Temporary HVAC Load Shedding Characterization and Comparison

by

Peter Rubis

Senior Project

ELECTRICAL ENGINEERING DEPARTMENT

California Polytechnic State University

San Luis Obispo

2013-2014

Table of Contents

List of Tables and Figures

Table *Page*

Figures

Abstract

At the Marine Corps Air Station Miramar, there is an ongoing project conducted by Raytheon that seeks to provide a renewable and reliable microgrid to provide energy during the time of a power outage. The microgrid system is demonstrated on a single test building on site. The Raytheon project consists of developing a battery that can support the electrical load from the tester building, while the power is generated and shared through an array of PV systems. This senior project specifically works on implementing a temporary load shedding scheme in order for the battery to support the building's electrical load longer. In order to implement a temporary load shedding scheme, the building shall be characterized as closely as possible using an energy modelling and simulation tool, eQuest.

Currently, the building has a limited set of temporary load shedding schemes using Demand Load Limit Response (DLLR). The DLLR focuses on eliminating cooling of the air and focuses on outputting room temperature air. This load scheme is compared to another temporary load shedding scheme called the Cycling Method, where this method focuses on turning the ventilation fans on and off throughout the building. Once the simulations were completed, both temporary loads shedding scheme showed similar results, but the Cycling Method achieved a load reduction of 23.9% while the DLLR achieved 23.1%.

Chapter 1: Background

Located in San Diego, California, the Marine Corps Air Station (MCAS) Miramar experienced an eight hour blackout that disrupted the Marine Corps Base's operations. They realized that losing power, as a major west coast aviation unit, is unacceptable. In order to combat these of problems, the Department of Defense (DoD) set goals that all military bases improve their energy security. The DoD contracted Raytheon to construct a micro grid system efficiently and safely and implement it at MCAS Miramar.

After multiple bases suffered power outages, the Navy required 50% of the shore based installations to be Net Zero loss, where energy consumption matches renewable generation. In order to follow this protocol, a self-sufficient renewable energy micro grid and battery system must be installed. The previous choice for a back-up power system was diesel generators. However, the generators suffered with startup problems and low power efficiency. This caused the choice of a solar powered energy grid system using the plentiful of sunlight in San Diego. The solar micro grid system shall store the available electrical energy and use it as a reserve when the main power grid system from San Diego Gas and Electric becomes unavailable for a period of time, also known as islanding.

Chapter 2: Introduction

The HVAC load management of the micro-grid system is completed through a building energy simulation tool called eQuest. The software tool is designed to perform detailed analysis through a combination of a building creation wizard, an energy efficiency measure wizard, and a graphical results display module. The program is based on the DOE-2 software, which is the algorithm which is used for calculating the building heating and cooling energy usage. The DOE-2 software was produced through the funding of the United States Department of Energy.

The current temporary load shedding scheme of the building is the DLLR which consists of three stages. The first stage involves increasing the temperature set points when the building is occupied. Then the next stage turns off the compressors in the HVAC units. Turning off the compressors in the HVAC units turns off cooling the air output from the units. In turn, room temperature air is output from the HVAC units constantly. Lastly, the third stage comprises of turning off the whole system.

In comparison to the DLLR, the Cycling Method involves the ventilation fans rather than the compressors. The first stage also involves increasing the temperature set points while the building is occupied. However, the second stage involves leaving the compressors on while turning the ventilation fans on and off. All the HVAC units start with their ventilation fans turned off, and then two HVAC units across the building turn on together. After a set period, the two units on turn off, and then another pair of units turn on. This process repeats constantly hence the name the Cycling Method.

Chapter 3: Requirements and Specifications

The specifications and requirements of the project were determined from the customer's need of temporary load reduction of the building. Likewise, the operational limits of the building require certain prerequisites for the proposed design. Table I shows the marketing requirements and subsequent engineering specifications for this paper along with the logic and justification behind each.

TABLE I

SENIOR PROJECT: REQUIREMENTS AND SPECIFICATIONS

Marketing Requirements	Engineering Specifications	Justification
1	The rate at which the building's load is measured shall be less than an hour	In order to accurately creating a temporary load shedding process, the interval between load measurements must be less than an hour, preferably within half an hour.
3	The amount of CO2 in the air must not reach a limit that will harm anyone in the building	Increasing temperature set points will create a fine line of breathable air
5	The project shall follow good practices for the design, operation, and integration of distributed resource island systems	The project involves the design of an islanding system, which means that guidelines shall be followed to ensure safety in the process
3,4	The system shall always be running and shall not be turned off	One of the priorities of the project is that the system is always running in order to keep operations at the building constant, as if there was never a power outage
1,2	Initial characterization must measure in accordance to previous standards	The initial power and load characterization measures through the previous ratings of the system.
1,2	The HVAC systems' load must decrease by 50%	The 50% load decrease is a target specification with which to design the PV and battery system

Marketing Requirements

1. Decrease the load from the HVAC systems
2. Increase the islanding time of the micro grid
3. Ensure that proper air quality is always present
4. Ensure the building is operational without any discontinuations
5. Work follow guidelines governed under IEEE 1547.4

Chapter 4: Functional Decomposition

4.1 Level Zero Decomposition

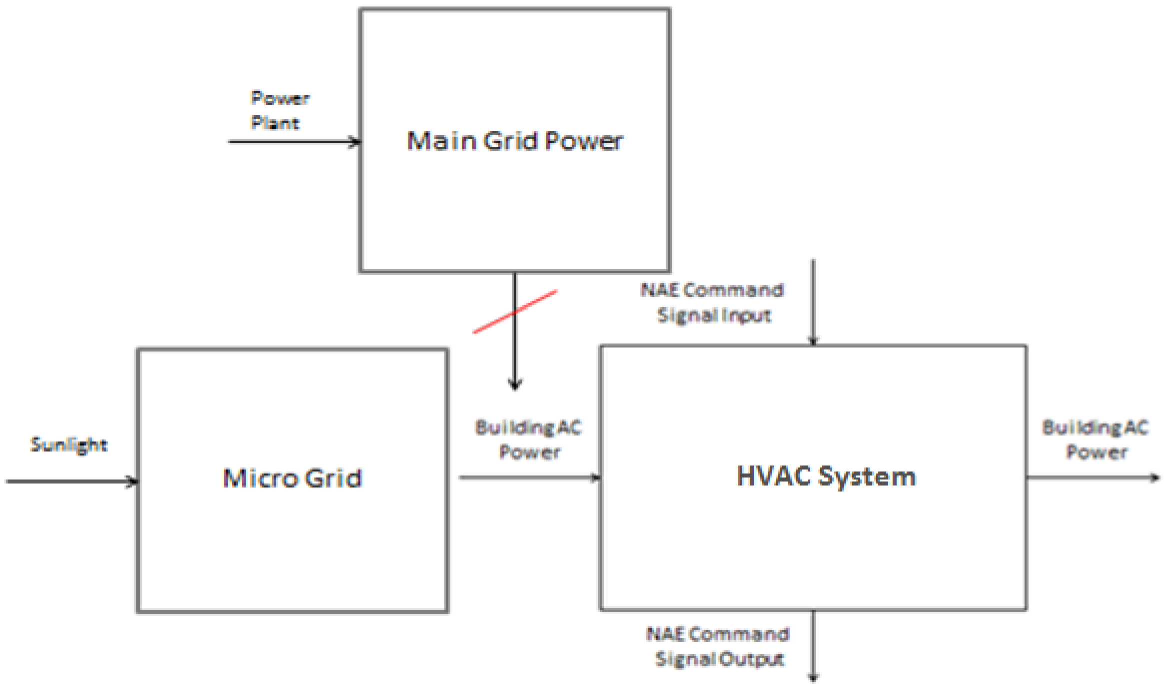


Figure 4-1: Level Zero Block Diagram

The system has three main components, the micro grid, the HVAC system, and the main grid system. The micro grid takes in sunlight which is converted and stored into electrical power into a battery system. When the main power grid is functional, the HVAC system draws its power from there. The distributor of this power is SDG&E (San Diego Gas and Electric). If SDG&E faults and blackouts occur, the HVAC system starts to receive power from the micro grid and battery, in which the project is focused on. The stored electrical power from the battery is then used in the DDC system, or also known as islanding.

4.2 Level One Decomposition

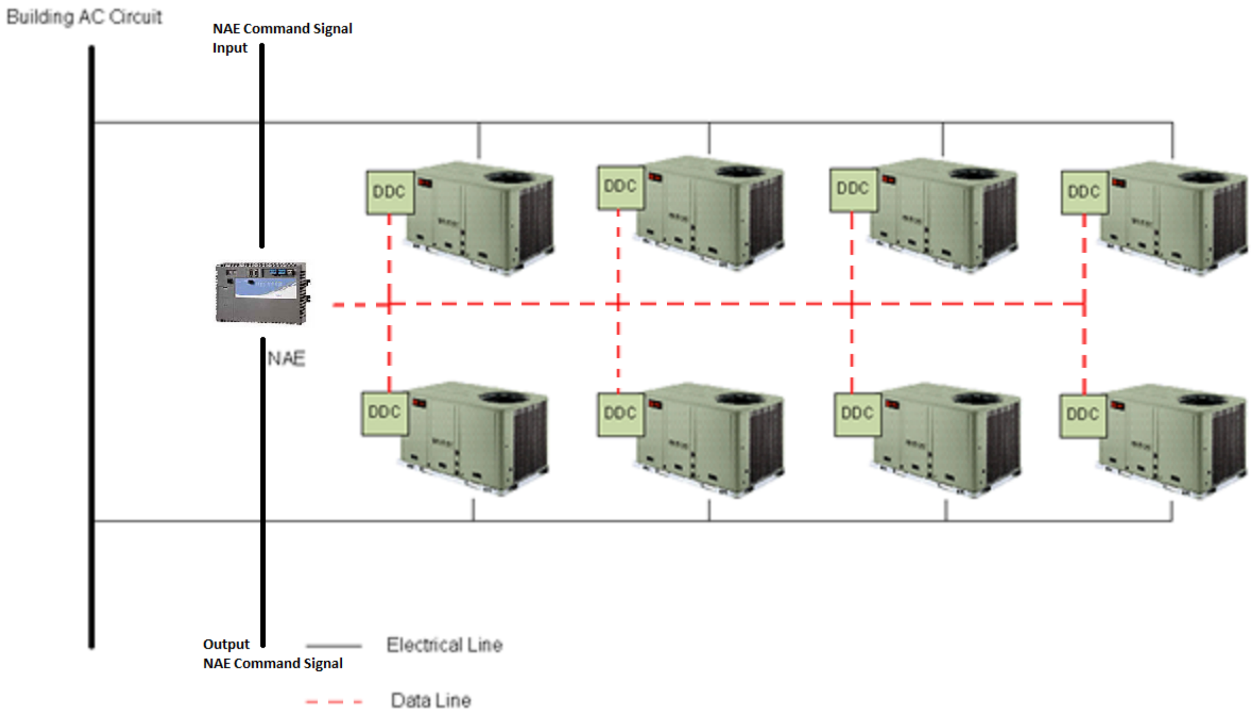


Figure 4-2: Level One Block Diagram of DDC System

Inside the DDC system architecture, each building has one NAE and many DDC controllers. The amount of DDC controllers depend on the size of the building and their placement. In the system, the main electrical power line distributes to each controller in series. Each DDC controller is also connected to a communication/data line that is centrally connected to the NAE. The NAE can receive signals from a technician that is able to manually control each controller. The NAE also can output the status of each controller informing the technician on its status. In order to allow for temporary load shedding schemes to work, the NAE is needed in order to communicate the instructions to each of the DDC controllers.

4.3 Temporary Load Shedding Scenario:

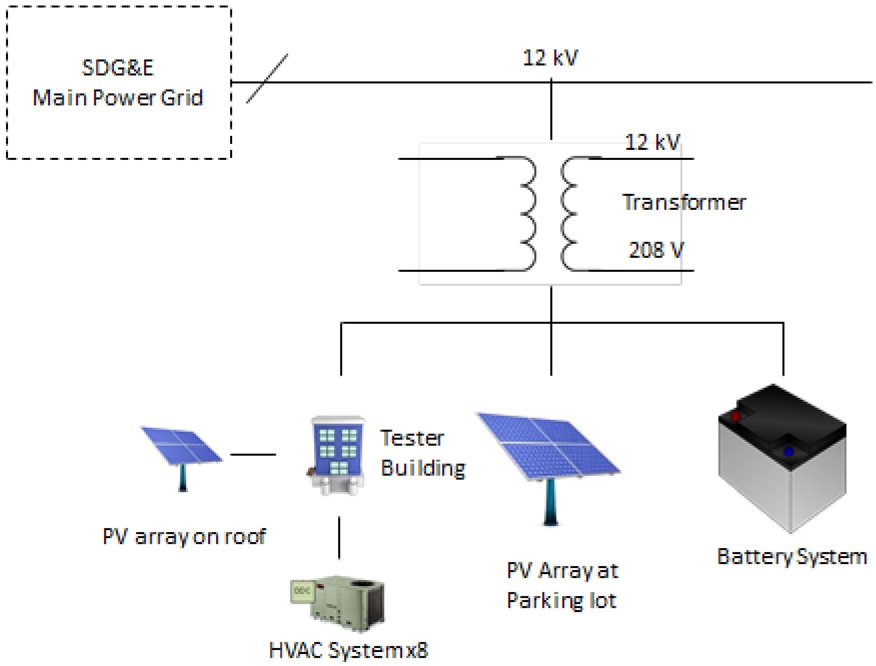


Figure 4-3: Temporary HVAC Load Shedding Scenario

Figure 4-3 represents the scenario in which the temporary HVAC load shedding process could occur. On a normal day, SDG&E would provide power to the building's energy usage. However, if SDG&E experienced some technical difficulties and their power to the building discontinued, then the building will have to rely on the uninterrupted power source of the battery. Once the building is relying on the battery, the only source of input energy from now is the PV array from the parking lot. The rate at which the PV array generates power is not given, along with the energy capacity of the battery. This battery has to now provide enough energy for the tester building to continue its operations from lighting to heating and air conditioning. The building has a couple of PV arrays on the roof that generates power for the building to use. The two biggest energy usages in the tester building are the HVAC system and then the lighting. The project will consist of reducing the HVAC system temporarily order to keep the battery lasting for longer while supplying energy to the building.

Chapter 5: Characterization of Building

Abraxas Energy Consulting wrote an energy efficiency audit report on December 19, 2010 in which the report was meant to provide several potential energy and water saving opportunities. The energy audit report consisted of completing the procedures for a Level 1 and Level 2 energy audit which are defined by ASHRAE's "Procedures for Commercial Building Energy Audits". [2] However, the report also gave valuable information for the heating and cooling systems, the lighting system, and the construction of the building. The construction details of the building are provided below.

1. 32,013 square feet two-story office
    a. First Floor Offices – 25,513 square feet
    b. Workshop – 2,500 square feet
    c. Second Floor Offices – 4,000 square feet
2. Typical # of Occupants: 102
3. General Occupancy: M-F: 0700- 1800
4. Walls – Concrete Block – Tan
5. Windows – Dynamic Glass
6. Roof – Flat Gravel - Grey

The tester building is divided into eight major air-conditioned zones, six of which are heat pumps, and the other two are gas fired Roof Top Package Units (RTPU). There are also four fan coil units which provide a minimal amount of air conditioning to the conference rooms. The fan coil units are typically left off and they are required to be overridden through a thermostat to turn on. For this project, the fan coils are left out due to their negligible effect upon the building's energy usage. Each of the heat pumps and the RTPUs are labeled as AC-1 through AC-8. The first floor plans with the location of any HVAC units are shown in Figure 5-1, while the second floor plans with the HVAC units are shown in Figure 5-2. The actual floor plans are sensitive information, so a general model of the floor was made in order to show the building's dimensions and HVAC locations.

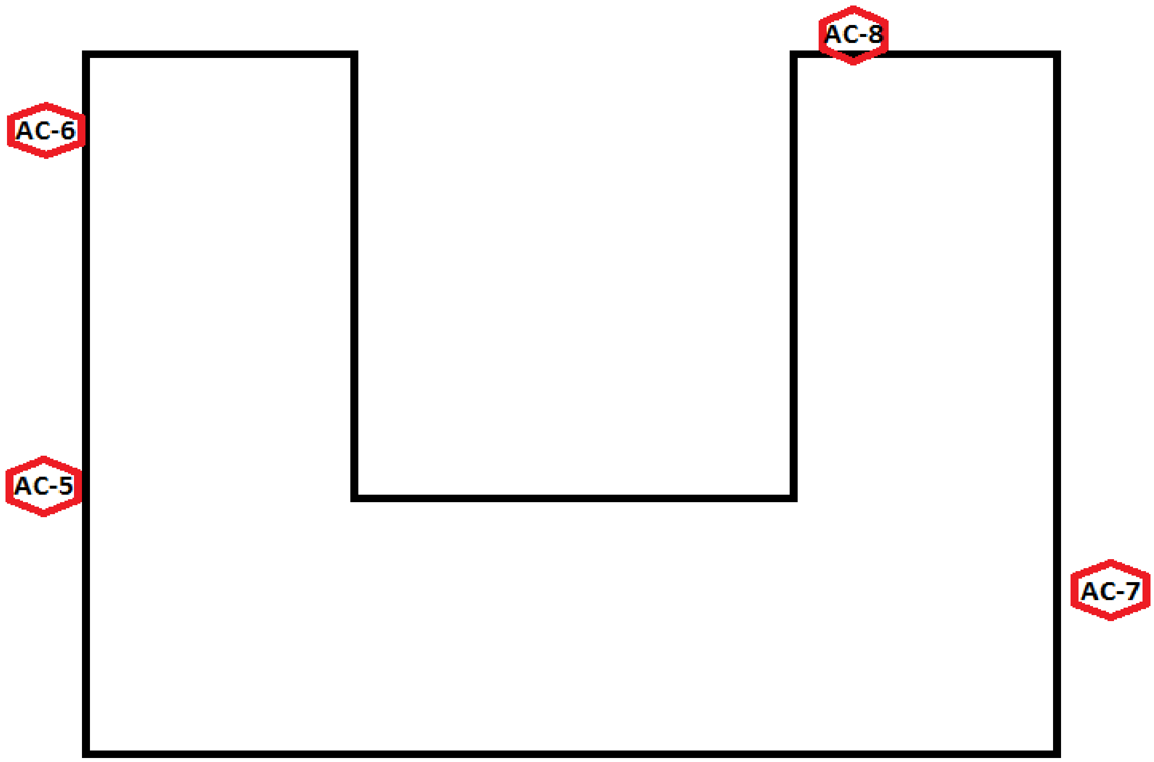


Figure 5-1: First Floor Plans of Tester Building

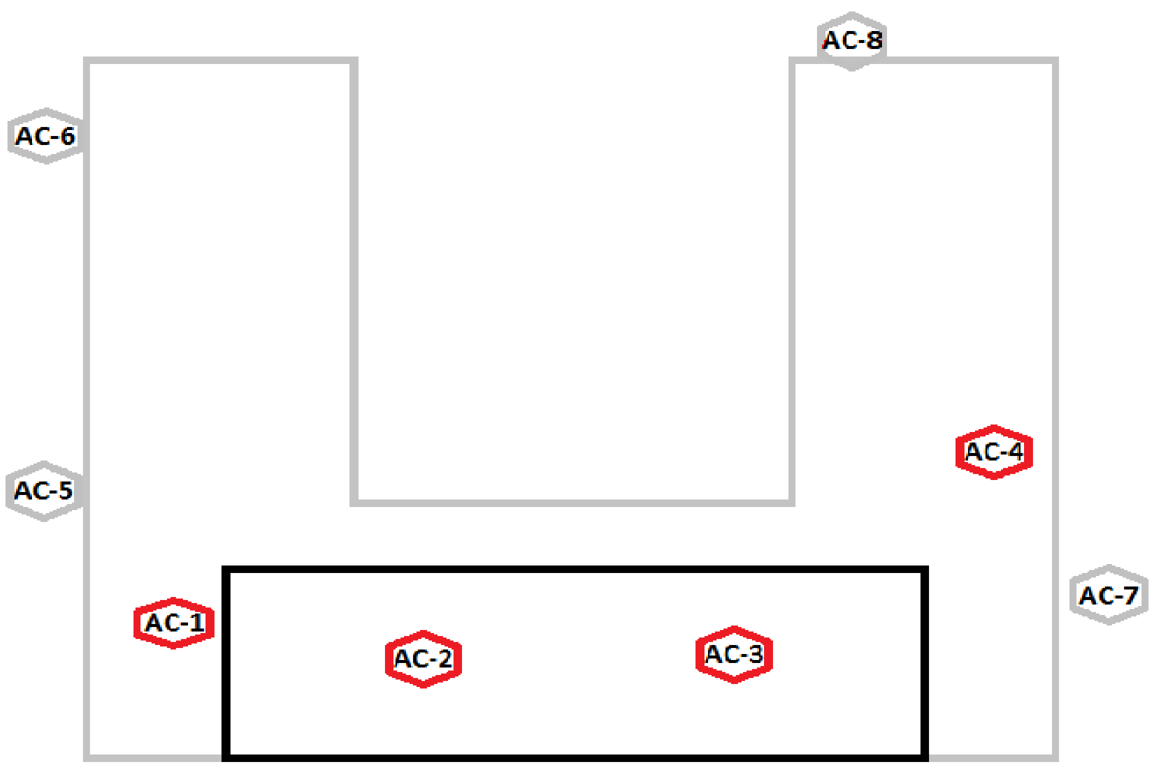


Figure 5-2: Second Floor Plans of Tester Building

5.1 Heat Pumps

In the tester building, there are six heat pumps which provide the primary heating and cooling for the first floor of the building. As of 2010 and cited from Abraxas' Energy Audit, the existing heat pump units are in good condition with the exception of the RUUD unit (AC-8) [2]. With this information, it can be assumed that the rest of the units are fully functional and they aren't limited in their performance. In between the months of September and November of 2013, dynamic glass in the tester building was installed. The dynamic glass uses predictive intelligence control technology in which the glass is always in the optimum state for comfort and performance. Dynamic glass is explained more thoroughly in section 5.4.

5.1.1 AC - 1

The first HVAC unit is located on the southwestern side of the second floor. It is a Carrier Make with the model number of 50HJQ012. Based from the Audit report and the datasheet, it has a cooling capacity of 10 tons and a heating capacity of 114 MBH. It was manufactured during October 2009. Before the installation of the dynamic glass, the VIEW glass company took load measurements from April 5, 2013 till September 3rd, 2013. With this data, I took the data points and plot out the System's Total Net Energy vs Time (Figure 5-3). The delta, the difference between the start and finishing electrical energy usage, during this time period is 3793.6 kWh.

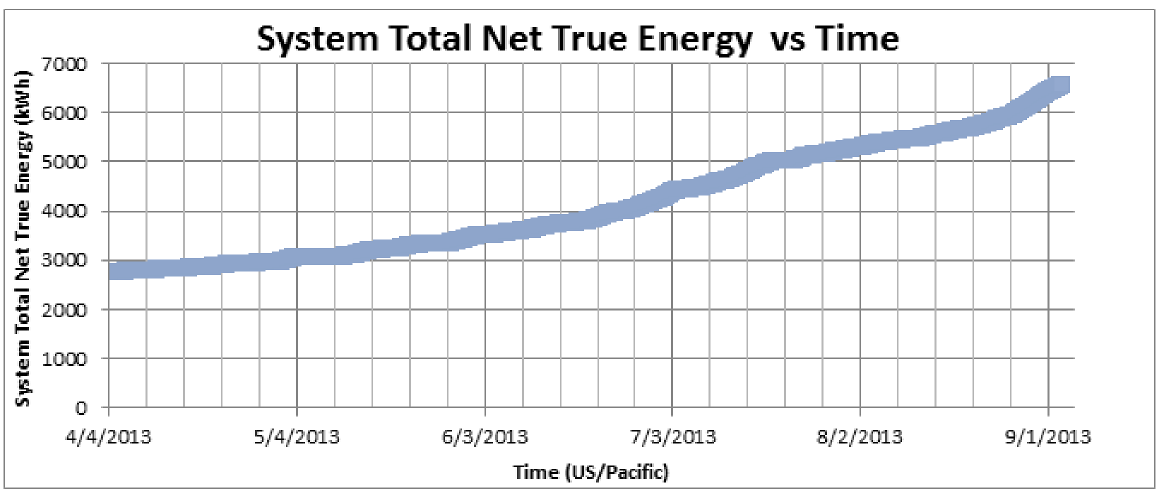


Figure 5-3: System's Total Net Energy vs Time, AC-1, pre-dynamic glass

After the dynamic glass was installed, another set of measurements from November 4th, 2013 till November 22nd, 2013. Here the data points were graphed out as System's Total Net True Energy vs Time (Figure 5-4). The delta during this time period is 25.8 kWh.

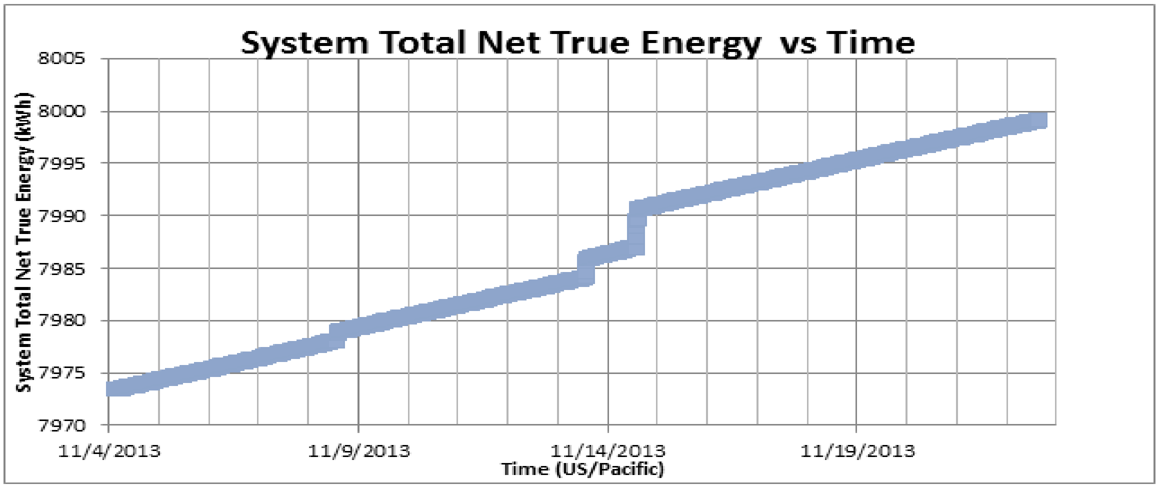


Figure 5-4: System Total Net True Energy vs Time, AC – 1, post-dynamic glass

5.1.2 AC - 4

The second HVAC unit is located on the eastern side on the roof of the first floor. It is a Carrier Make with the model number of 50TCQA04A0A3A0A0A0. It has a cooling capacity of 3 tons and a heating capacity of 36 MBH. It was manufactured during June 2009. Before the installation of the dynamic glass, the VIEW glass company took load measurements from April 5, 2013 till September 3rd, 2013. With this data, I took the data points and plot out the System's Total Net Energy vs Time (Figure 5-5). The delta during this time period is 405.82 kWh.

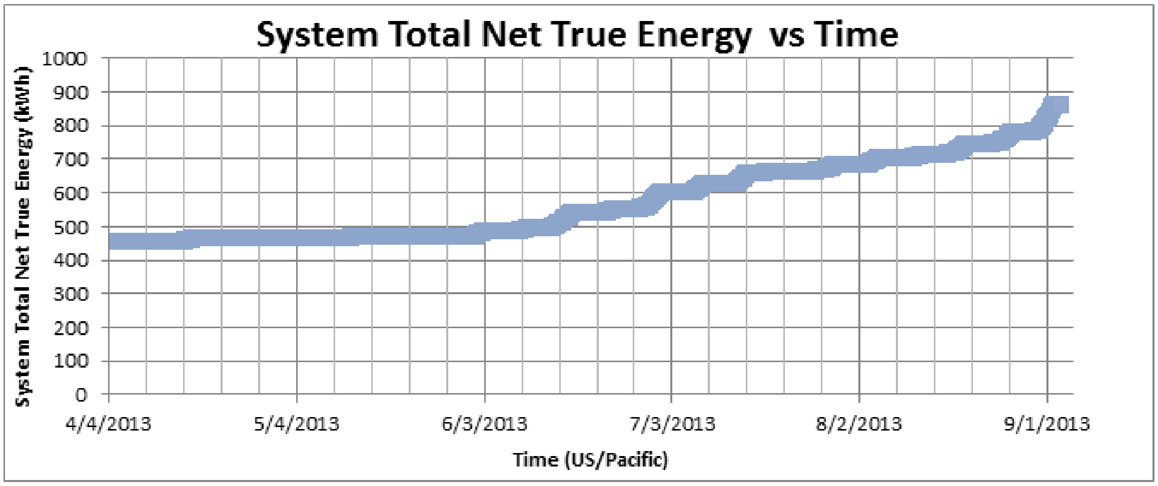


Figure 5-5: System's Total Net Energy vs Time, AC-4, pre-dynamic glass

After the dynamic glass was installed, another set of measurements from November 4th, 2013 till November 22nd, 2013. Here the data points were graphed out as System's Total Net True Energy vs Time (Figure 5-6). The delta during this time period is 74.95 kWh.

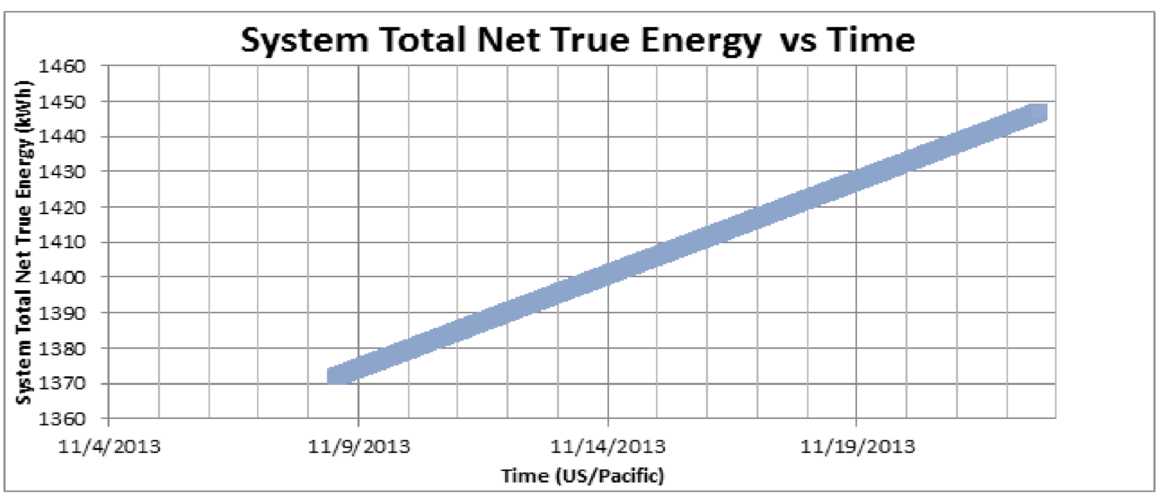


Figure 5-6: System Total Net True Energy vs Time, AC – 4, post-dynamic glass

5.1.3 AC – 5

The AC -5 unit is located on the western side on the ground outside of the first floor. It is a Trane make with the model number of WSC120E3R0A. It has a cooling capacity of 10 tons and a heating capacity of 118 MBH. It was manufactured during November 2009. Before the installation of the dynamic glass, the VIEW glass company took load measurements from April 5, 2013 till September 3rd, 2013. With this data, I took the data points and mapped out the System's Total Net Energy vs Time (Figure 5-7). The delta during this time period is 6907.4 kWh.

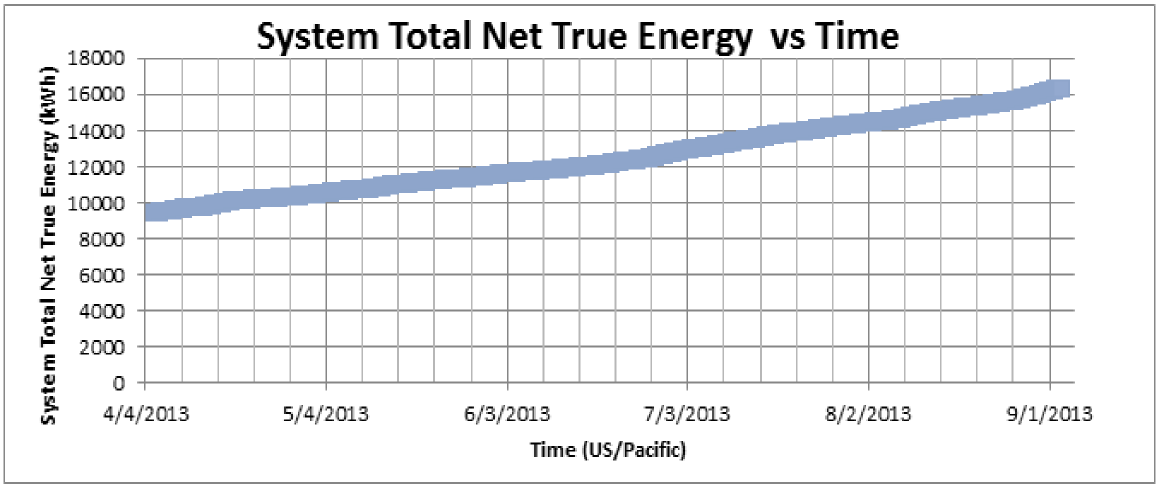


Figure 5-7: System's Total Net Energy vs Time, AC-5, pre-dynamic glass

After the dynamic glass was installed, another set of measurements from November 4th, 2013 till November 22nd, 2013. Here the data points were graphed out as System's Total Net True Energy vs Time (Figure 5-8). The delta during this time period is 616.5 kWh.

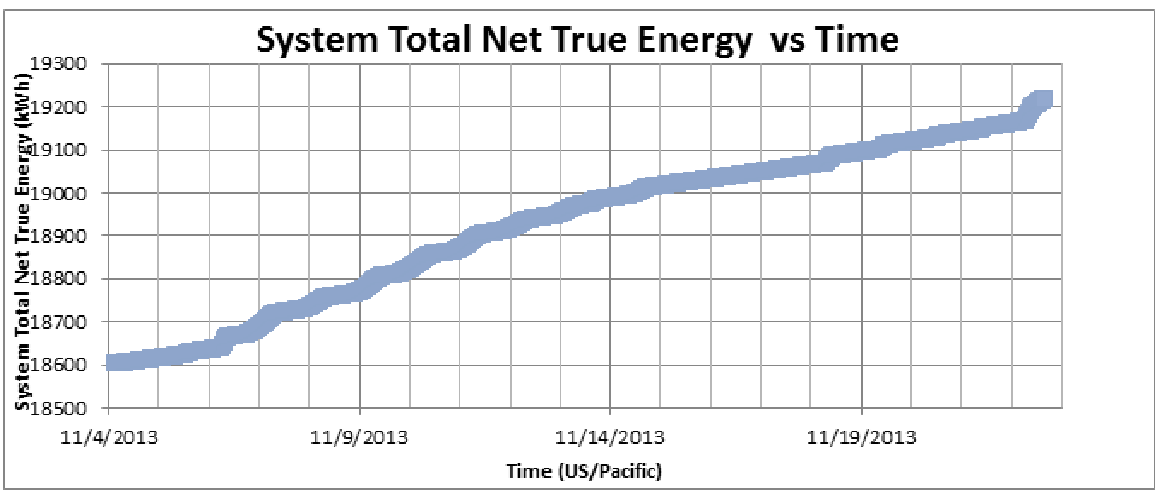


Figure 5-8: System Total Net True Energy vs Time, AC – 5, post-dynamic glass

5.1.4 AC – 6

The AC -6 unit is located on the northwestern side on the ground outside of the first floor. It is a Trane make with the model number of WSC120E3R0A. It has a cooling capacity of 10 tons and a heating capacity of 118 MBH. It was manufactured during October 2009. Before the installation of the dynamic glass, the VIEW glass company took load measurements from April 5, 2013 till September 3rd, 2013. With this data, I took the data points and mapped out the System's Total Net Energy vs Time (Figure 5-9). The delta during this time period is 8730.96 kWh.

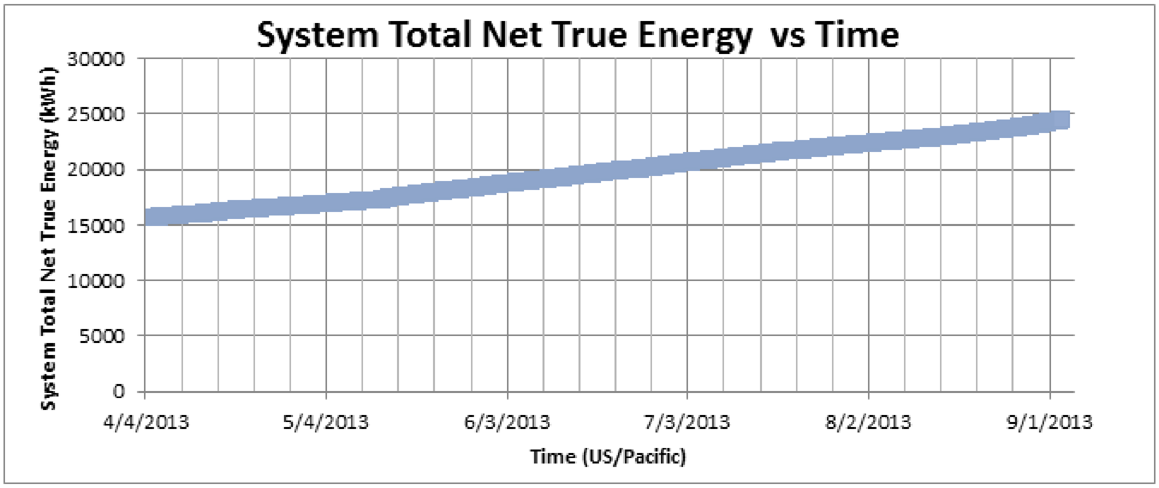


Figure 5-9: System's Total Net Energy vs Time, AC-6, pre-dynamic glass

After the dynamic glass was installed, another set of measurements from November 4th, 2013 till November 22nd, 2013. Here the data points were graphed out as System's Total Net True Energy vs Time (Figure 5-10). The delta during this time period is 739.33 kWh.

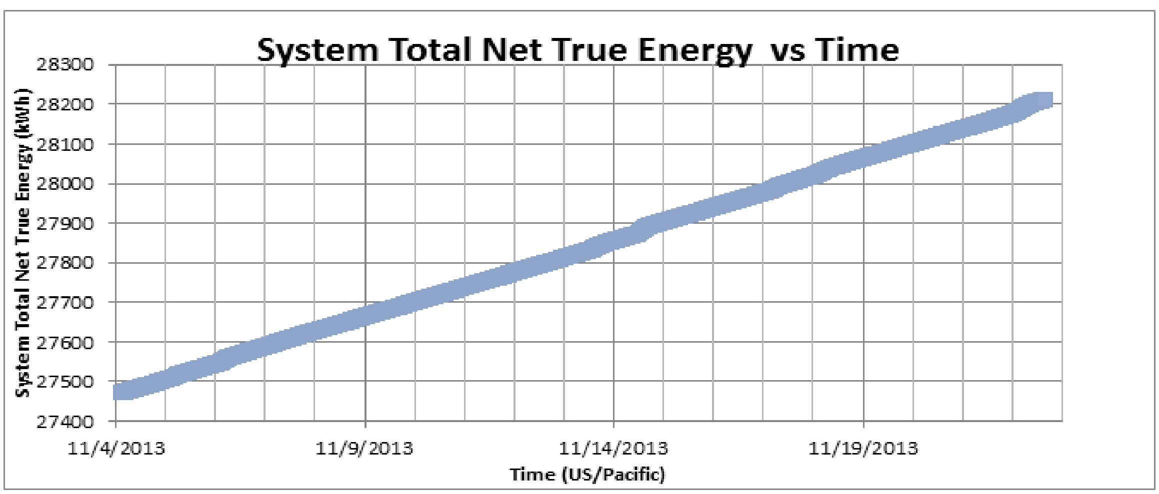


Figure 5-10: System Total Net True Energy vs Time, AC – 6, post-dynamic glass

5.1.5 AC – 7

The AC -7 unit is located on the southeastern side on the ground outside of the first floor. It is a Trane make with the model number of WCH180B300FA. It has a cooling capacity of 15 tons and a heating capacity of 177 MBH. It was manufactured during November 2011. Before the installation of the dynamic glass, the VIEW glass company took load measurements from April 5, 2013 till September 3rd, 2013. With this data, I took the data points and mapped out the System's Total Net Energy vs Time (Figure 5-11). The delta during this time period is 10443.64 kWh.

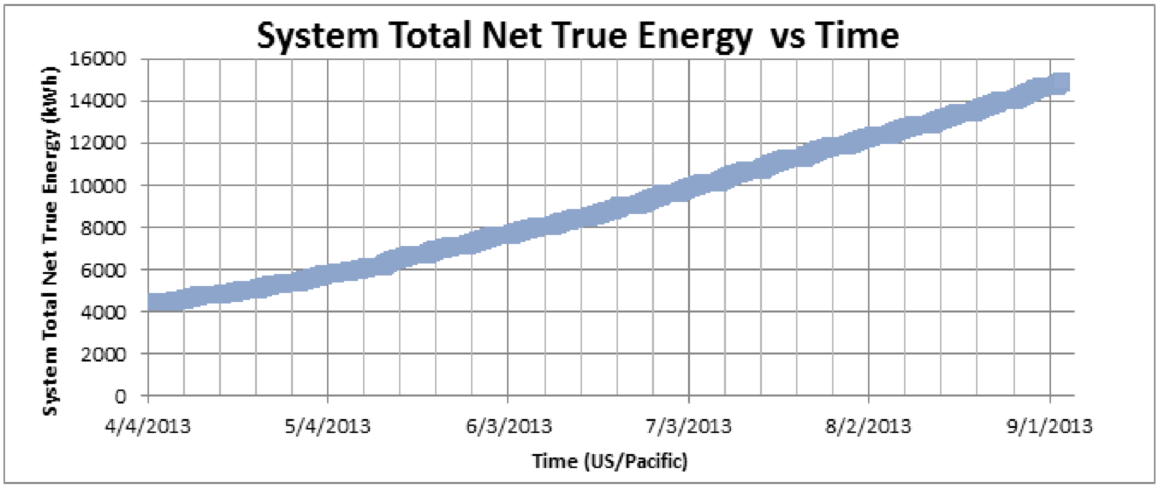


Figure 5-11: System's Total Net Energy vs Time, AC-7, pre-dynamic glass

After the dynamic glass was installed, another set of measurements from November 4th, 2013 till November 22nd, 2013. Here the data points were graphed out as System's Total Net True Energy vs Time (Figure 5-12). The delta during this time period is 793.56 kWh.

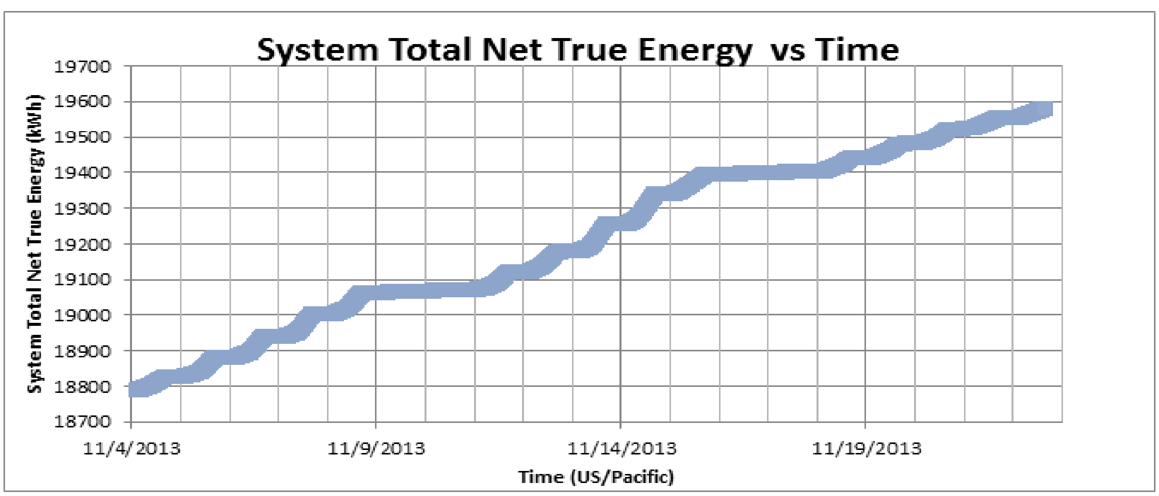


Figure 5-12: System Total Net True Energy vs Time, AC – 7, post-dynamic glass

5.1.6 AC – 8

The AC -8 unit is located on the northeastern side on the ground outside of the first floor. It is a RUUD make with the model number of UJKA-A060CL. It has a cooling capacity of 5 tons and a heating capacity of 59 MBH. It was manufactured during November 1998. Before the installation of the dynamic glass, the VIEW glass company took load measurements from April 5, 2013 till September 3rd, 2013. With this data I took the data points and mapped out the System's Total Net Energy vs Time (Figure 5-13). The delta during this time period is 2902.4 kWh.

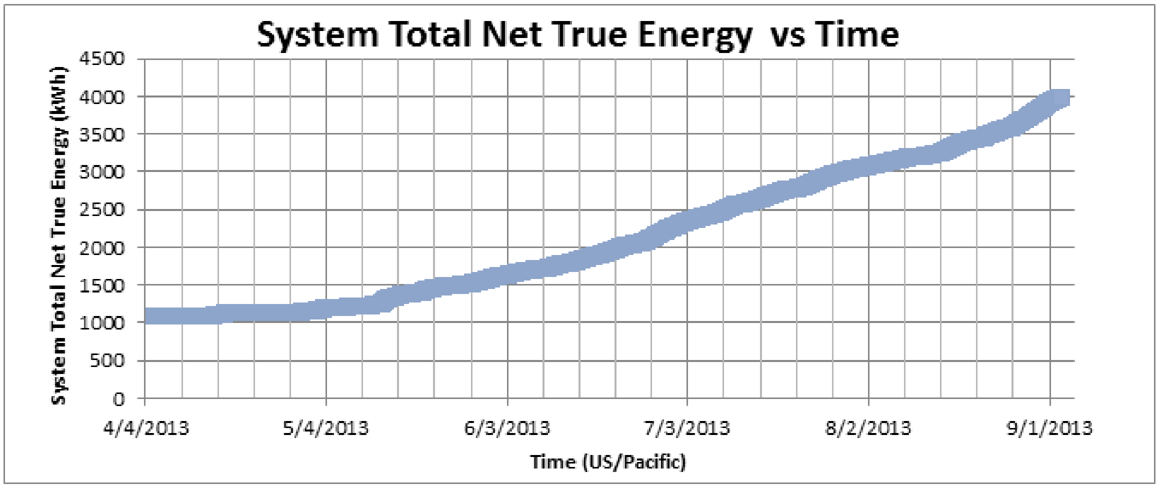


Figure 5-13: System's Total Net Energy vs Time, AC-8, pre-dynamic glass

After the dynamic glass was installed, another set of measurements from November 4th, 2013 till November 22nd, 2013. Here the data points were graphed out as System's Total Net True Energy vs Time (Figure 5-14). The delta during this time period is 45.4 kWh.

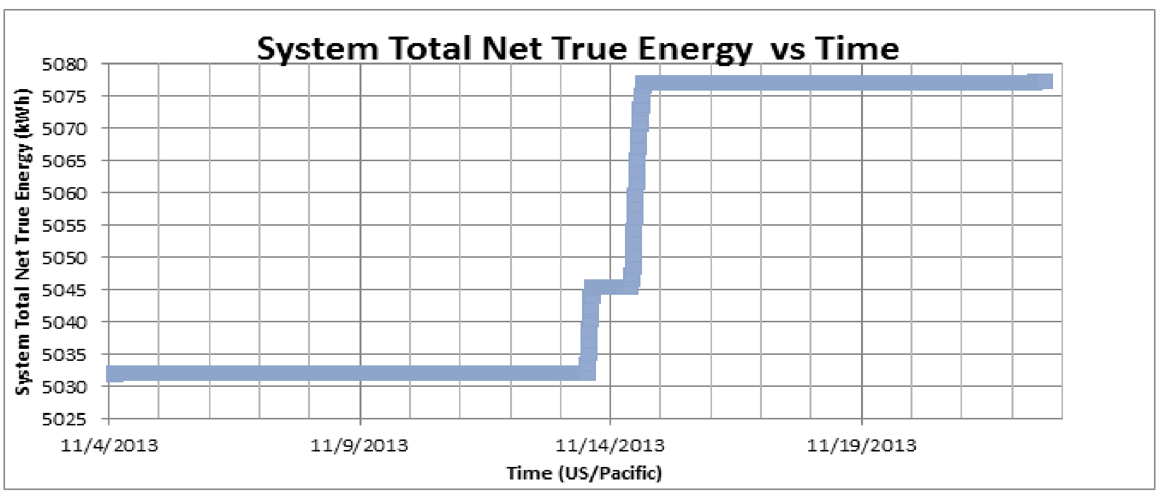


Figure 5-14: System Total Net True Energy vs Time, AC – 8, post-dynamic glass

5.2 Roof Top Units

The last two HVAC units, AC-2 and AC-3, are located on top of the second floor roof. They are both Carrier makes and their models are the Weathermaster series. However, each serial number is unknown. The heating is provided by gas-fired furnaces, and the cooling is provided by direct expansion (DX) coils. They both have broken economizers and damaged coils, which will reduce the performance of each unit. Their status was labeled in the audit report as shown in Table II.

TABLE II

ROOFTOP UNITS CLASSIFICATION

Unit ID	Location	Make	Model #	Serial #	Type	Clg Capacity (Btu/hr)	Htg Capacity	Control	Notes	Date Mfg
AC-2	2nd floor roof	Carrier	Weather-master	Unknown	RTPU	Unknown	Unknown	EMS	Broken economizer; dirty damaged coils; gas heat	Unknown
AC-3	2nd floor roof	Carrier	Weather-master	Unknown	RTPU	Unknown	Unknown	EMS	Broken economizer; dirty damaged coils; booster fan on return air; gas heat	Unknown

After finding the Carrier Weathermaster datasheet, comparative analysis was used to determine which of the previous HVAC units modeled the AC-2 and AC-3 the closest. Comparing the System total net true energy of AC-2 to the rest of the HVAC units came up with AC-2 being the most similar to AC-5, while AC-3 was the most similar to AC-6. Both AC-5 and AC-6 have a cooling capacity of 10 tons. Using the estimated cooling capacity, there were two models, D11 and D12 of the weathermaster series, which matched that criteria. Since AC-2 output slightly less than AC-3, it can be assumed that AC-2 would be a D11 unit and the AC-3 would be a D-12 unit. The classification of the weathermaster series is shown below in Table III.

TABLE III

CARRIER WEATHERMASTER CLASSIFICATION

Table 3 – AHRI COOLING RATING TABLE 2-STAGE COOLING

UNIT	COOLING STAGES	NOM. CAPACITY (TONS)	NET COOLING CAPACITY (MBH)	TOTAL POWER (kW)	EER	IEER WITH SINGLE SPEED INDOOR MOTOR	IEER WITH 2-SPEED INDOOR MOTOR
D08	2	7.5	89.0	7.4	12.0	13.0	13.8
D09	2	8.5	97.0	8.1	12.0	13.0	13.8
D11	2	10.0	111.0	9.3	12.0	12.6	14.3
D12	2	10.0	115.0	10.0	11.5	12.0	12.4
D14	2	12.5	146.0	11.9	12.2	13.0	13.9

5.2.1 AC - 2

Before the installation of the dynamic glass, the VIEW glass company took load measurements from April 5, 2013 till September 3rd, 2013. With this data, I took the data points and mapped out the System's Total Net Energy vs Time (Figure 5-15). The delta during this time period is 8612.7 kWh.

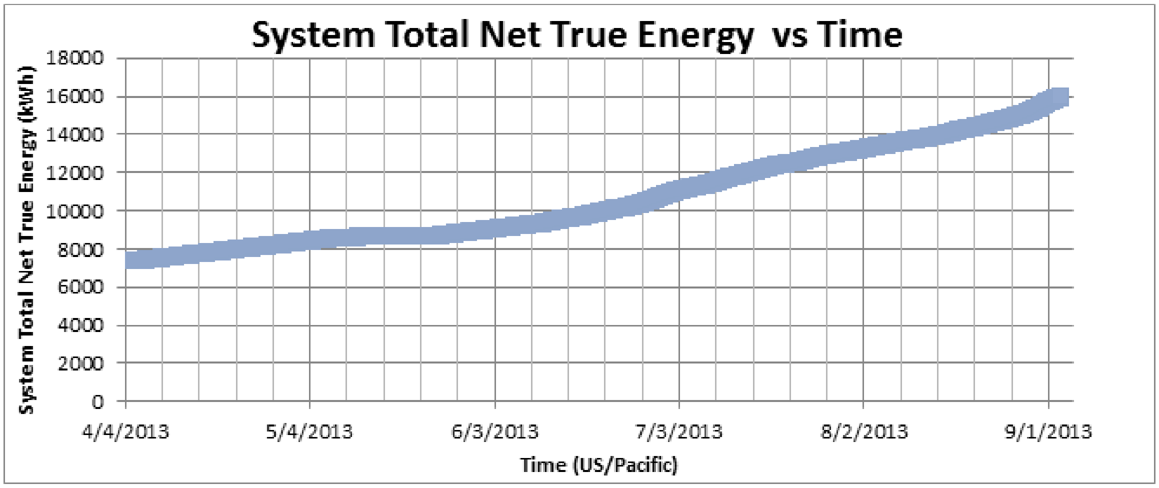


Figure 5-15: System Total Net True Energy vs Time, AC – 2, pre-dynamic glass

After the dynamic glass was installed, another set of measurements from November 4th, 2013 till November 22nd, 2013. Here the data points were graphed out as System's Total Net True Energy vs Time (Figure 5-16). The delta during this time period is 787.4 kWh.

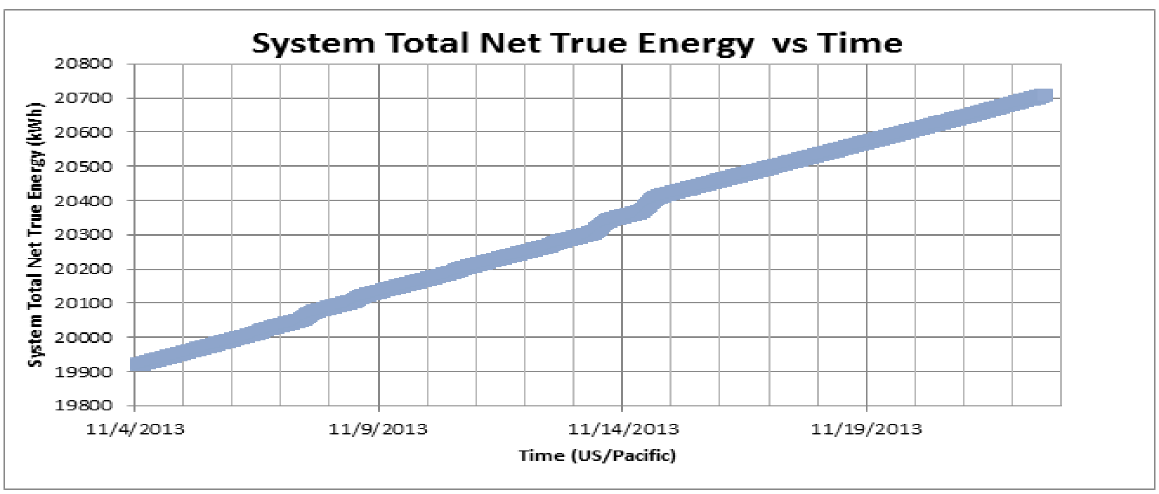


Figure 5-16: System Total Net True Energy vs Time, AC – 2, post-dynamic glass

5.2.2 AC - 3

Before the installation of the dynamic glass, the VIEW glass company took load measurements from April 5, 2013 till September 3rd, 2013. With this data, I took the data points and mapped out the System's Total Net Energy vs Time (Figure 5-17). The delta during this period is 12954.9 kWh.

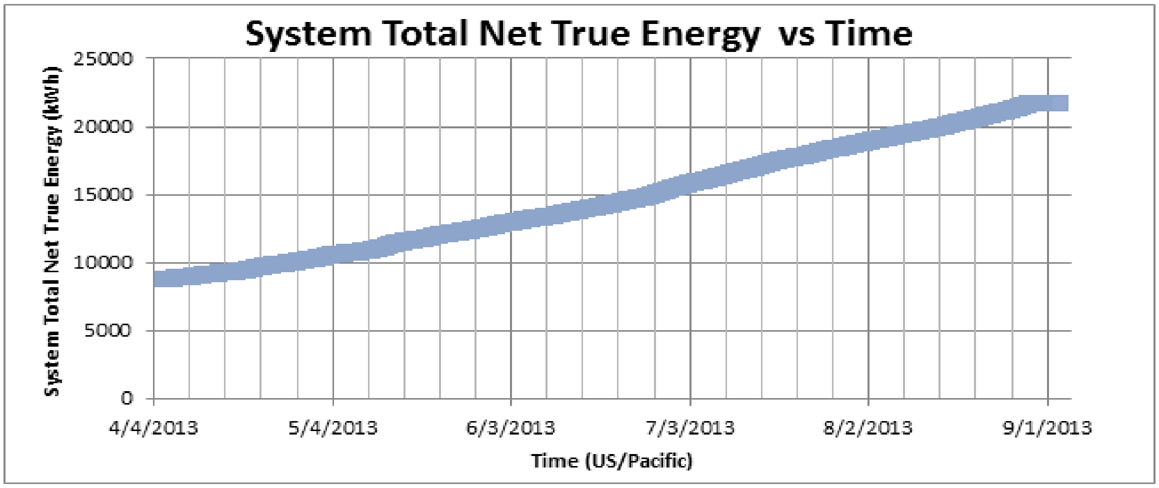


Figure 5-17: System Total Net True Energy vs Time, AC – 3, pre-dynamic glass

After the dynamic glass was installed, another set of measurements from November 4th, 2013 till November 22nd, 2013. Here the data points were graphed out as System's Total Net True Energy vs Time (Figure 5-18). The delta during this time period is 816.6 kWh.

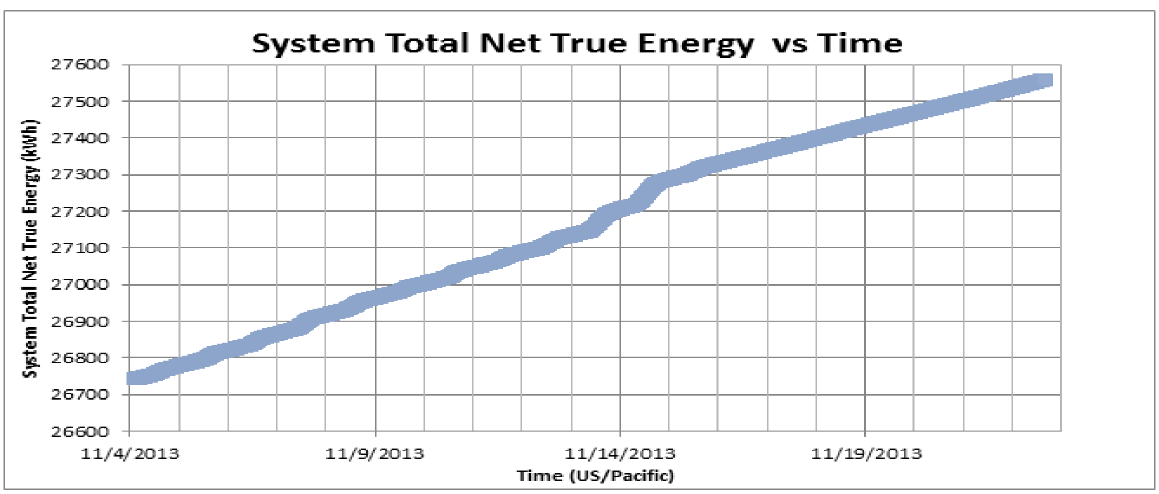


Figure 5-18: System Total Net True Energy vs Time, AC – 3, post-dynamic glass

5.3 Fan Coil Units

There are four outdoor Fan Coil Units (FC), and each with a dedicated Condensing Unit (CU). These units are each controlled by programmable thermostats. Three of these serve the three conference rooms and the other FC services the GIS office/server room. These units are typically in the unoccupied mode, but once occupants want to use the room, they press the override button to provide cooling for a limited time. The GIS office is set in an automated setting in which it cools the room continually.

5.3.1 Server Room

Before the installation of the dynamic glass, the VIEW glass company took load measurements from April 5, 2013 till September 3rd, 2013. With this data, I took the data points and mapped out the System's Total Net Energy vs Time (Figure 5-19). The delta during this time period is 2768.57 kWh.

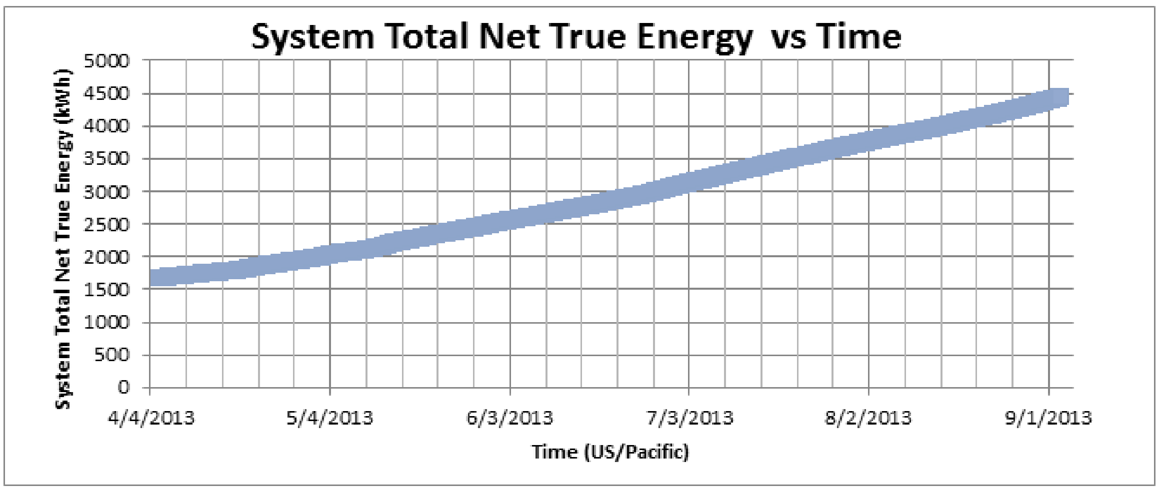


Figure 5-19: System Total Net True Energy vs Time, Server Room, pre-dynamic glass

After the dynamic glass was installed, another set of measurements from November 4th, 2013 till November 22nd, 2013. Here the data points were graphed out as System's Total Net True Energy vs Time (Figure 5-20). The delta during this time period is 217.79 kWh.

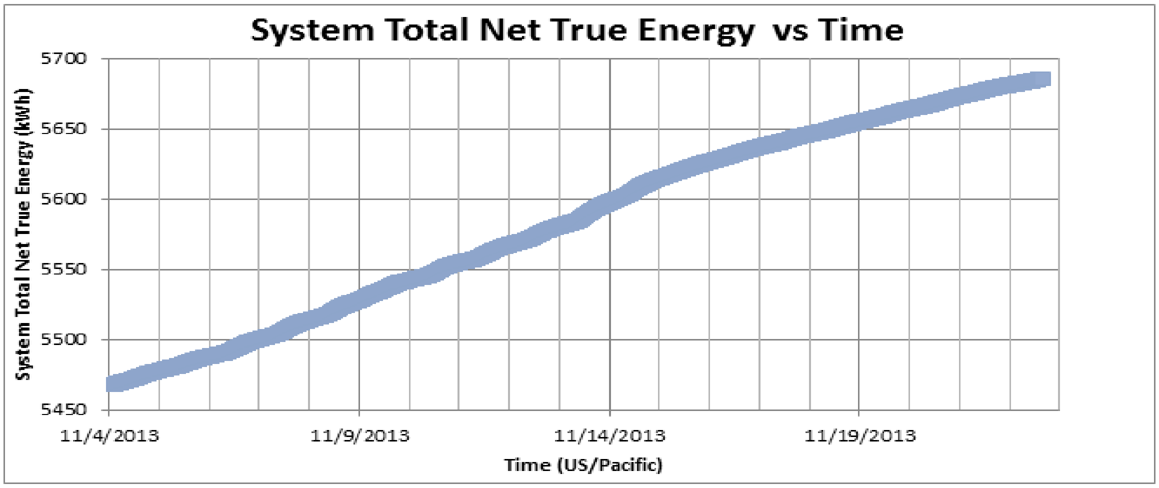


Figure 5-20: System Total Net True Energy vs Time, Server Room, post-dynamic glass

5.3.2 FC – 1,2,3

In eQuest, there were limitations in the software. The program isn't able to model a smaller HVAC unit like the fan coils accurately. Since the fan coil units are also not used that often, it will be left out of the characterization of the building along with the simulation portion.

5.4 Dynamic Glass

One of the major aspects of the building is the addition of dynamic glass. The glass was installed by a company called VIEW glass. The window uses predictive intelligence control technology in which the glass is always in the optimum state for comfort and performance. The tint will adjust according to location, space type, weather, and user preference. During a clear day during summer there are high sun angles, no direct glare, so then the glass will rarely by at 4% (darkest tint). The glass state is determined by the radiation which is measured by a photo sensor. During a clear day in winter, there are low sun angles, a direct glare, and the glass will most likely be at a 4%. Right now there is an automatic control, in which from sunrise to sunset, the intelligence is active, but from sunset to sunrise, intelligence is not active due to the building being unoccupied. On the windows are wall switches in which the user can override the glass to any of the 4 states (4%, 20%, 40%, 60%). Two picture examples are shown below in which they show how the glass states work for the first and second floor in Figure 5-21 and 5-22.

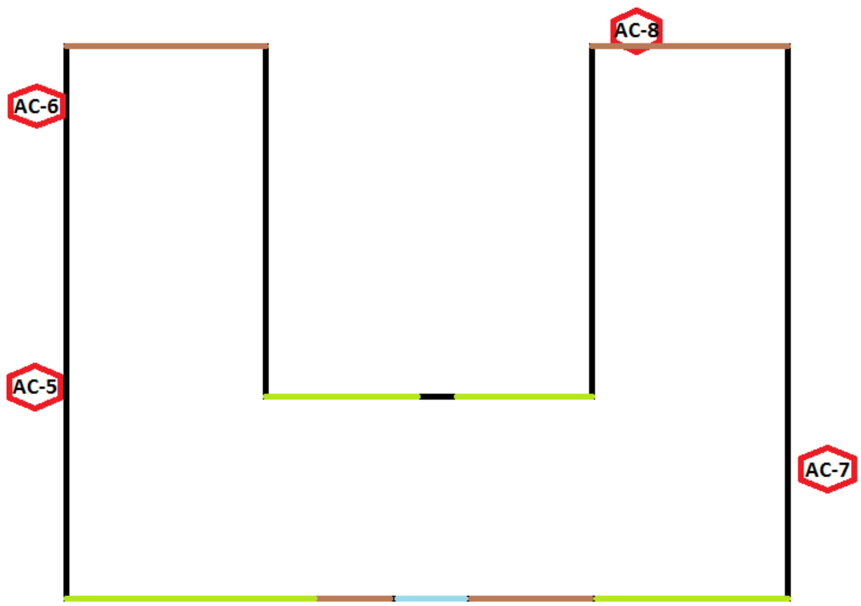


Figure 5-21: First Floor Dynamic Glass Operations

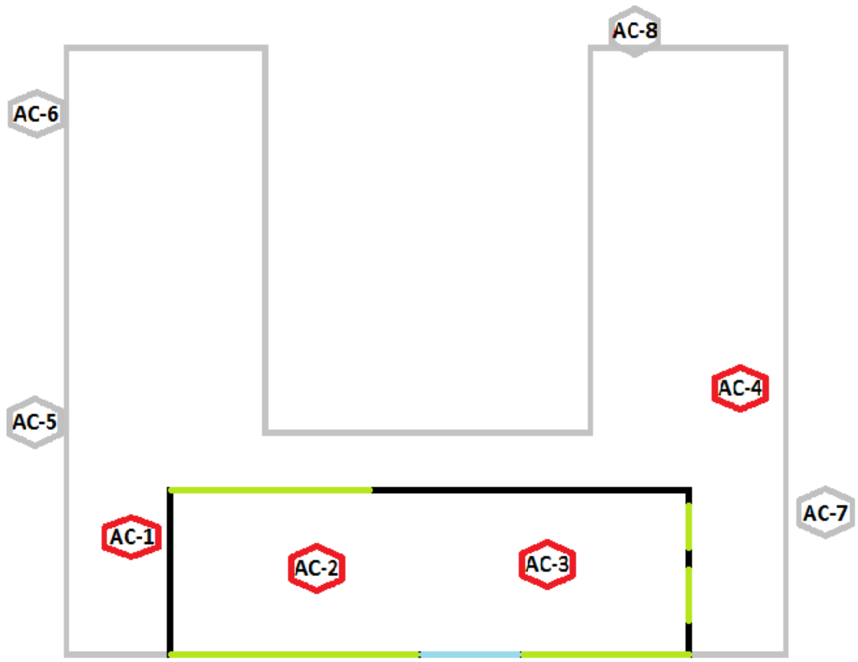


Figure 5-22: Second Floor Dynamic Glass Operations

TABLE IV
DYNAMIC GLASS LEGEND

Space	Glare Threshold (Sun Penetration Depth)	Glass State
	< 2ft	State that maximizes daylight while balancing heat gain
	> 2 ft	Dynamic 4
	< 5ft	State that maximizes daylight while balancing heat gain
	> 5ft	Dynamic 4
	< 10 ft	State that maximizes daylight while balancing heat gain
	>10 ft	Dynamic 4

5.5 Lighting

During the Abraxas' Energy Audit, they were able to label how many light fixtures there was, the space type they were located, and the energy usage of each fixture which is shown below in Table V [2]. The interior lighting is almost entirely controlled by manual switches, with the exception of a few occupancy sensors. This allows for a lighting control process that could cut down on energy usage. The exact whereabouts of the light fixtures were not provided.

TABLE V
LIGHTING INVENTORY

Space Type	Fixture Type	Qty	Watts per Fixture	kW
Breakroom	1L 32W T8 U-tube w/ Elec. Ballast	1	31	0.0
Breakroom	2L 32W T8 w/ Elec. Ballast	3	58	0.2
Conference Room	2L 20W LED	2	40	0.1
Conference Room	2L 32W T8 U-tube w/ Elec. Ballast	12	58	0.7
Conference Room	2L 32W T8 w/ Elec. Ballast	20	58	1.2
Corridor	2L 32W T8 w/ Elec. Ballast	24	58	1.4
Corridor	2L 32W T8 U-tube w/ Elec. Ballast	16	58	0.9
Lobby	2L 32W T8 U-tube w/ Elec. Ballast	5	58	0.3
Mechanical Room	2L 32W T8 w/ Elec. Ballast	3	58	0.2
Open Office	1L 32W T8 w/ Elec. Ballast	43	31	1.3
Open Office	32W T8 U-tube w/ Elec. Ballast	23	58	1.3
Open Office	2L 32W T8 w/ Elec. Ballast	124	58	7.2
Private Office	2L 32W T8 w/ Elec. Ballast	31	58	1.8
Private Office	2L 32W T8 U-tube w/ Elec. Ballast	34	58	2.0
Restroom	2L 32W T8 w/ Elec. Ballast	6	58	0.3
Restroom	2L 15W CFL	4	31	0.1
Restroom	1L 107W Incandescent	1	60	0.1
Restroom	2L 32W T8 U-tube w/ Elec. Ballast	4	58	0.2
Shop	2L 32W T8 w/ Elec. Ballast	39	58	2.3
Storage	2L 32W T8 w/ Elec. Ballast	8	58	0.5
Storage	2L 32W T8 U-tube w/ Elec. Ballast	5	58	0.3

Chapter 6: Setting Up the Building's Simulator

Once the characterization of the building is complete, the characteristics are input into eQuest. More information about the software program can be seen in Appendix A, where the simulation basics are described. The building is created using the Building Creation Wizard in eQuest. Any characteristics of the building that weren't previously given were filled in by the default values given by eQuest.

6.1 Building Shell

The tester building is a horseshoe-shaped building with concrete block walls and a flat gravel roof. The second floor is rectangular shaped and positioned in the center of the North-South axis. In the simulation, the first floor dimensions to 24,965 square feet and the second floor to 4,000 square feet. Figure 6-1 shows the simulated building shell generated through eQuest.

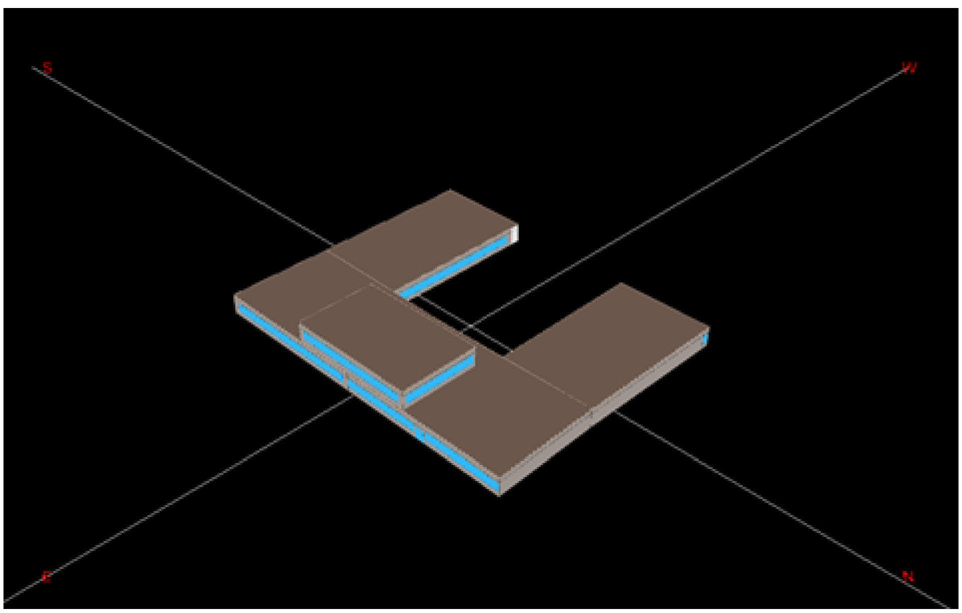


Figure 6-1: Simulated Building Shell

6.2 HVAC Zoning

Using the building shell's dimensions, the HVAC zones are placed with respect to their heating/cooling size and the actual HVAC unit placement. The larger HVAC units, AC-5 and AC-7, take the most amount of area on the first floor. On the second floor, AC-2 and AC-3, took equally the same amount of space to air condition. The small notch of no air conditioning on the second floor is due to a limitation in the eQuest software that wouldn't allow the HVAC zoning to completely fill in the building shell.

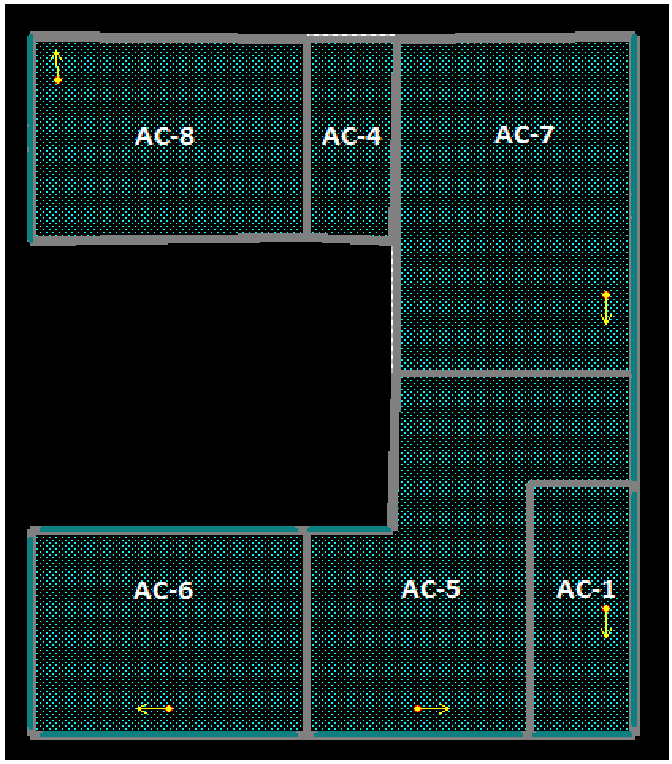


Figure 6-2: HVAC Zoning of the First Floor

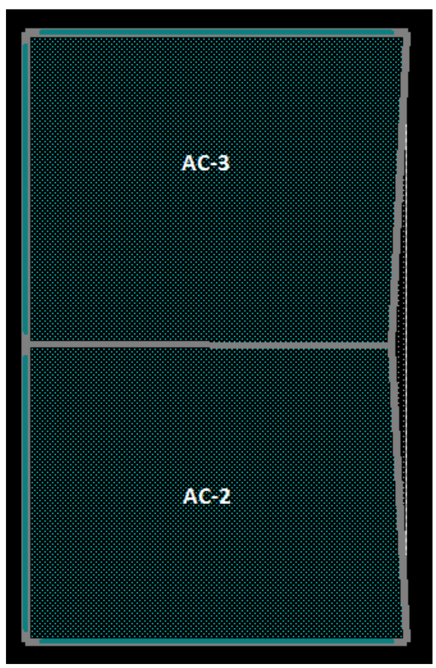


Figure 6-3: HVAC Zoning of the Second Floor

6.3 Fan Schedule

The fans of the building are scheduled to turn on an hour before people start work in the building and scheduled to turn off an hour after people leave work. Figure 6-4 shows the fan schedule for the building during normal occupational hours.

Type: On/Off Flag

Hourly Values

Mdnt - 1:	0	8-9 am:	1	4-5 pm:	1
1-2 am:	0	9-10 am:	1	5-6 pm:	1
2-3 am:	0	10-11 am:	1	6-7 pm:	1
3-4 am:	0	11-noon:	1	7-8 pm:	1
4-5 am:	0	noon-1:	1	8-9 pm:	1
5-6 am:	0	1-2 pm:	1	9-10 pm:	0
6-7 am:	1	2-3 pm:	1	10-11 pm:	0
7-8 am:	1	3-4 pm:	1	11-Mdnt:	0

Figure 6-4: Standard Fan Schedule

6.4 Occupancy Schedule

The occupancy of the building has a major impact on how hard the HVAC units need to work. Using the preset values from eQuest, Figure 6-5 shows the following ratio of how occupied the building is set with 1 referring to max occupancy the building can hold.

Type: Fraction

Hourly Values

Mdnt - 1:	0.0000	ratio	8-9 am:	0.8953	ratio	4-5 pm:	0.8434	ratio
1-2 am:	0.0000	ratio	9-10 am:	0.8811	ratio	5-6 pm:	0.6624	ratio
2-3 am:	0.0000	ratio	10-11 am:	0.7491	ratio	6-7 pm:	0.3048	ratio
3-4 am:	0.0000	ratio	11-noon:	0.5417	ratio	7-8 pm:	0.1229	ratio
4-5 am:	0.0120	ratio	noon-1:	0.5493	ratio	8-9 pm:	0.0990	ratio
5-6 am:	0.1601	ratio	1-2 pm:	0.7869	ratio	9-10 pm:	0.0881	ratio
6-7 am:	0.6373	ratio	2-3 pm:	0.8887	ratio	10-11 pm:	0.0305	ratio
7-8 am:	0.8481	ratio	3-4 pm:	0.8943	ratio	11-Mdnt:	0.0033	ratio

Figure 6-5: Standard Occupancy Schedule

6.5 Temperature schedule

Regularly, the temperature set points are 76°F for cooling, and 68°F for heating. As shown below in Figure 6-6, these set points are within the two boxes which represent the "comfort box". The comfort box shows the temperature range with respect to humidity of what would be comfortable for a human being. In the temporary load shedding, the temperature set points will be widened which will push the comfort levels boundaries. Figure 6-7 shows the standard cooling temperature schedule throughout the day, while Figure 6-8 shows the heating temperature schedule. Each HVAC unit's temperature set points with supply air temperature and design flow is shown below in Figure 6-9.

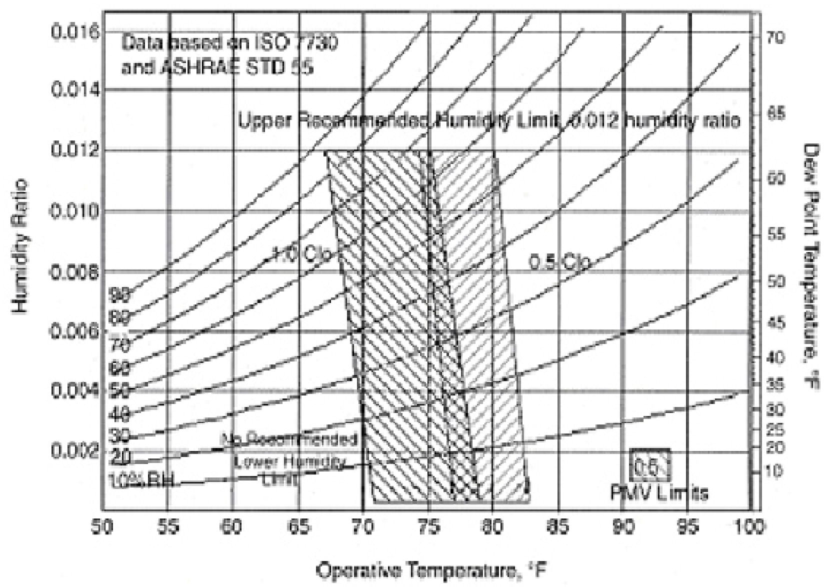
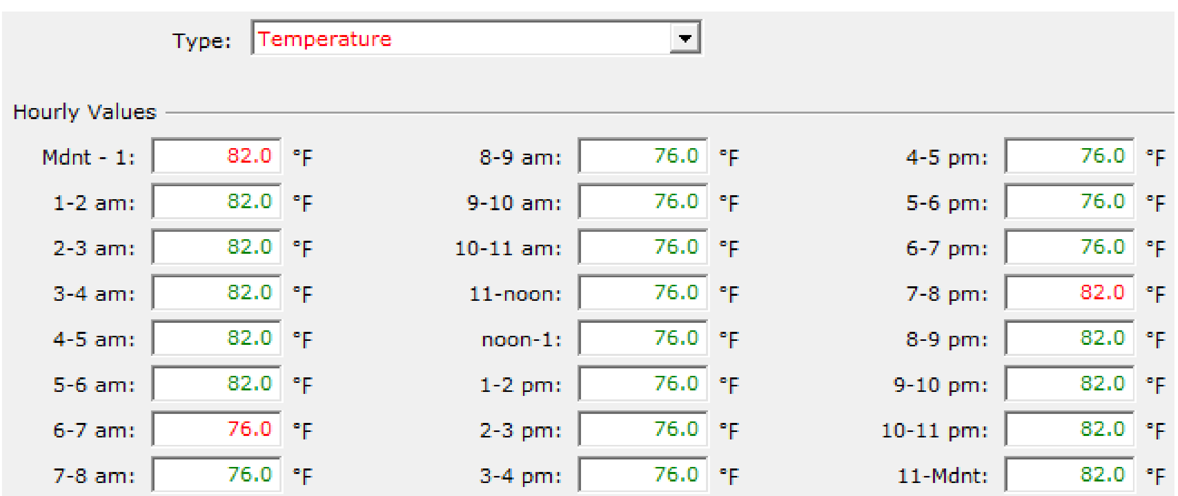


Figure 6-6: ASHRAE Humidity vs Temperature



Type: Temperature

Hourly Values

Mdnt - 1:	82.0	°F	8-9 am:	76.0	°F	4-5 pm:	76.0	°F
1-2 am:	82.0	°F	9-10 am:	76.0	°F	5-6 pm:	76.0	°F
2-3 am:	82.0	°F	10-11 am:	76.0	°F	6-7 pm:	76.0	°F
3-4 am:	82.0	°F	11-noon:	76.0	°F	7-8 pm:	82.0	°F
4-5 am:	82.0	°F	noon-1:	76.0	°F	8-9 pm:	82.0	°F
5-6 am:	82.0	°F	1-2 pm:	76.0	°F	9-10 pm:	82.0	°F
6-7 am:	76.0	°F	2-3 pm:	76.0	°F	10-11 pm:	82.0	°F
7-8 am:	76.0	°F	3-4 pm:	76.0	°F	11-Mdnt:	82.0	°F

Figure 6-7: Standard Cooling Temperature Schedule

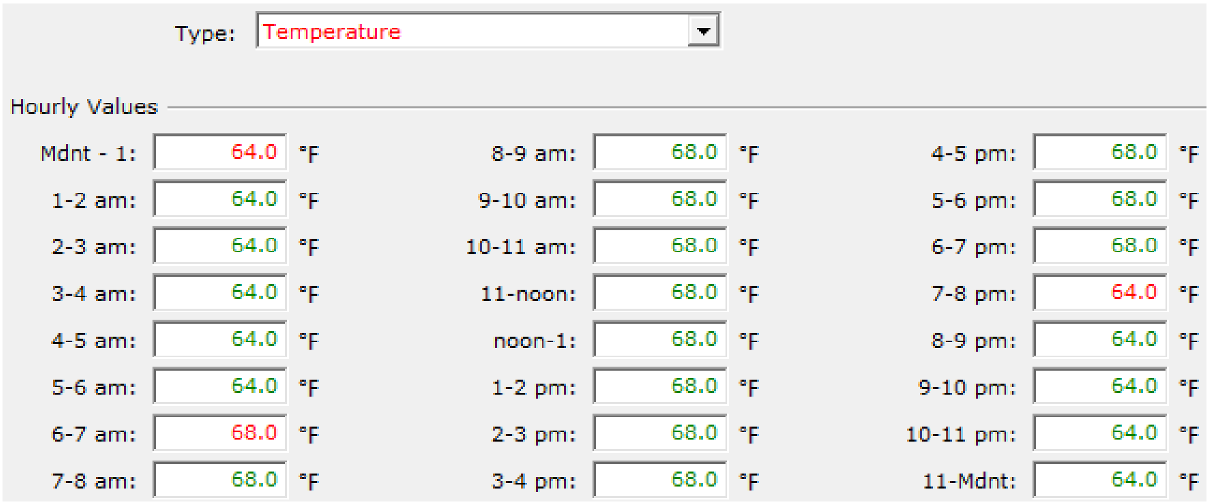


Figure 6-8: Standard Heating Temperature Schedule

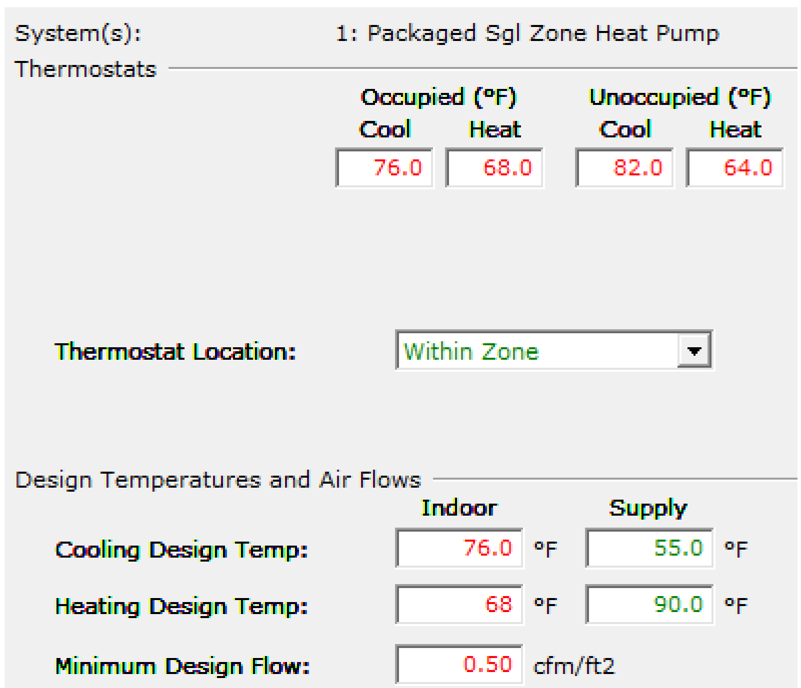


Figure 6-9: Standard HVAC Unit Temperature Set Points

6.6 Initial Simulations

Once the simulation was set up, the initial energy usage simulations are developed. The simulator shows that the building currently uses 201.69 kWh annually as shown in the plot below in Figure 6-10. The hourly intervals are set up with 12 major gridlines which represent each month. The initial electrical energy usage also shows a trend line that represents the averaged electrical usage throughout the year. This shows that during the summer, the electrical usage is lower than usual and then during fall, the electrical usage increases.

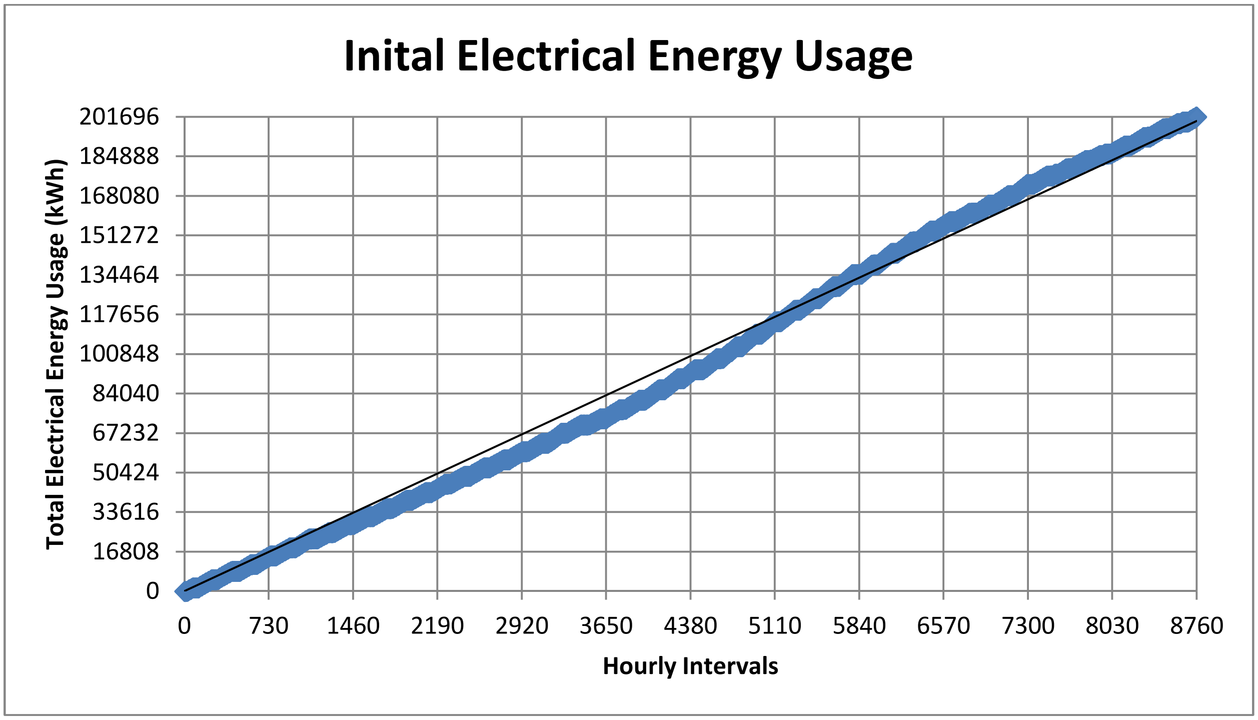


Figure 6-10: Initial Electrical Energy Usage

Along with the hourly load intervals, eQuest plots out different criterion and its load usage per month. One notable load usage is the increased amount of space cooling during the summer months as shown in Figure 6-11. The space cooling becomes one of the most energy consuming especially during the months of July-September. Space heating during the winter months uses little electrical consumption but more gas consumption. The other noticeable energy consumers are ventilation fans, area lighting, and misc. equipment. These three consumers have steady usage throughout the year. Figure 6-12 shows the numerical values for each of the different criterion for each month and their totals.

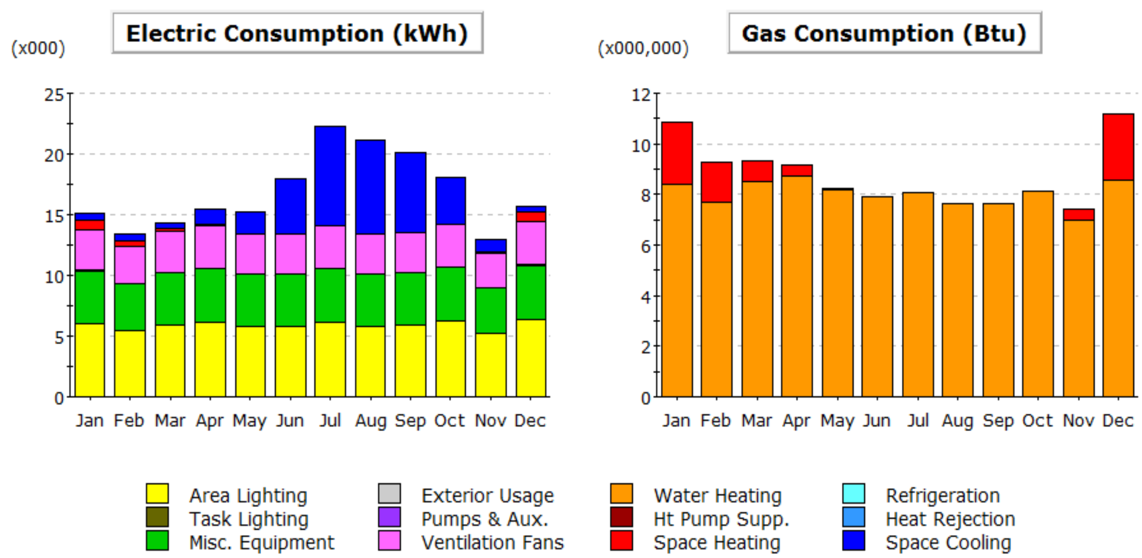


Figure 6-11: Standard Electrical and Gas Consumption, Bar Graph

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.49	0.47	0.44	1.27	1.79	4.55	8.27	7.64	6.61	3.89	0.99	0.52	36.92
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.76	0.52	0.26	0.12	0.01	-	-	-	0.00	-	0.13	0.77	2.57
HP Supp.	0.06	-	-	-	-	-	-	-	-	-	-	0.01	0.07
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	3.33	3.01	3.33	3.49	3.33	3.33	3.49	3.33	3.33	3.49	2.86	3.49	39.82
Pumps & Aux.	0.06	0.04	0.03	0.02	0.00	-	-	-	-	0.00	0.03	0.07	0.25
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.30	3.89	4.30	4.45	4.30	4.28	4.47	4.30	4.28	4.47	3.76	4.47	51.26
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	6.06	5.43	5.92	6.10	5.82	5.80	6.09	5.83	5.90	6.25	5.21	6.38	70.79
Total	15.06	13.36	14.28	15.46	15.24	17.96	22.31	21.10	20.12	18.10	12.97	15.71	201.69

Figure 6-12: Standard Electrical Consumption, Tabularized

Chapter 7: DLLR Simulation

Currently, the building has its own temporary load shedding scheme of the Demand Load Limit Response (DLLR). The DLLR monitors and limits the electrical demand through two programs: demand minimization and time of day demand limiting. The demand minimization program is activated manually by an operator when either a utility peak is expected or occurred. The time of day demand limiting program is active at all times in accordance with the seasonal schedules and peak demand limits. In this building, there are two different HVAC units, the split system air conditioning units and heat pumps, both of which follow the same three stages of DLLR. The steps are as follows:

Stage 1. Reset space temperature upwards

Stage 2. Turn off compressors

Stage 3. Turn off system

One of the requirements for the program is that the system shall always be on. Therefore, stage 3 is eliminated from this simulation.

7.1 Stage 1

Stage 1 consists of resetting the occupied cooling and heating set points by 4°F via the demand limit cooling offset command. The occupied cooling and heating temperature set points then becomes as follows in Figures 7-1 and 7-2.

Type: Temperature

Hourly Values

Mdnt - 1:	82.0 °F	8-9 am:	80.0 °F	4-5 pm:	80.0 °F
1-2 am:	82.0 °F	9-10 am:	80.0 °F	5-6 pm:	80.0 °F
2-3 am:	82.0 °F	10-11 am:	80.0 °F	6-7 pm:	80.0 °F
3-4 am:	82.0 °F	11-noon:	80.0 °F	7-8 pm:	82.0 °F
4-5 am:	82.0 °F	noon-1:	80.0 °F	8-9 pm:	82.0 °F
5-6 am:	82.0 °F	1-2 pm:	80.0 °F	9-10 pm:	82.0 °F
6-7 am:	80.0 °F	2-3 pm:	80.0 °F	10-11 pm:	82.0 °F
7-8 am:	80.0 °F	3-4 pm:	80.0 °F	11-Mdnt:	82.0 °F

Figure 7-1: DLLR Stage 1, Cooling Temperature Schedule

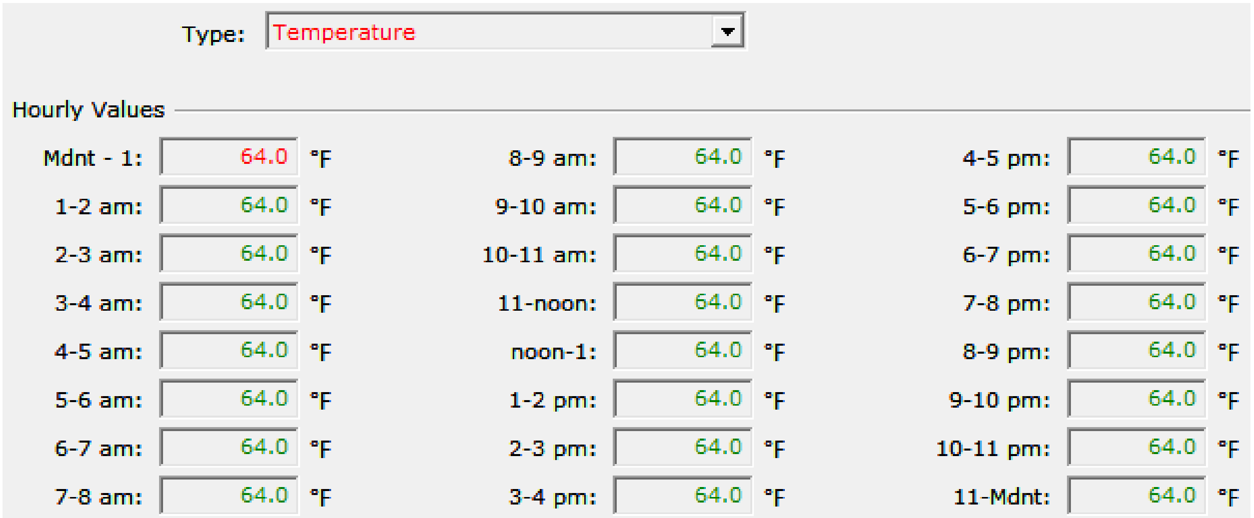


Figure 7-2: DLLR Stage 1, Heating Temperature Schedule

Once Stage 1 is implemented onto the simulator, the following results are given. Figures 7-3 and 7-4 are given in the same format as previously in the initial simulations. Then with the hourly results, the load intervals are plotted showing the characteristics of the building annually as shown in Figure 7-5.

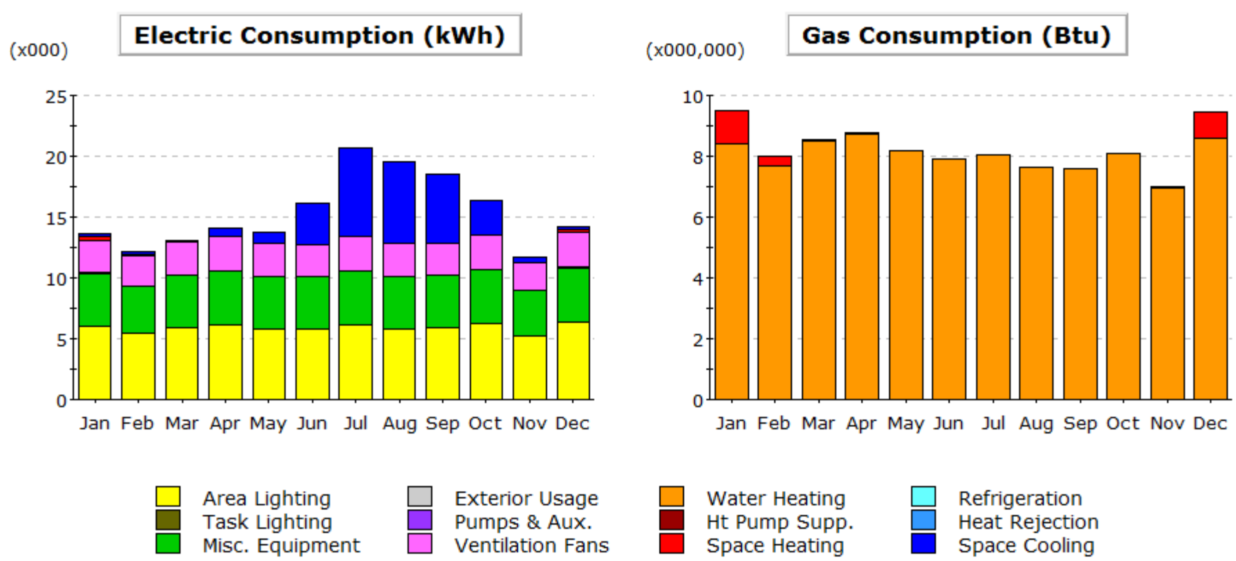


Figure 7-3: DLLR Stage 1, Electrical and Gas Consumption, Bar Graph

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.20	0.23	0.10	0.67	0.96	3.41	7.33	6.71	5.66	2.82	0.46	0.21	28.75
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.32	0.10	0.01	0.01	0.00	-	-	-	-	-	0.01	0.24	0.69
HP Supp.	0.01	-	-	-	-	-	-	-	-	-	-	0.00	0.02
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	2.68	2.42	2.68	2.81	2.68	2.68	2.81	2.68	2.68	2.81	2.30	2.81	32.03
Pumps & Aux.	0.06	0.04	0.03	0.02	0.00	-	-	-	-	0.00	0.03	0.07	0.27
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.30	3.89	4.30	4.45	4.30	4.28	4.47	4.30	4.28	4.47	3.76	4.47	51.26
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	6.06	5.43	5.92	6.10	5.82	5.80	6.09	5.83	5.90	6.25	5.21	6.38	70.79
Total	13.64	12.11	13.04	14.06	13.76	16.17	20.70	19.52	18.52	16.35	11.76	14.18	183.81

Figure 7-4: DLLR Stage 1, Electrical Consumption, Tabularized

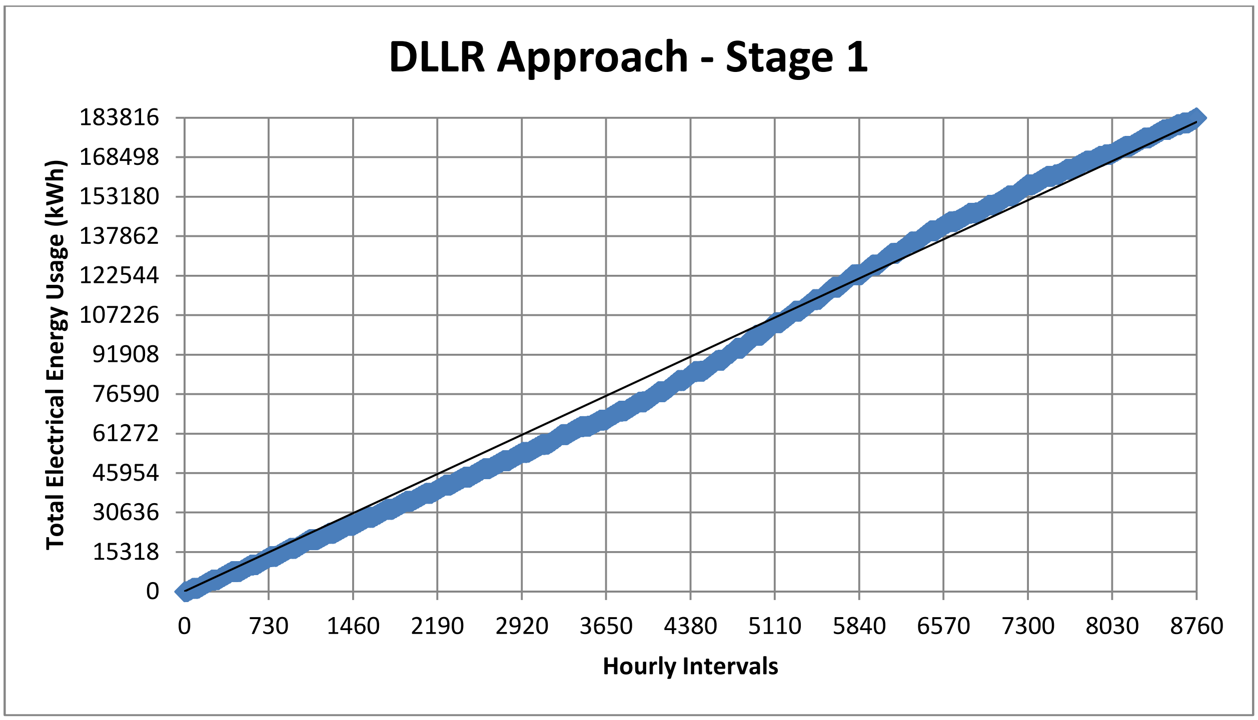


Figure 7-5: DLLR Stage 1 Electrical Energy Usage

After Stage 1 was simulated, the building's electrical energy usage became 183.81 kWh annually. The initial simulation's electrical energy usage was 201.69 kWh, which results for a 17.88 kWh decrease or an 8.87% decrease. This drop is due to an 8.17 kWh decrease in the space cooling and a 7.79 kWh decrease in the ventilation fan. Figure 7-5 shows the same characteristics as the initial simulations in Figure 6-10, where the electrical usage drops during the early spring till early summer duration, while increasing from summer till early fall.

7.2 Stage 2

After stage 1 is completed, then stage 2 commences where the compressor is shutdown. In eQuest, there wasn't a simple function to allow the compressor to turn off. In a HVAC system, the compressor pumps the refrigerant gas up to a high pressure and temperature, and from there it enters a heat exchanger or also called a condenser. Essentially, the cooling is turned off in the building and room temperature air is being pushed out throughout the building. In order to try to mimic this stage in eQuest, the cooling power and the cooling compressor ratios are turned to zero as shown in Figure 7-6.

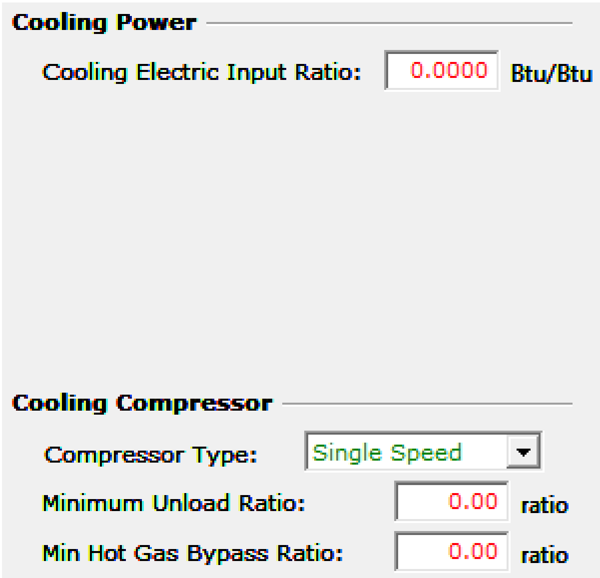


Figure 7-6: DLLR Stage 2, HVAC Compressor

Once Stage 2 is implemented onto the simulator, the following results are given. Figures 7-7 and 7-8 are given in the same format as previously in the initial simulations. Then with the hourly results, the load intervals are plotted showing the characteristics of the building annually as shown in Figure 7-9.

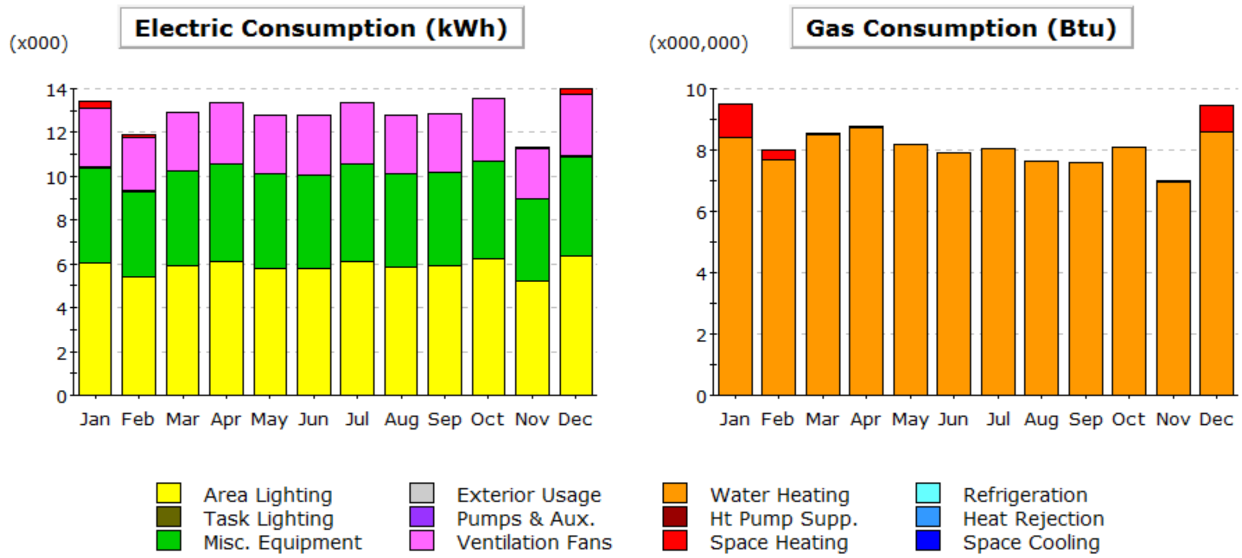


Figure 7-7: DLLR Stage 2, Electrical and Gas Consumption, Bar Graph

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.32	0.10	0.01	0.01	0.00	-	-	-	-	-	0.01	0.24	0.69
HP Supp.	0.01	-	-	-	-	-	-	-	-	-	-	0.00	0.02
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	2.68	2.42	2.68	2.81	2.68	2.68	2.81	2.68	2.68	2.81	2.30	2.81	32.03
Pumps & Aux.	0.06	0.04	0.03	0.02	0.00	-	-	-	-	0.00	0.03	0.07	0.26
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.30	3.89	4.30	4.45	4.30	4.28	4.47	4.30	4.28	4.47	3.76	4.47	51.26
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	6.06	5.43	5.92	6.10	5.82	5.80	6.09	5.83	5.90	6.25	5.21	6.38	70.79
Total	13.43	11.88	12.94	13.39	12.80	12.76	13.37	12.81	12.86	13.53	11.30	13.97	155.05

Figure 7-8: DLLR Stage 2, Electrical Consumption, Tabularized

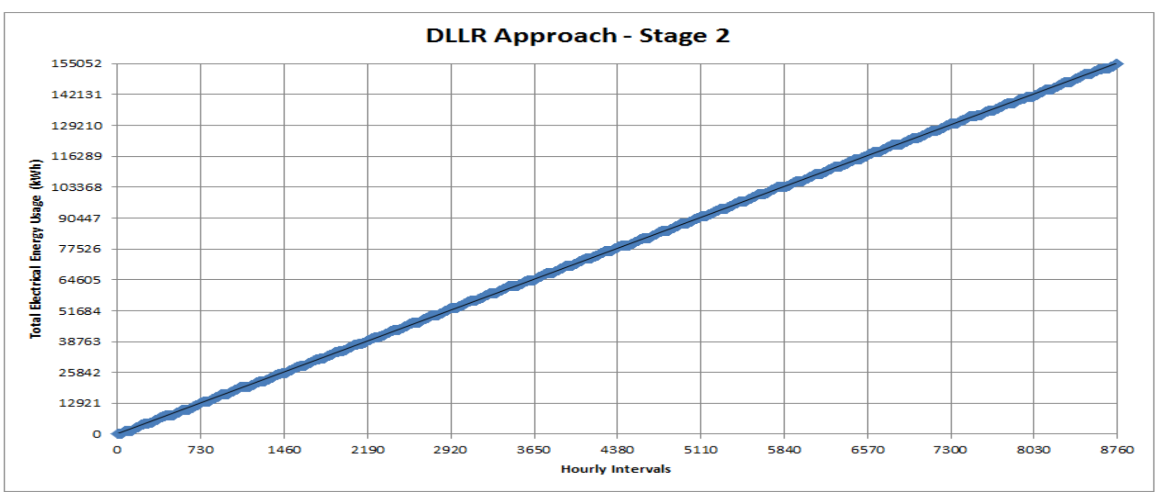


Figure 7-9: DLLR Stage 2 Electrical Energy Usage

In Stage 2, the annual electrical usage became 155.05 kWh, which is a 23.1% load reduction in the HVAC system in reference to the initial simulations. The space cooling is completely eliminated with the cooling power ratio set to zero. This accounts for 36.92 kWh of the load reduction, while the ventilation fans remained the same as stage 1 with a 7.79 kWh load reduction. These two categories account for 44.71 kWh of the 46.64 kWh total reduction in the building. The rest of the 1.93 kWh accounts from the space heating and the heat pump supply usage. Figure 7-9 shows that without space cooling, the electrical energy usage averages out steadily throughout the year. This shows that after Stage 2, the electrical energy usage is around 11-13 kWh each month with small variation.

Chapter 8: Cycling Method Simulation

Now the proposed comparative temporary load shedding analysis is the cycling method. The cycling method consists of the HVAC units turning on and off in pairs in a circular fashion. For example, AC-1 and AC-8 are located in the opposite corners of the building so they would be paired together. That pair will have its ventilation fans on for 15 minutes and then afterwards the next pair, AC-5 and AC-4 will turn on for 15 minutes. After an hour, the whole building would have cycled through and another rotation will continue.

8.1 Stage 1

The first stage is similar to the DLLR's stage 1, but the temperature set points are widened further. The temperature set points will be set to the unoccupied settings of 82°F and 64°F, which are pushing the comfort levels in the building to their maximum. Figure 8-1 shows the cooling temperature schedule, while Figure 8-2 shows the heating temperature schedule.

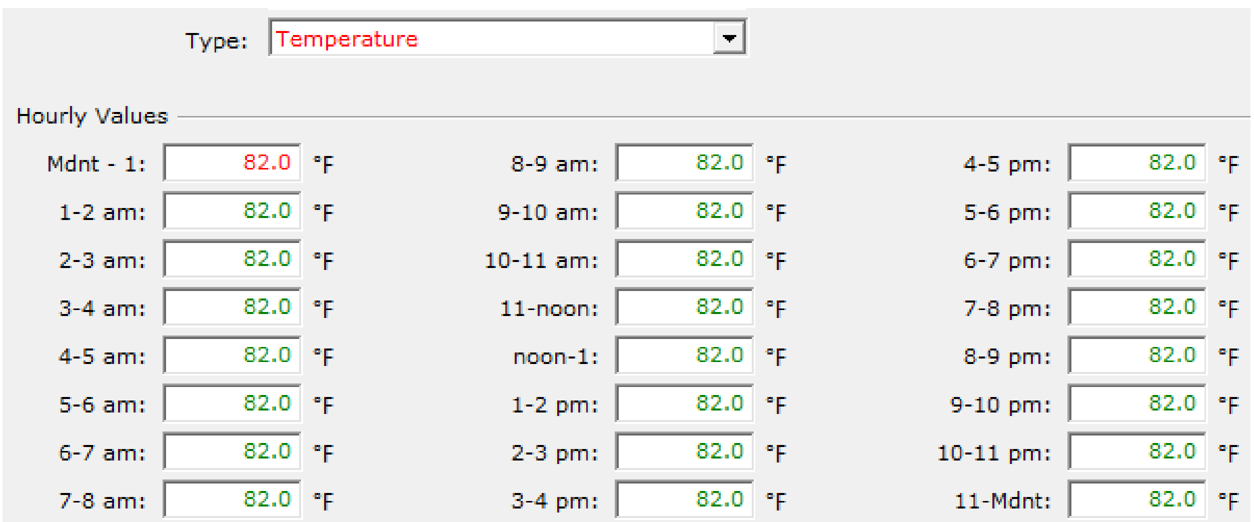


Figure 8-1: Cycling Method Stage 1, Cooling Temperature Schedule

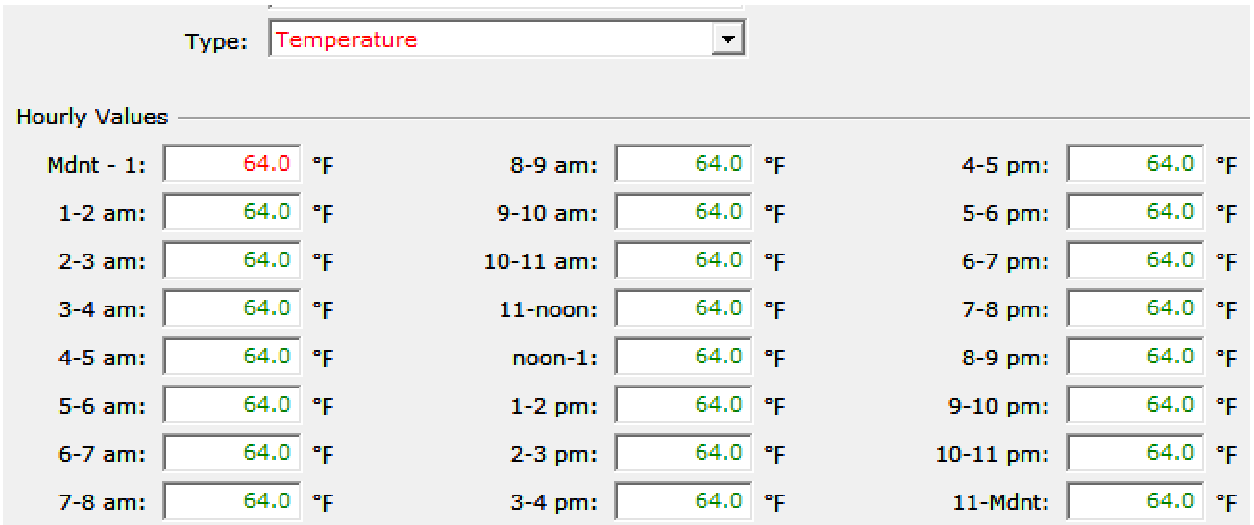


Figure 8-2: Cycling Method Stage 1, Heating Temperature Schedule

Once Stage 1 is implemented onto the simulator, the following results are given. Figures 8-3 and 8-4 are given in the same format as previously in the initial simulations. Then with the hourly results, the load intervals are plotted showing the characteristics of the building annually as shown in Figure 8-5.

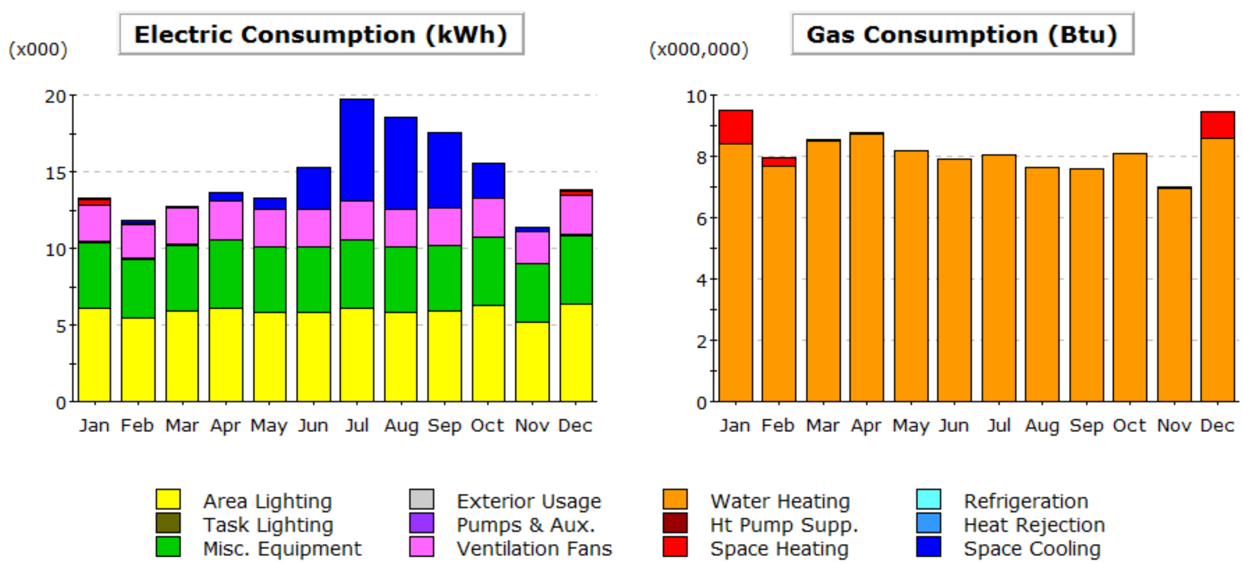


Figure 8-3: Cycling Method Stage 1, Electrical and Gas Consumption, Bar Graph

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.13	0.16	0.03	0.46	0.71	2.80	6.59	5.97	4.97	2.29	0.30	0.13	24.54
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.32	0.09	0.02	0.01	0.00	-	-	-	-	0.00	0.01	0.24	0.69
HP Supp.	0.01	-	-	-	-	-	-	-	-	-	-	0.00	0.02
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	2.43	2.20	2.43	2.54	2.43	2.43	2.54	2.43	2.43	2.54	2.08	2.54	29.00
Pumps & Aux.	0.06	0.04	0.03	0.02	0.00	-	-	-	-	0.00	0.03	0.07	0.27
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.30	3.89	4.30	4.45	4.30	4.28	4.47	4.30	4.28	4.47	3.76	4.47	51.26
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	6.06	5.43	5.92	6.10	5.82	5.80	6.09	5.83	5.90	6.25	5.21	6.38	70.79
Total	13.31	11.81	12.72	13.59	13.25	15.31	19.69	18.53	17.57	15.56	11.38	13.84	176.57

Figure 8-4: Cycling Method Stage 1, Electrical Consumption, Tabularized

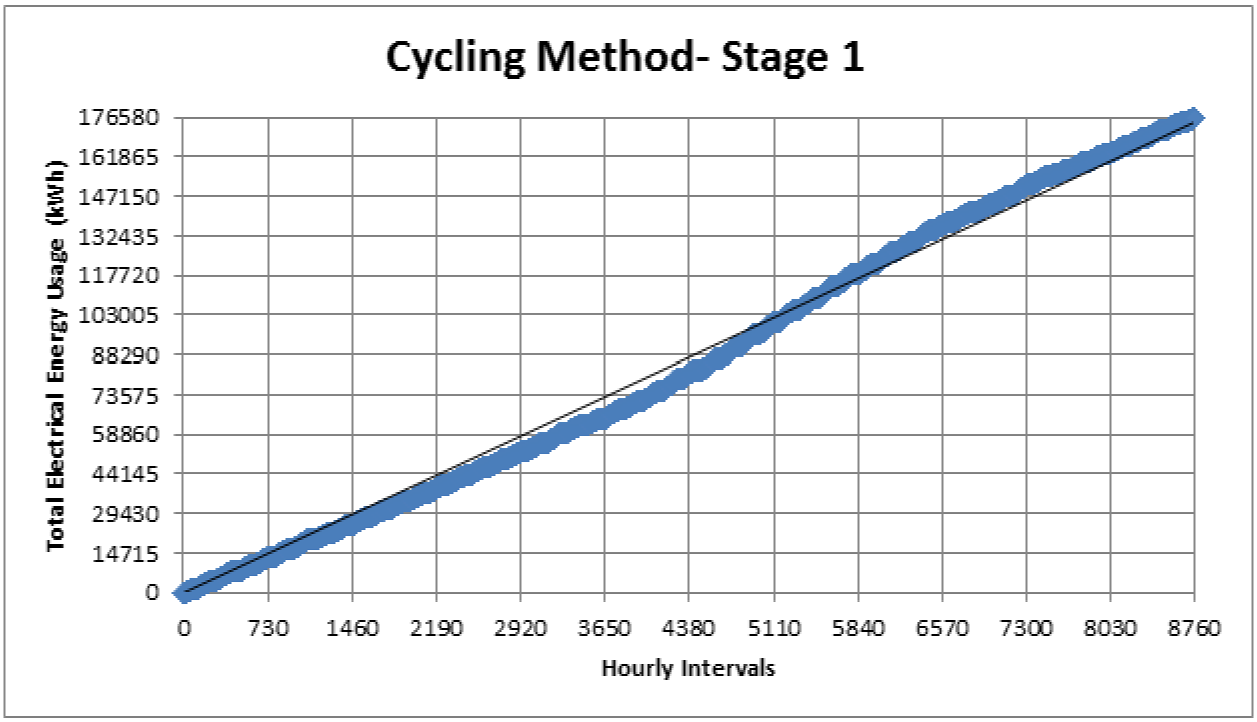


Figure 8-5: Cycling Method Stage 1 Electrical Energy Usage

By changing the temperature set points to the unoccupied settings, the annual electrical energy usage decreased to 176.58 kWh. Therefore this causes a 12.45% load reduction, specifically a 25.12 kWh decrease. 12.38 kWh of the load reduction comes from the space cooling, and 10.82 kWh of the load reduction comes from the ventilation fans. By adding an extra two degrees to the cooling temperature schedule during the occupied schedule, the building's electrical energy usage decreases an additional 7.23 kWh. Figure 8-5 shows the same characteristics like stage one of the DLLR response where the electrical energy usage decreases during early spring-early summer and increases again during summer-early fall.

8.2 Stage2

The proposed plan was to have the cycling method in 15 minute intervals, but due to the limitations in the software, there were only hour intervals for the fans to turn on and off. There was research in trying to find other software that would allow for 15 minute intervals but there was no luck. Since the hourly intervals can cause CO_2 levels to increase into harmful levels, the electrical energy usages can still be used for analysis. Figure 8-6 shows the fan schedule with hourly intervals.

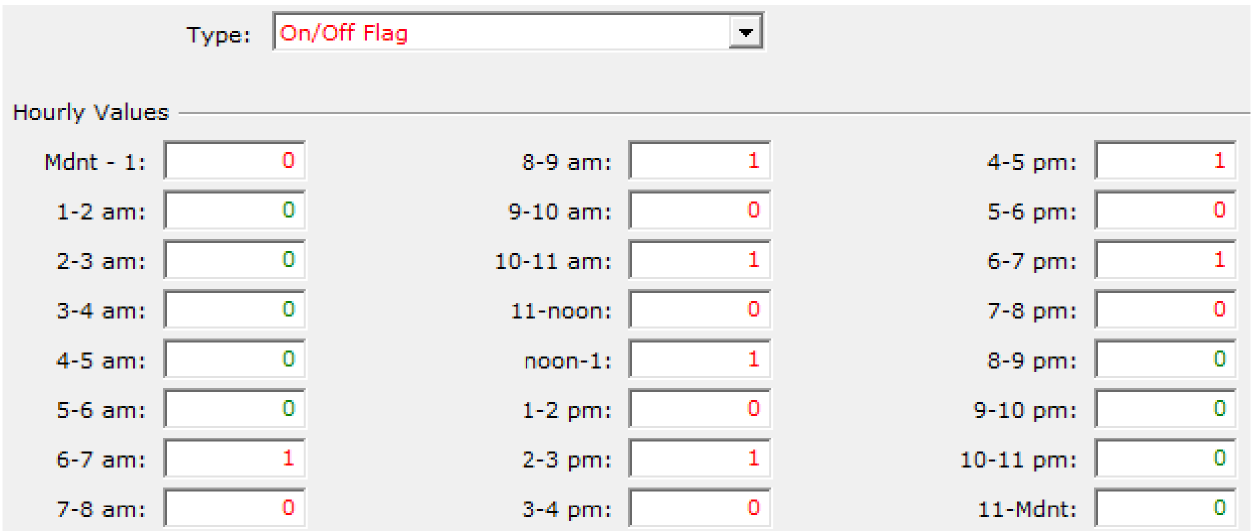


Figure 8-6: DLLR Stage 2, Fan Schedule

Once Stage 2 is implemented onto the simulator, the following results are given. Figures 8-7 and 8-8 are given in the same format as previously in the initial simulations. Then with the hourly results, the load intervals are plotted showing the characteristics of the building annually as shown in Figure 8-9.

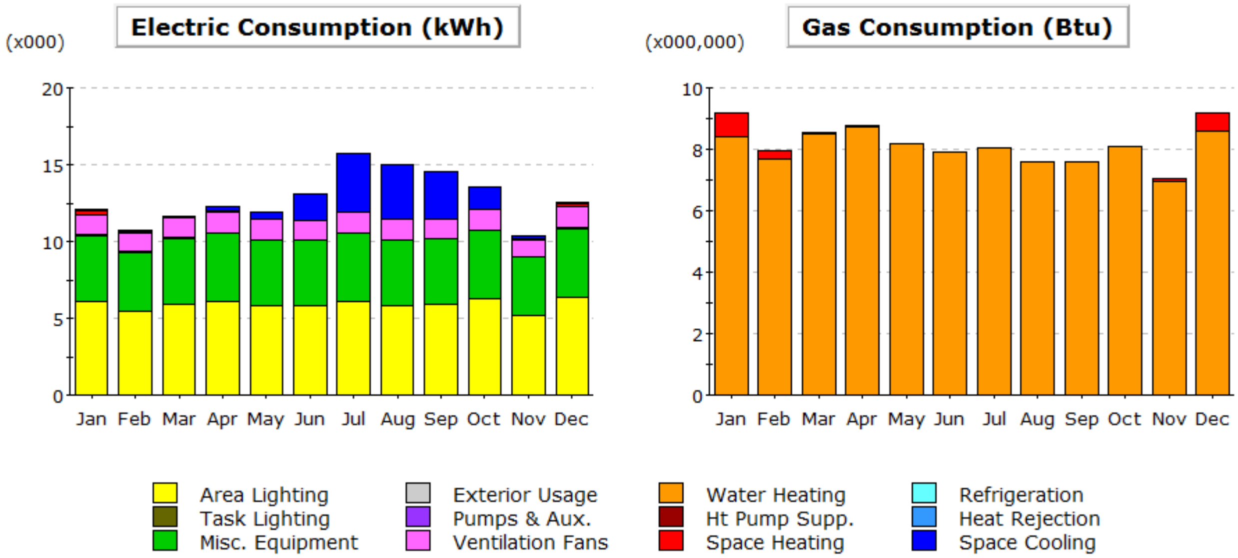


Figure 8-7: Cycling Method Stage 2, Electrical and Gas Consumption, Bar Graph

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.08	0.09	0.04	0.29	0.47	1.75	3.84	3.57	3.01	1.45	0.19	0.09	14.86
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.24	0.08	0.04	0.03	0.02	-	-	-	0.00	0.01	0.05	0.18	0.65
HP Supp.	0.01	-	-	-	-	-	-	-	-	-	-	0.00	0.02
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	1.31	1.18	1.31	1.37	1.31	1.31	1.37	1.31	1.31	1.37	1.12	1.37	15.62
Pumps & Aux.	0.06	0.04	0.03	0.02	0.00	-	-	-	-	0.00	0.03	0.08	0.27
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.30	3.89	4.30	4.45	4.30	4.28	4.47	4.30	4.28	4.47	3.76	4.47	51.26
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	6.06	5.43	5.92	6.10	5.82	5.80	6.09	5.83	5.90	6.25	5.21	6.38	70.79
Total	12.05	10.71	11.64	12.27	11.91	13.13	15.77	15.01	14.50	13.54	10.36	12.56	153.46

Figure 8-8: Cycling Method Stage 2, Electrical Consumption, Tabulized

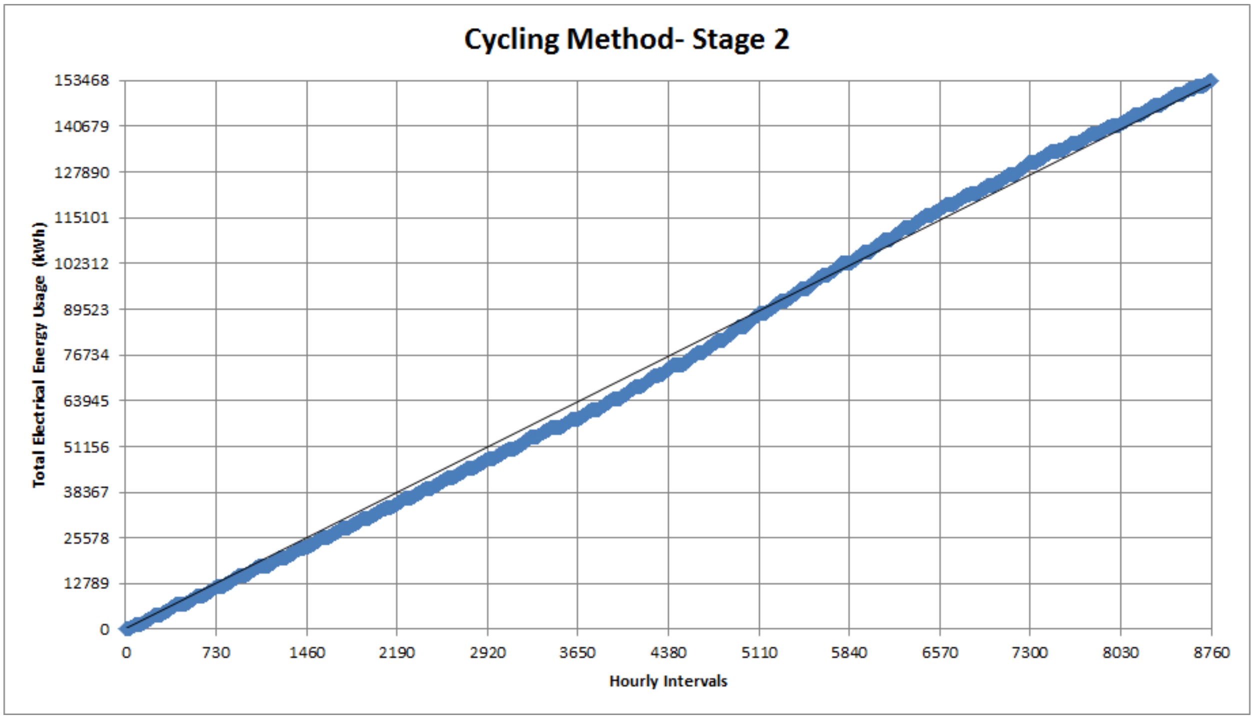


Figure 8-9: Cycling Method Stage 2 Electrical Energy Usage

At the end of the cycling method, the annual electrical energy usage was 153.46 kWh, which totals for a 23.9 % load reduction. The ventilation fans and the space cooling are each partially reduced from their initial values. The space cooling reduced 22.06 kWh, and the ventilation fans reduced by 24.20 kWh. The rest of the 1.97 kWh load reduction accounts from the space heating and the heat pump supply usage. Figure 8-9 shows that the Cycling Method acts similar to the initial simulation where from early spring till early summer decreases and from summer till early fall, the electrical energy usage increases above the average.

Chapter 9: Conclusion

Despite early troubles with the government shutdown, the analysis of the two temporary load shedding schemes were completed. The goal was to analyze the building's characteristics and determine if the current temporary load shedding scheme were able to achieve a load reduction of 50%. However, each load reduction scheme fell short of this goal. The DLLR approach was able to achieve a 23.1% load reduction, while the Cycling Method achieved a 23.9% load reduction. At the end of the DLLR approach, the electrical energy usage became constant through each month. While the Cycling Method had electrical energy usage between early spring till early summer decreased below the average, and the electrical energy usage between summer and early fall increased above the average.

One future recommendation is creating a hybrid load shedding scheme. Stage one from the Cycling Method produces a larger electrical energy use drop, so it's preferred to use these temperature set points of 82° F and 64°F. Since the Cycling Method focuses on decreasing the use of the ventilation fans, it would be ideal to use it during the winter months because space cooling isn't used much. This is confirmed by comparing the months of January-May and November-Dec from the DLLR in Figure 7-8 to the Cycling Method in Figure 8-8. The comparison shows that the Cycling Method has lower electrical energy usages during those months. During the summer months of June-October, the DLLR method uses less electrical energy as expected since the space cooling is one of the major electrical energy usages during those months and it gets turned off due to the compressor's shutdown. While it isn't possible to implement a hybrid system like this in eQuest, the monthly rates can be added together to get an estimate. The estimate for this hybrid load shedding scheme ends up adding to 146.83 kWh. This accumulates to an electrical load reduction of 27.2%. There is a possibility that this estimate doesn't account for other miscellaneous electrical energy usages through the DOE-2 algorithm if it actually had been simulated. However, this can give hope that this hybrid system would work more efficiently than the DLLR or Cycling Method given the logic behind it. The comparisons between the initial simulation results and each load shedding scheme is shown below in Figure 9-1.

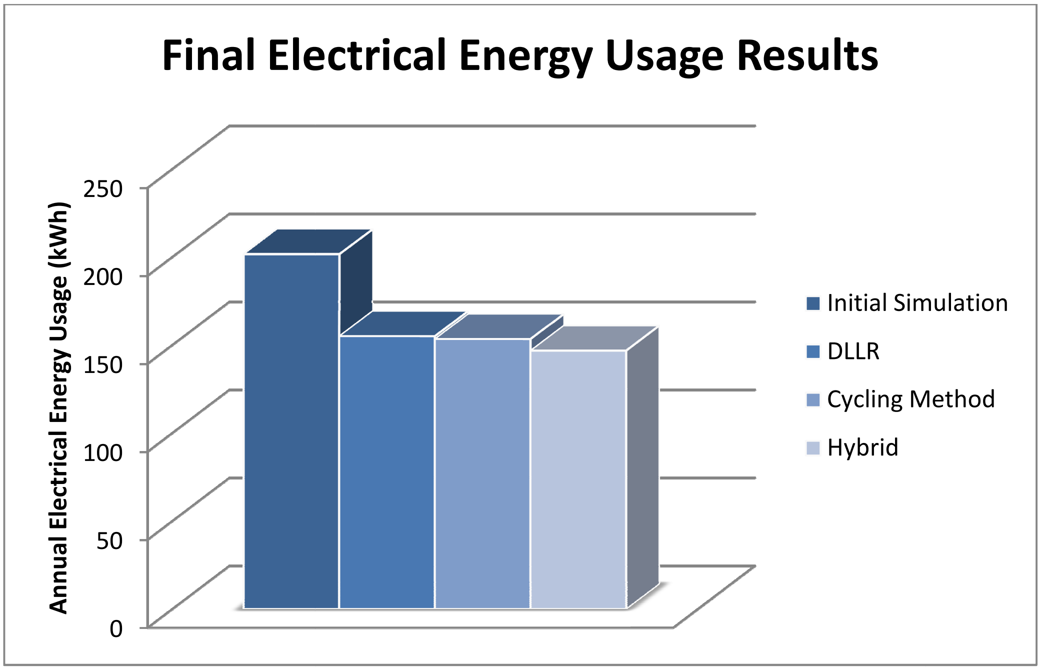


Figure 9-1: Final Electrical Energy Usage Results

References

[1] Johnson Controls, *VMA16 VAV Modular Assembly Controller Series*, January 26, 2012.

[2] Abraxas Energy Consulting, “Energy Efficiency Audit” December 19, 2010

[3] Electronic Control Systems, “Split System AC Unit Flow Diagram” 2012

[4] VIEW, “Dynamic Glass Control Tutorial”, 2013

[5] Tang, Fan. “HVAC system modeling and optimization: a data-mining approach.” Master’s thesis, University of Iowa, 2010. [Online] Available: http://ir.uiowa.edu/etd/895.

[6] K.F. Fong, V.I. Hanby, and T.T. Chow. “HVAC System Optimization for Energy Management by Evolutionary Programming” May 10, 2005 [Online] Available: www.sciencedirect.com

[7] L. Lu, W. Cai, L. Xie, S. Li, C. Soh, “HVAC System Optimization – In-Building Section” December 15, 2003 [Online] Available: www.sciencedirect.com

[8] J.J. Hirsch & Associates. “eQuest Introductory Tutorial, version 3.63” April 2009 [Online] Available: http://doe2.com/download/equest/eQ-v3-63_Introductory-Tutorial.pdf

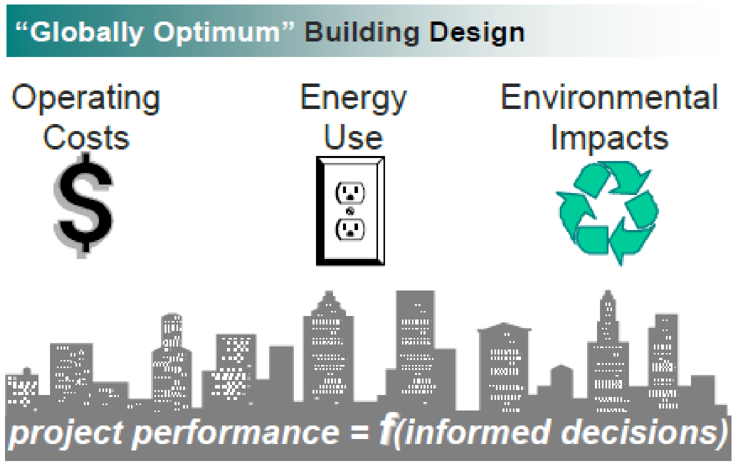
Appendix A: EQuest Simulation Basics

Simulation Basics

The reader who is already familiar with building energy use simulation may wish to skip this section, and continue this tutorial at the next section (Quick Start). For the reader who is new to the use of building energy use simulation, this section provides an overview from a "how-to" perspective. Two Energy Design Resources (EDR) publications will also be very helpful to the new simulation practitioner, providing an overview and a perspective of the role simulation plays in the energy-efficient design process. Both are highly recommended and are briefly described below and on the following page.

Background Information

Integrated Energy Design
Today's building designers must view their design responsibilities from a much broader, even global, perspective. From operating costs, to energy efficiency, to broader issues of sustainability, the quality of building design decisions can only be as good as the information entering the design process, i.e., the performance levels our building design projects ultimately realize is a function of how well informed our design decisions are.

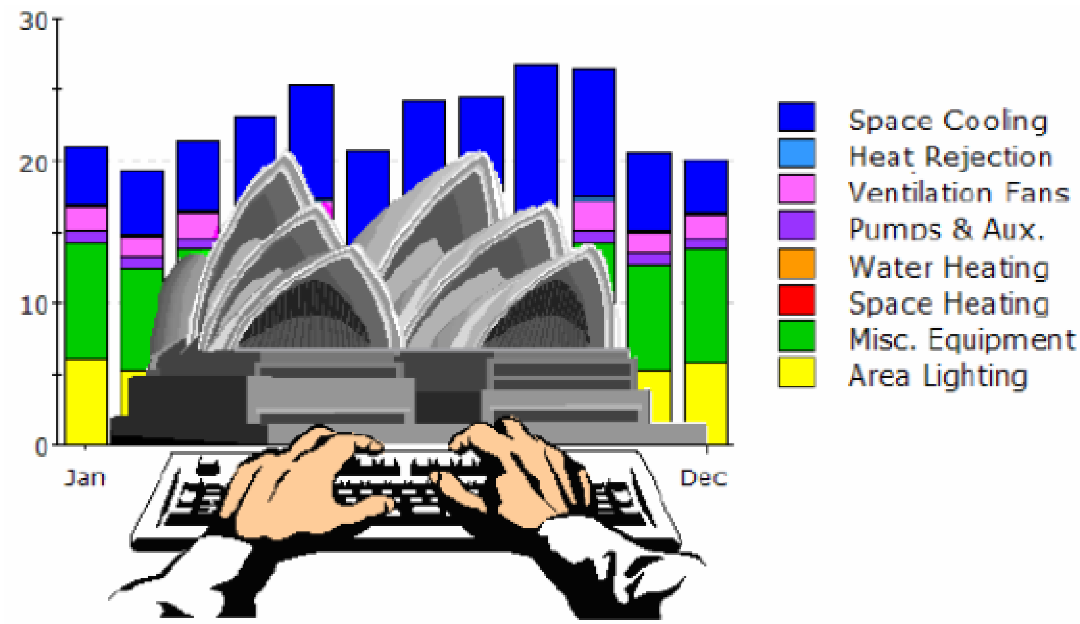


The EDR Design Brief, *Integrated Energy Design*, uses examples to describe the "whole-building" design process necessary to realize the full potential of energy-efficient buildings. Simulation provides the performance information critical to the "whole-building" energy-efficient building design process. The *Integrated Energy Design* EDR Design Brief is available on-line or via free download (PDF file) at:
http://www.energydesignresources.com/Resources/Publications/DesignBriefs.aspx

Background Information

Building Simulation

In recent years, the remarkable gains in desktop computing power and simulation tool technology have placed unprecedented analytical power literally at the finger tips of building design professionals. Building designers and developers can now take their intended building designs for a "test drive" before "signing on the dotted line", something previously only possible under the most generous design budgets.



Additional introductory background to building energy use simulation is available in an EDR Design Brief entitled *Building Simulation*. Using examples, it describes what simulation is, how it can be used to greatest advantage, what simulation tools are widely used, and where to go to obtain them or more information about them. The EDR *Building Simulation* Design Brief is available on-line or via free download (PDF file) at: http://www.energydesignresources.com/Resources/Publications/DesignBriefs.aspx

eQUEST = DOE-2 + Wizards + Graphics

DOE-2-derived engine in eQUEST

DOE-2 is the most widely recognized and respected building energy analysis program in use today. Although DOE-2 was first released in the late 1970's, it used as starting points earlier simulation tools and methods developed and funded by ASHRAE, NASA, the U.S. Postal Service, and the electric and gas utility industries. During the first half of the 1980's, it continued under DOE support, but decreasing national concern about energy created the need for industry support, which became its principal source of support through much of the 1990's. Through this long, and collaborative history, DOE-2 has been widely reviewed and validated in the public domain. The simulation "engine" within eQUEST is derived from the latest official version of DOE-2, however, eQUEST's engine extends and expands DOE-2's capabilities in several important ways, including: interactive operation, dynamic/intelligent defaults, and improvements to numerous long-standing shortcomings in DOE-2 that have limited its use by mainstream designers and buildings professionals.

eQUEST and Integrated Energy Design

While DOE-2 has long been available for designers to "test drive" the energy performance of their building designs, it has been too difficult and expensive to use for most projects. Imagine instead, a building energy simulation tool so comprehensive that it would be useful to ALL design team members, yet so intuitive ANY design team member could use it, in ANY or ALL design phases, including schematic design. *eQUEST* is well named because it provides something the buildings industry has been looking for, but until now has been unable to find … a sophisticated, yet easy-to-use building energy analysis tool… powerful enough to address every design team member's domain (e.g., architectural, lighting, mechanical) but simple enough to permit a collaborative effort by ALL design team members in ALL design phases.

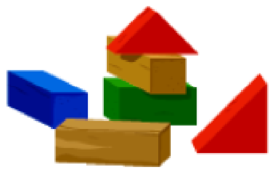
eQUEST was designed to allow you to perform detailed analysis of today's state-of-the-art building technologies using today's most sophisticated building energy use simulation techniques… without requiring extensive experience in the "art" of building performance modeling. This is possible because eQUEST's DOE-2-derived engine is combined with a building creation wizard, an energy efficiency measure wizard, industry standard input defaults, and a graphical results display module. eQUEST will step you through the creation of a detailed building model, allow you to automatically perform parametric simulations of your design alternatives and provide you with intuitive graphics that compare the performance of your design alternatives. Reliable detailed simulation has never been easier. With eQUEST, you'll be able to provide professional-level results in an affordable level of effort. Imagine being able to evaluate today's newest building technologies, at the speed of today's design process. Well… imagine no longer!

Overview of the Process

eQUEST calculates hour-by-hour building energy consumption over an entire year (8760 hours) using hourly weather data for the location under consideration. Input to the program consists of a detailed description of the building being analyzed, including hourly scheduling of occupants, lighting, equipment, and thermostat settings. eQUEST provides very accurate simulation of such building features as shading, fenestration, interior building mass, envelope building mass, and the dynamic response of differing heating and air conditioning system types and controls. eQUEST also contains a dynamic daylighting model to assess the effect of natural lighting on thermal and lighting demands.

The simulation process begins by developing a "model" of the building based on building plans and specifications. A base line building model that assumes a minimum level of efficiency (e.g., minimally compliant with California Title24 or ASHRAE 90.1) is then developed to provide the base from which energy savings are estimated. Alternative analyses are made by making changes to the model that correspond to efficiency measures that could be implemented in the building. These alternative analyses result in annual utility consumption and cost savings for the efficiency measure that can then be used to determine simple payback, life-cycle cost, etc. for the measure and, ultimately, to determine the best combination of alternatives.

Building Blocks of Simulation



Building simulation requires that a ***model*** of the proposed building be created… not a physical model but a virtual model… capable of simulating the important thermodynamics of the proposed building. Experienced modelers learn to prize *parsimony* in their work… elegant simplicity capturing the essential details, and no more. Great minds, in addition to your's, have come to appreciate this aspiration — "make things as simple as possible, and no simpler" (Albert Einstein). Toward that end, the following list summarizes essential components, steps, or building blocks, in a how-to description of the process of simulation modeling.

Before "building" anything, including your simulation model, first consider and collect the following…

- **Analysis Objectives (Begin with the End in Mind)…**

Try to approach your simulation model with a clear understanding of the design questions you wish to answer using your simulation model. Simplifications that you build into your model will both unclutter your model so you can focus on the important issues and at the same time, limit the questions you can use your model to answer. Experience will teach you how best to strike this important balance for each new project.

- **Building Site Information and Weather Data…**

Important building site characteristics include latitude, longitude and elevation, plus information about adjacent structure or landscape capable of casting significant shadows on your proposed (or existing) building. Your eQUEST CD (or download) comes with long-term average weather data (~30-year average) for the sixteen standard climate zones in California. For users outside of California, over 650 weather files are available via automatic download (as-needed). Some international locations are also available. Visit http://DOE2.com/download/weather/ to browse available eQUEST weather locations.

- **Building Shell, Structure, Materials, and Shades…**

eQUEST is interested in the walls, roof, and floor of your proposed building only in so far as they transfer or store heat (or "coolth"). You will need to have some idea of the geometry (dimensions) and construction materials of each of the heat transfer surfaces in your proposed building. Only the most significant need be included (e.g., many modelers omit parapet walls or walls inclosing unconditioned spaces since they do not directly enclose conditioned space). This will include glass properties of windows and the dimensions of any window shades (e.g., overhangs and fins). eQUEST provides users with simple, user-friendly, choices for each of these.

Building Blocks of Simulation (continued)

- **Building Operations and Scheduling…**

A clear understanding of the schedule of operation of the existing or proposed building is important to the overall accuracy of your simulation model. This includes information about when building occupancy begins and ends (times, days of the week, and seasonal variations such as for schools), occupied indoor thermostat setpoints, and HVAC and internal equipment operations schedules. eQUEST defaults operations schedule information based on building type.

- **Internal Loads…**

Heat gain from internal loads (e.g., people, lights, and equipment) can constitute a significant portion of the utility requirements in large buildings, both from their direct power requirements and the indirect effect they have on cooling and heating requirements. In fact, internal loads can frequently make large buildings relatively insensitive to weather. More importantly, the performance of almost all energy-efficient design alternatives will be impacted either directly or indirectly by the amount of internal load within a building. Although eQUEST contains reasonable defaults by building type, the experienced user will take care to estimate these as carefully as possible. The industry standard source for these data is the ASHRAE *Handbook of Fundamentals* (published every four years), available through ASHRAE at www.ashrae.org. Recent research into this important topic also is available from LBNL via http://eetd.lbl.gov/EA/Buildings/PubsList.

- **HVAC Equipment and Performance…**

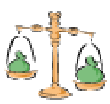
Few model components will have as much influence on overall building energy use and the performance of most energy-efficient design alternatives as will the HVAC (Heating, Ventilating, and Air Conditioning) equipment. It follows that good information regarding HVAC equipment efficiency will be important to the accuracy of any energy use simulation. eQUEST assumes default HVAC equipment efficiencies according to California's Title 24 energy standard. Where possible, equipment efficiencies specific to each analysis should be obtained, e.g., from the building design engineers or directly from equipment manufactures. Most HVAC equipment manufactures now publish equipment performance data on their web sites. Additionally, detailed equipment performance data is also available to the public from the Air-Conditioning and Refrigeration Institute (ARI) via http://www.ari.org/directories/ and from the California Energy Commission (CEC) via http://www.energy.ca.gov/efficiency/appliances/index.html.

Building Blocks of Simulation (continued)

- **Utility Rates …**

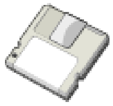
A great strength of detailed energy use simulation using eQUEST is the ability to predict hourly electrical demand profiles that can then be coupled with full details of the applicable utility rates (tariffs). eQUEST comes with the principal residential and commercial electric and natural gas rates from the sponsoring California utilities. For California locations (weather file selections), eQUEST defaults the rate selection depending on climate zone and on estimated peak electrical demand. Users outside California must create their own utility rate descriptions using eQUEST's DOE-2-derived Building Description Language (BDL) and save these descriptions as text files for eQUEST's use. The syntax and structure of BDL utility rate files is explained in a file named "BDL Utility Rate Documentation.pdf" found in the "C:\Program Files\eQUEST\Rates" folder. A "Readme.txt" file in the same folder overviews the procedure.

- **Economic Parameters …**



Energy Design Resources concurs with a growing chorus including the U.S. DOE's Federal Energy Management Program (FEMP) and the National Institute of Standards and Technology (NIST) in recommending life-cycle economics above simple payback methods of economic analysis. Because energy efficiency investments usually return benefit over the entire life of the building or system, considering their life-cycle impact is most appropriate. Imagine selecting a variable rate mortgage based on no more information than the initial interest rate. While few would be comfortable ignoring the longer-range terms of any loan or investment, it is common practice among building developers and designers to recommend building efficiency investments with equal shortsightedness. A summary discussion of life-cycle costing with examples, including a comparison to simple payback is now part of eQUEST v 3.63 (right click on *any* input field in eQUEST and select Tutorials and Reference, then *Life-Cycle Costs*). While life-cycle economics analysis is included in eQUEST, several free life-cycle cost tools and resources are also available to the interested user. These include the *Building Life-Cycle Cost Program* from NIST (free at http://www1.eere.energy.gov/femp/information/download_blcc.html), and *User-Friendly Life-Cycle Costing*, an Excel® form of the widely used NIST/BLCC methodology (free at http://www.doe2.com). Energy Design Resources also offers *eVALUator*, user-friendly life cycle economics tool that goes beyond traditional life-cycle cost tools by including payroll and productivity data, lease rates, and occupancy rates. *eVALUator* is available free at http://www1.eere.energy.gov/femp/information/download_blcc.html.

Data Requirements



The image below illustrates in detail, the type of data you should either assemble prior to developing your simulation model, or confirm in the course of your modeling, and the point in the design process each item of building information typically becomes finalized.

Item	*Source*	*Schematic*	*Design Development*	*Construction Documents*
Architectural				
building and zone areas	plan sheets	x	x	x
envelope construction materials	wall sections		x	x
surface areas (by orientation)	building elevations	x	x	x
fenestration areas (by orientation)	building elevations	x	x	x
fenestration u-value & SC	window schedule			x
	or specifications			x
Mechanical				
HVAC zoning	HVAC plans		x	x
design flow rates	HVAC plans		x	x
equipment descriptions	equipment schedules			x
	or specifications			x
control sequences	control diagrams			x
	or specifications			x
Electrical				
lighting equipment	lighting layout		x	x
	or lighting schedule			x
Internal Loads				
peak occupancy (by zone)	owner, operator	x	x	x
peak lighting (by zone)	lighting plans		x	x
peak equipment (by zone)	mech or owner		x	x
Operations				
per zone:				
occ, lights, equip schedules	owner or operator	x	x	x
thermostat schedules	owner or operator	x	x	x
per terminal system:				
outside air operations	HVAC equip schedule			x
hot & cold deck temperatures	HVAC equip schedule			x
fan schedules	owner or operator	x	x	x
fan kW	HVAC equip schedule		x	x
per primary system:				
lock-out schedules	control sequences			x
Economic				
utility schedules (all fuels)	utility representative	x	x	x
equipment costs	designer or manufacturer		x	x
life-cycle cost parameters	owner	x	x	x

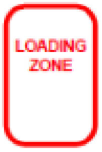
Data Requirements (continued)

The same list of data (from previous page) is organized below to help the modeler make and manage data collection assignments to other design team members. Date columns allow more detailed data to be targeted as it becomes available or necessary.

Modeling Information Request
Project Name / Date

assignment	DATES *date1*	*date2*	*date3*	INFORMATION	
				ARCHITECTURAL	
	❑			floor plans	space layout/areas, surface orientations
	❑			elevations	surface areas (windows, doors)
		❑		building/wall/roof sections	materials composition
	❑			site plans	adjacent structures and landscape
		❑		roof plans	skylights and overhangs
	❑			gross area & net (conditioned area)	
				ENVELOPE MATERIALS	
		❑		glazing shading coefficient, u-value, frame type, interior shading	
		❑		u-values: wall, roof, ceiling, skylight, slab & spandral	
				MECHANICAL	
		❑		HVAC plans	approximate HVAC zoning layout
	❑			equipment types	
		❑		approx equipment sizes, design conditions, & efficiencies	
		❑		anticipated control sequences	
				ELECTRICAL / INTERNAL LOADS	
		❑		lighting plans	
		❑		lighting power density (by HVAC zone)	
		❑		design illuminance (by HVAC zone)	
		❑		peak occupancy (by HVAC zone)	
		❑		peak equipment (by HVAC zone)	
				OPERATIONS	
				per HVAC zone	
		❑		occupancy, lights & equipment schedules	
		❑		thermostat settings and schedules	
				per air handler	
		❑		anticipated coil leaving air temperatures	
		❑		minimum outside air	
		❑		fan schedules	
		❑		anticipated fan static & efficiency	
				central plant (if applicable)	
		❑		chilled & hot water temperatures	
		❑		equipment control sequences	
				ECONOMIC	
			❑	base case first costs (for equipment & systems affected by ECM's)	
			❑	ECM first costs	
	❑			applicable & optional utility rates	
				POTENTIAL ECM's	
	❑			envelope	
	❑			lighting	
	❑			mechanical	

HVAC Zoning



HVAC zoning recognizes that load profiles seen by different spaces in a building differ. Identifying those areas with similar load profiles and grouping them under the same thermostat control improves comfort and may reduce energy. For example, imagine measuring indoor air temperatures at many locations throughout a building during hours when the HVAC fans are turned off. Internal gains, solar gains, and envelope gains/losses would cause the temperatures to vary with time. If, after some number of hours or days, you carefully examined the temperature histories, grouping together those that shared similar profiles, you would have effectively grouped together those areas of the building that share similar load characteristics. Each such area or "zone" could, therefore, be adequately controlled by a single thermostat. In other words, HVAC thermal zoning seeks to group together those areas (rooms) in a building that share similar load and usage characteristics, for purposes of control. Of course, this imagined procedure is not how HVAC engineers actually zone any building. Rather, the rules listed below are followed. The same rules apply when zoning a simulation model.

- when modeling existing buildings, refer to the actual zoning indicated by the HVAC plans, if available
- for new buildings and when simplifying the zoning of an existing building consider:
- magnitude and schedule of internal loads
- magnitude and schedule of solar gains
- schedule of fan system operations
- outside air requirements
- intended efficiency measures (ECM's)
- location of thermostats called out on the HVAC plans

In general, provide:

- one exterior zone per major orientation (12 to 18 feet deep)
- one internal zone per use schedule
- one plenum zone (if plenum returns) for each air handler to be modeled separately
- one zone each for special uses (e.g., conference rooms, cafeterias, etc.)
- separate ground and top floor zones

Currently, eQUEST provides the user with two automatic zoning schemes, one-zone-per-floor, and simple core-vs-perimeter zoning. Based on this user selection, eQUEST will automatically zone your model for you.

Appendix B: Nomenclature

TABLE VI
SENIOR PROJECT: LEGEND

Abbreviation	Phrase/ Explanation
DDC	Direct Digital Controller
NAE	Network Automation Engine
HVAC	Heating, Ventilation, and Air Conditioning
MCAS	Marine Corps Air Station
IEEE 1547.4	Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems
DoD	Department of Defense
DoE	Department of Energy
Islanding	When the buildings are relying on the micro grid's power system for a limited amount of time
SDG&E	San Diego Gas and Electric
RTPU	Roof Top Package Unit
FC	Fan Coil
CU	Condenser Unit
PV	Photovoltaic
DLLR	Demand Load Limit Response

Appendix C: Senior Project Analysis

Project Title: Miramar Base Temporary HVAC Load Shedding Characterization and Comparison

Student's Name: Student's Signature:

Advisor's Name: Advisor's Initials: Date:

• **Summary of Functional Requirements**

Raytheon approached Cal Poly looking for a student to help analyze the ability for HVAC load management of a micro grid system. My project's job is to compare the difference between the current temporary load shedding scheme of the DLLR to a proposed load shedding scheme called the Cycling Method.

• **Primary Constraints**

The project's first challenge was the government shutdown. During the shutdown, all the employees at the base were furloughed which cut off communication for a couple of months. This caused some disarray in figuring out the project and caused a delay in figuring out the specifications of the project. The second constraint is learning the whole current HVAC system present at the base. The HVAC system is more of a mechanical engineering discipline, so as an electrical engineer, it took some time to become knowledgeable on the subject.

• **Economic**

A financial capital effect is that solar energy allows the base to save financial wealth due to using a free natural resource, sunlight. Sunlight allows for a free and limitless energy rather than diesel generators which use the natural gas diesel that's expensive and limited. In the natural capital aspect, the base takes out the limited quantity of diesel which degrades the bio-capacity due to the pollution caused by the generators. Solar energy eliminates the pollution problem which allows for a green solution.

Since the project focuses on researching and upgrading the current HVAC system by load shedding, the benefits occur immediately due to the load reduction of the system. With a load reduction, the power efficiency of the micro grid increases which allows for a lower utility bill that should remain lowered for as long as the implementation lasts. The experiment requires the input of solar energy to the micro grid system which eventually becomes the building's AC power. Due to the project being research based, there's no component cost involved.

The specific earnings of the research can't be easily calculated. Since the temporary load shedding relies on emergency based situations, one can't just calculate how often these emergencies could happen. Once the load calculations are completed, the rate at which SDG&E charges MCAS would be necessary. This limits the calculations of the specific earnings of the research.

In order to plan economic success, a Gantt chart was made in order to ensure the project is done in a timely manner. Fall quarter deals with the design of the system, the winter quarter implements the system, and the spring quarter reviews and fine tunes the final system.

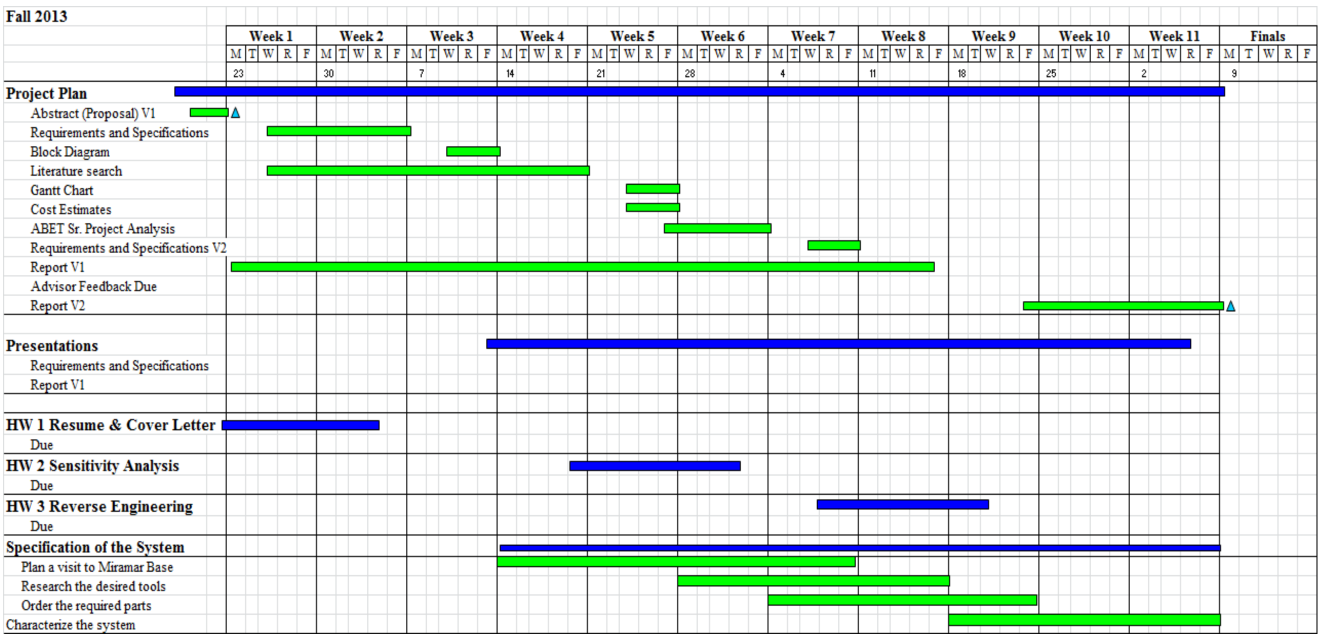


Figure C-1: Fall Quarter 2013 Gantt Chart

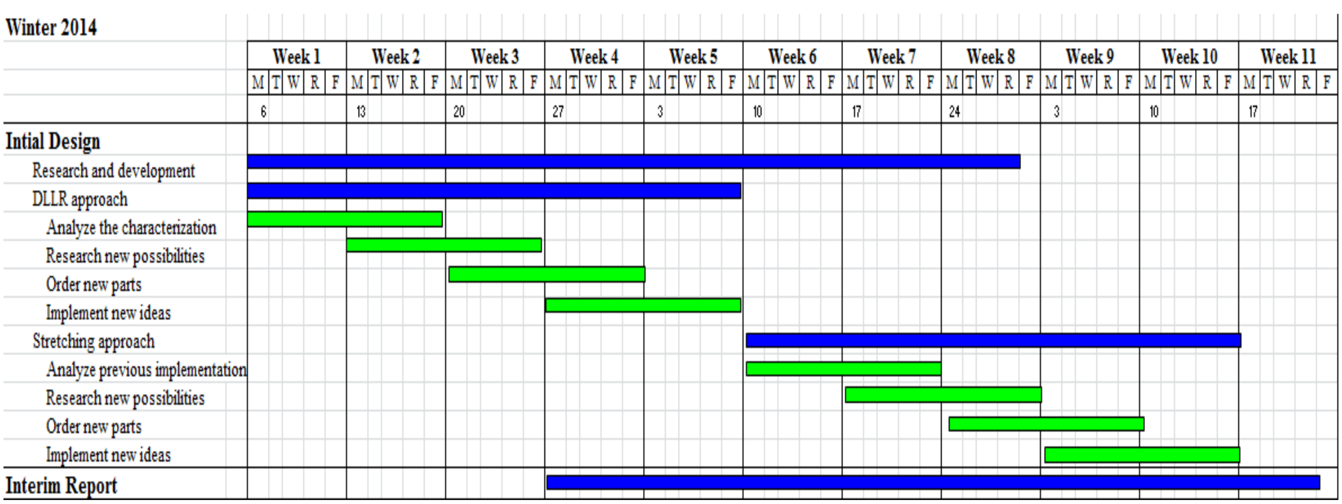


Figure C-2: Winter Quarter 2014 Gantt Chart

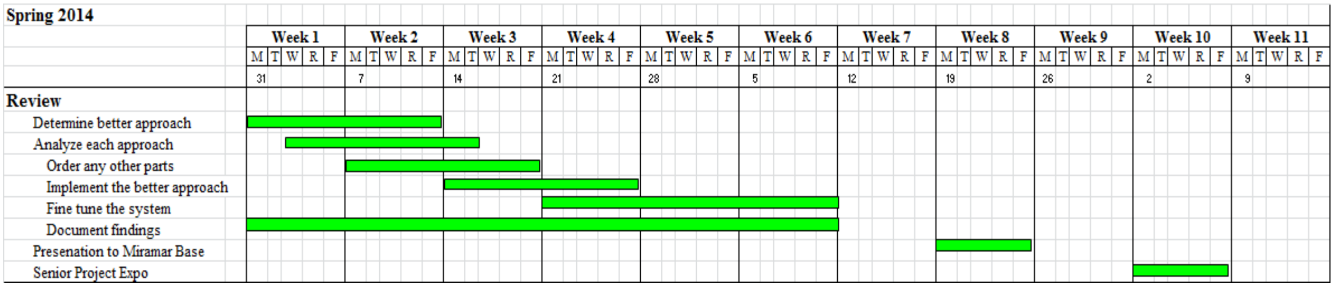


Figure C-3: Spring Quarter 2014 Gantt Chart

Cost Estimates:

The project is solely research based and through software simulations, so there were no costs. If translated to a professional company, labor costs would be in effect.

• If manufactured on a commercial basis:

The project is software based and a government project, so the project will not be manufactured on a commercial basis.

• Environmental

One environmental impact associated with the research is eliminating the backup generator which eliminates the use of diesel. The generators cause pollution into the environment and eliminating the generators improves the environment. Also, using solar is a green method of protecting the environment since solar does not emit any harmful emissions. The project directly uses the sun's energy for the micro grid, and indirectly uses water for the chilled water engines.

The project improves the natural resource, solar energy, by making the micro grid more power efficient which will output more power for the same amount of solar energy. With the addition of solar energy, it takes away the diesel generators, which takes away the use of diesel and allow for the natural resource to be used for other products like cars and trucks. The only impact that the project could impact other species is through taking away the diesel generators. with less demand for diesel, the need for drilling for the natural resource also decreases, and species around the dig sites can be protected.

• Manufacturability

The project does not require manufacturing

• Sustainability

A challenge with maintaining the system is the system's stability during peak hours. During summer, there are moments when the outside air reaches peak heat temperature and causes a higher demand for air conditioning inside the building. in controls, the system is dependent on poles and zeroes which cause stability in the system. in order to reduce the load reduction, the system stretches out and causes instability. The challenge requires maintaining the relationship between stability and load reduction.

The project impacts the sustainable use of resources by using a dependable and green resource of sunlight. Diesel generators don't classify as a sustainable source because diesel is a limited natural resource that will eventually run out on our planet. As long as the sun provides sunlight, the micro grid provides a constant and dependable energy source. As a research project that involves upgrading the current system, the design should be the most upgraded product after the project. Money and cost could hinder the project from upgrading to the highest standard. Upgrading certain equipment could potentially cost a lot, and Raytheon might not deem it necessary for how much it could cost.

• Ethical

2. To avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;

In rule 2 of the IEEE code of ethics, I need to ensure that the affected parties, Miramar Base and Raytheon, of any conflicts of interests that could occur. Miramar Base could want the system to go in one direction, while Raytheon could want to go in another direction. as an engineer, I need to ensure to disclose any conflicts of interest to the affected parties whenever they exist.

7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;

In rule 7 of the IEEE code of ethics, I need to accept and offer any honest criticism of technical work to acknowledge and learn from errors. as a student, I will receive criticism of my work, which I can benefit from. I want to learn more and gather as much experience as I can receive.

• Health and Safety

Since the project is done through a simulation tool, there are no health and safety concerns. However, if the program is implemented , there are two health concerns. One is

dealing with high voltage and the other is ensuring the right amount of CO_2 in the building. The power system deals with high amounts of current in which could cause harm to a human. The more realistic concern is the amount of CO_2 for the tenants. Since comfort levels are pushed to the maximum, CO_2 can reach unhealthy levels. CO_2 sensors will need to be installed in the building to ensure the unhealthy limit never gets reached.

• Social and Political

A social and political issue is that Miramar Base has the final say on what happens in the project. They are in charge of the project and they get to choose how the project can turn out. I need to ensure that the project has their best interest in it. The project impacts Raytheon and MCAS Miramar. as the direct stakeholders, they have invested a lot of money into the project and they expect results from the project. The project benefits the stakeholders as it decreases the utility bill and provides money to the stake holders.

MCAS Miramar benefits the most as they are going to receive the decreased utility bill. Raytheon just receives a contract in which they receive a one-time bonus for the project. The project doesn't create any inequities since Raytheon is a contractor and if they do a well enough job, they could receive more contracts in which it can create more jobs for them. Raytheon is located all across the nation along with multiple government bases. Raytheon also has a lot of economic power in which it could grab more contracts since they complete jobs very well. The base also has a lot of economic and political power since they are part of the government.

• 11. Development

A new technique I learned is the DLLR (Demand Limit Load Response), which takes various steps ensuring when to reduce the load. Along with the cycling method, I was able to learn how that load shedding scheme affected the electrical energy usage through the ventilation fans. I am currently researching how to continue reducing the electrical energy usage to eventually get to the desired 50% goal.