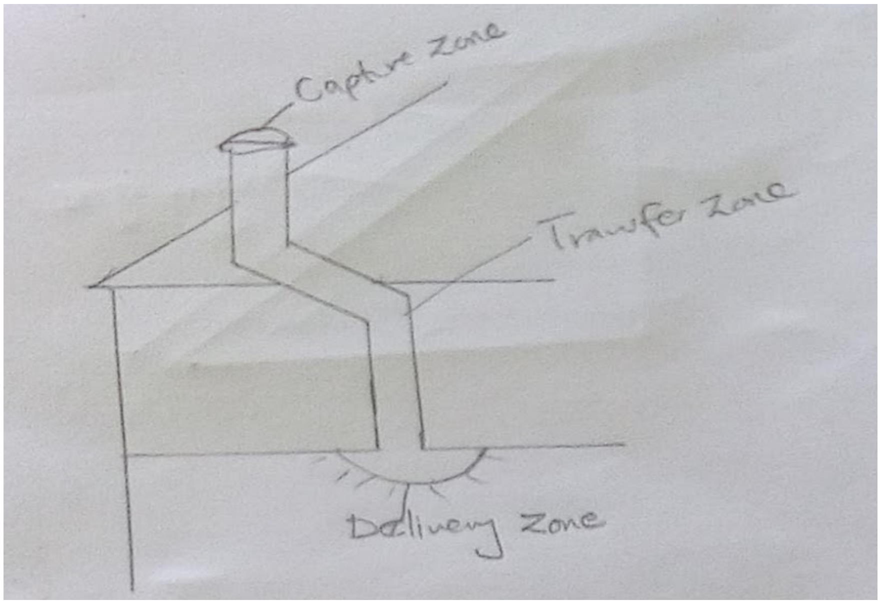


Figure 8.4.4: Solar tubes

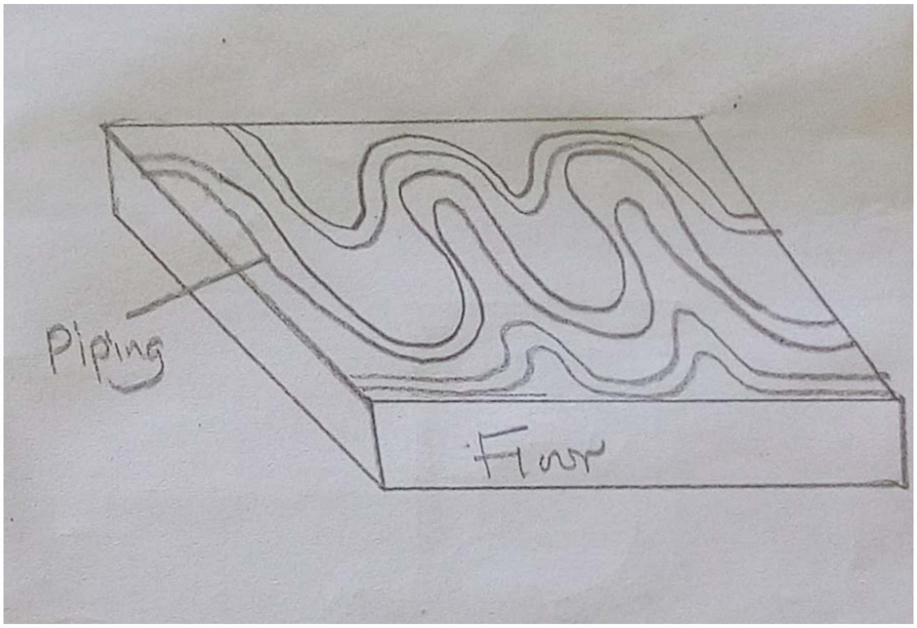


Figure 8.4.5: Radiant heating

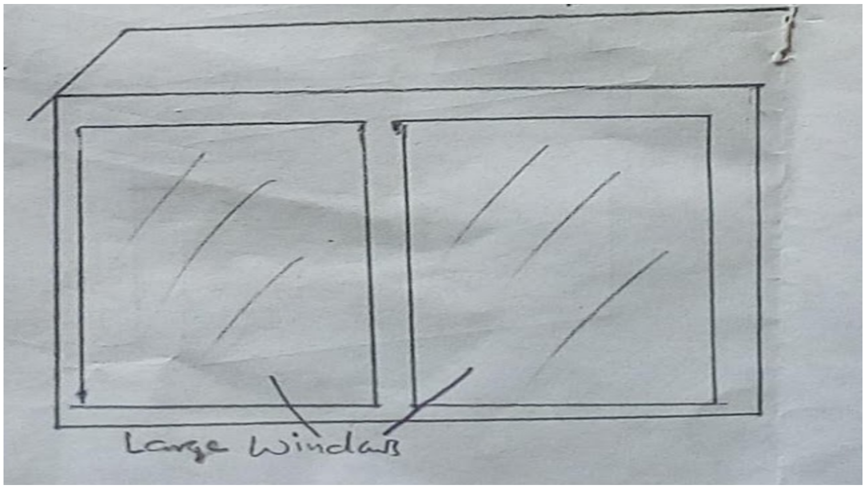


Figure 8.4.6: Large windows

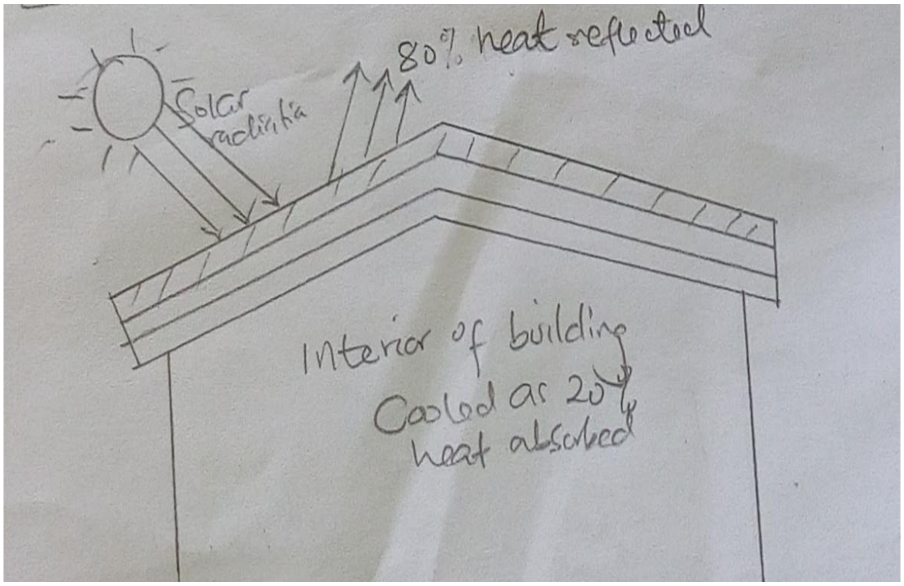


Figure 8.4.7: Use of cool roofs

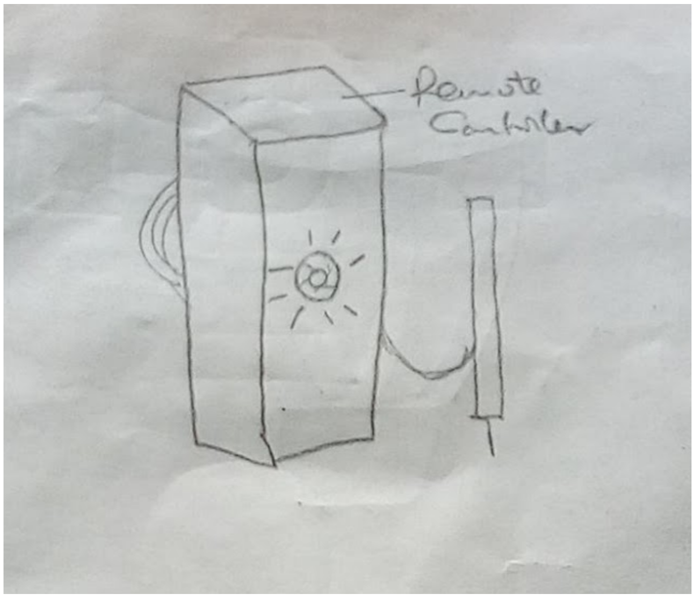


Figure 8.4.8: Remote temperature controls

8.5 Proposed Design

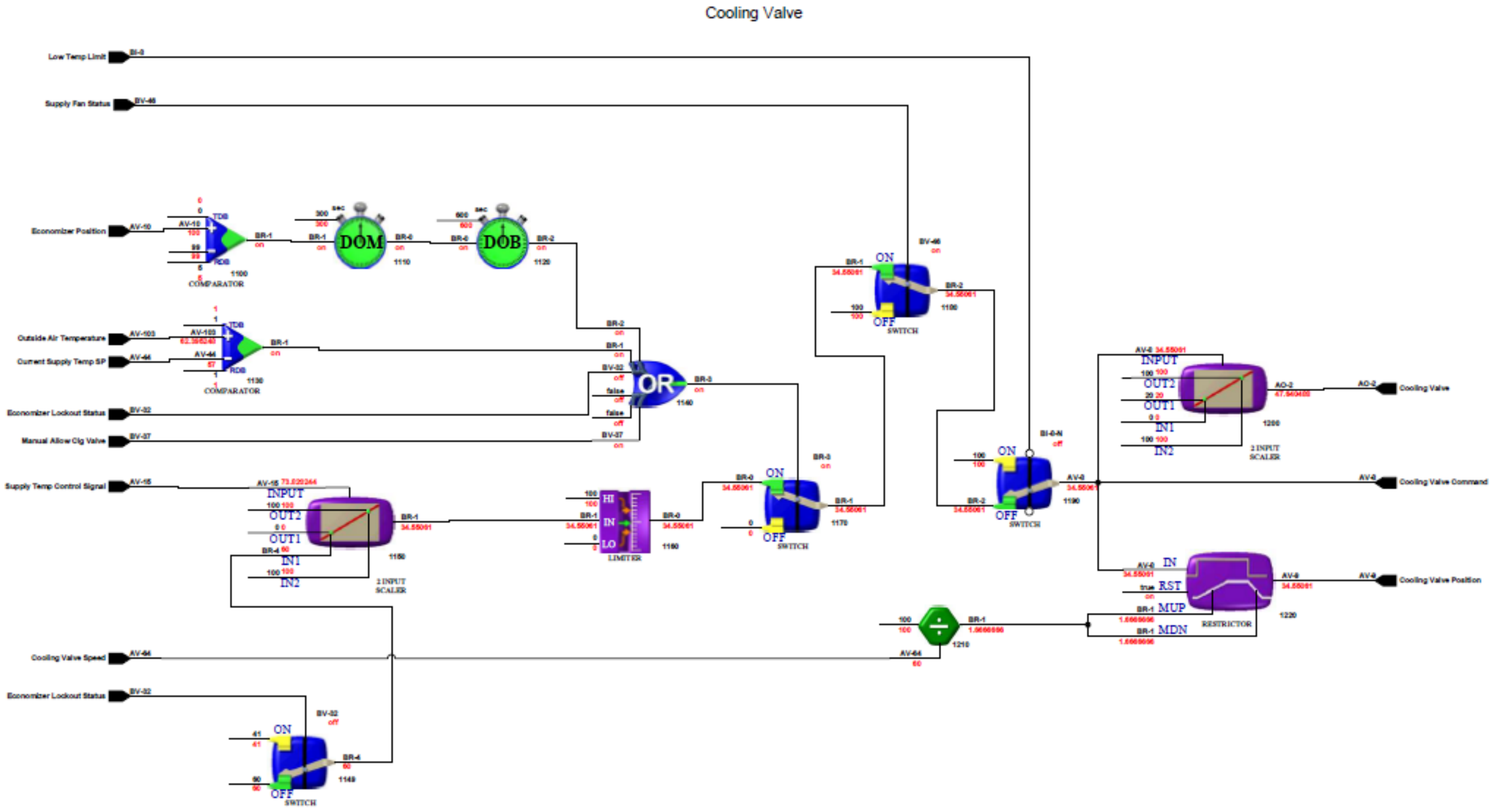


Figure 8.5.1

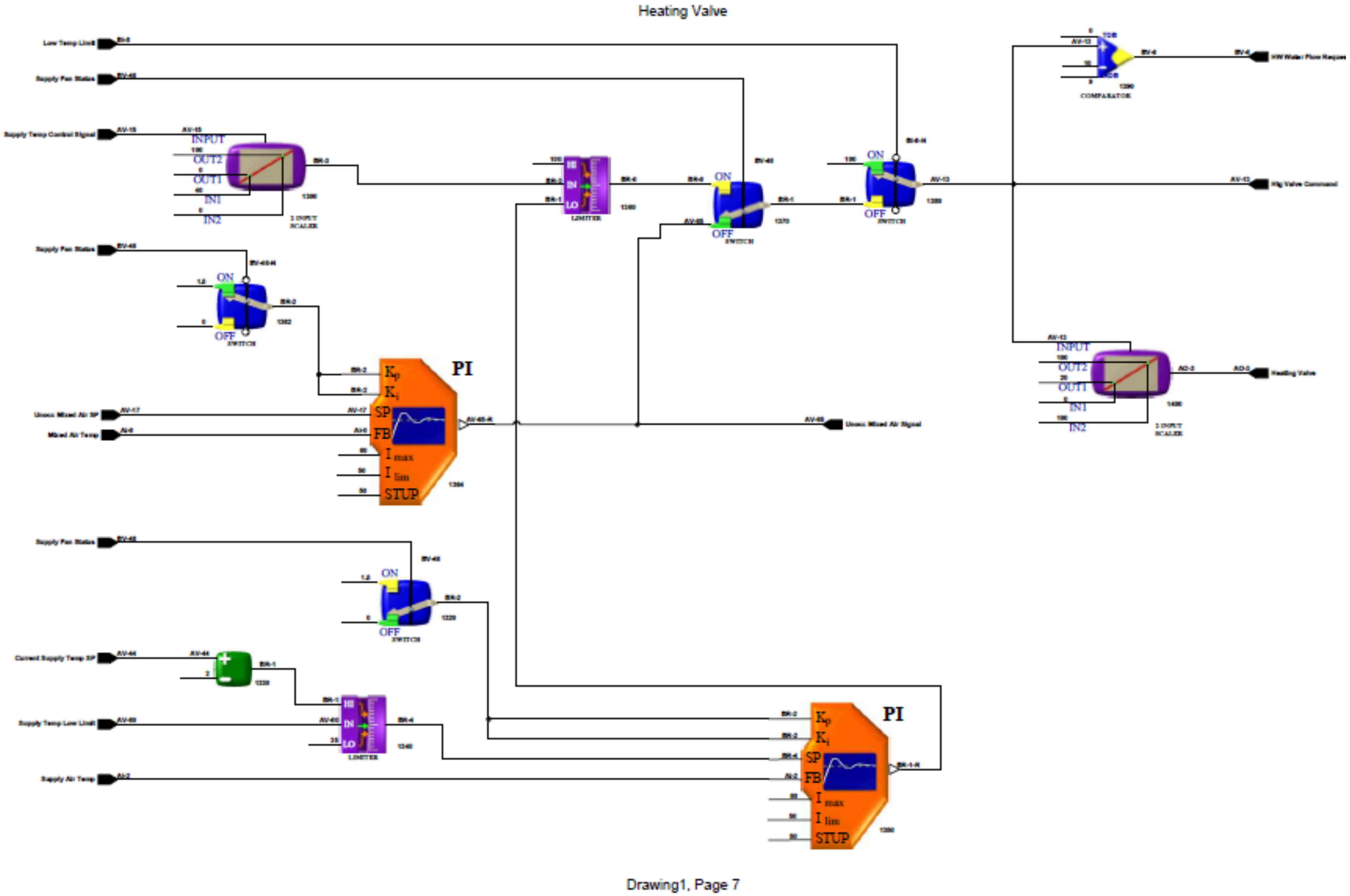

Heating Valve
Low Temp Limit
Supply Fan Status
BV-48
Supply Temp Control Signal
AV-15
INPUT
OUT2
OUT1
IN1
IN2
100
0
40
2 INPUT
SCALER
BR-2
HI
IN
LO
LIMITER
BV-48
ON
OFF
SWITCH
BR-1
AV-13
COMPARATOR
TDB
BV-6
HW Water Flow Request
Hlg Valve Command
1.0
PI
Kp
Ki
SP
FB
I max
I lim
STUP
Unocc Mixed Air SP
AV-17
Mixed Air Temp
Unocc Mixed Air Signal
AO-3
Heating Valve
Current Supply Temp SP
AV-44
2
Supply Temp Low Limit
35
Supply Air Temp
AI-2
Drawing1, Page 7

Figure 8.5.2