MECHANICAL ENGINEERING DEPARTMENT

UNIVERSITY OF SASKATCHEWAN

University of Saskatchewan Education Building Mechanical Controls Re-Design

Group 3

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MECHANICAL ENGINEERING 495.6

A DESIGN PROJECT
PREPARED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR
THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING
UNIVERSITY OF SASKATCHEWAN

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February 24, 2015

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Executive Summary

The University of Saskatchewan Education Building has been identified for a potential upgrade in its mechanical control system. The current system runs using an analog control system while the upgrade would introduce digital controls. The Education Building HVAC system is split into four main areas: the Quance Theatre, the penthouse/main area, the gym, locker room, and pool area, and the Audio/Visual Room. The Quance Theatre has undergone significant improvements to its HVAC operation. It utilizes PID loops and makes use of carbon dioxide sensors, therefore is it difficult to find potential energy reduction in this area. The Audio/Visual Room is extremely small thus any savings are insignificant. As a result, the penthouse and gym, locker room, and pool zones are the focus of reducing the Education Building's energy consumption.

Three main energy savings opportunities were identified which include implementing an optimal start, applying a nighttime purge, and adjusting system set points. An optimal start will delay the startup of the based on outdoor weather conditions. Nighttime purge cools the building at night in the summer, which delays conditioning of air in the morning. Adjustment of set points simply results in reduction of heating or cooling introduced into the air. In order to assess the positive impact these alternatives have on the operation of the system, the energy usage of the current system in the penthouse was modeled in excel.

A recommendation given for the gym heat recovery system requires the preheat coil to work at max capacity at all times. This raises the incoming outdoor air temperature the maximum amount while minimizing the downstream heating coil energy consumption. This recommendation also cools incoming air when outdoor air temperature in above 25°C.

The penthouse system was found to use 7143 GJ of energy per year to heat and cool the building. The energy usage is split into 51% fan power, 39% heating energy, and 10% cooling energy. Given Saskatoon's climate, heating makes up a far greater portion of the energy than cooling.

Implementation of an optimal start in the penthouse system results in a 6.21% reduction of annual energy consumption. Minimal labour is required to introduce an optimal start so it is a worthy option to consider. Similar savings could be expected if an optimal start is used in the gym, locker room, and pool system as well.

Nighttime purge results in a 0.3% reduction of energy. This alternative is ineffective because of Saskatoon's cold climate; therefore nighttime pure is only viable for a few weeks throughout the year.

Varying set points proves there is a large amount of potential savings. The six set points adjusted are the upper and lower limits of each the hot deck, cold deck, and mixed air temperatures. A 1°C change in all of these parameters results in a 6.21% reduction of annual energy consumption. Further changing these values another 1°C decreases annual energy consumption by 7.86%. Adjustments to these set points may affect the comfort of the occupancy (i.e. room temperature may rise or fall out of acceptable limits), therefore adjustments must be made manually with follow up measurements to ensure the system operates within acceptable parameters.

When utilizing all methods, a total reduction in energy of 14.39% is attained for the penthouse. Similar results could be achieved by implementing all three of these strategies in the gym, locker room, and pool, and Quance Theatre. An objective given by the Department of Sustainability stated a 15% reduction in energy consumption, therefore the savings attained were slightly below this goal. In order to verify these results, estimates were made using Education Building electrical data. Averages of 10,968 kWh on a weekday and 9,251 kWh on a weekend are used, resulting in a total of 3,835,975 kWh for the year. In conclusion, approximately 51% of the yearly energy used in the Education Building is put to heating, cooling, and fans in the penthouse, while the remainder goes to heating, cooling, and fan power in the other areas, as well as plug loads, and lighting.

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1. Problem Definition- Background Information

With today's emphasis on ecofriendly measures, the University of Saskatchewan is showing a commitment to sustainability. Together with the Facilities Management Division and Office of Sustainability, the University of Saskatchewan is looking to reduce the environmental footprint of several of the older buildings on campus. A building where multiple prospective improvements can be made is the Education Building. The University of Saskatchewan Education Building was built in 1968 and currently uses a control system installed in 1988. Two minor improvements have been made since the building's construction: once in 1988 and a second time in 1990. To update the building's operation, the University of Saskatchewan is planning to upgrade the mechanical control system from an inefficient analog *Robert Shaw* controls to a more effective and modern digital *Delta* controls system.

Analog control systems are inefficient because of the unnecessary fan power pushing air through the HVAC system. Analog simply means the fans can be turned on or off; the fans cannot be adjusted to different speeds. The only means of modulating the amount of air flowing into the building is a number of air dampers. The air dampers open and close depending on the amount of heating or cooling the building requires. The wastefulness of the analog system is present when the building requires a small amount of air: the fans will be running at max capacity, which pushes an unnecessary amount of air into the building. The excess air will simply be exhausted outdoors instead of being used. This means the fans are wasting energy by running at such a high rate. A digital control system will correct this wastefulness. A digital controller allows the fans to be throttled to different speeds, depending on the amount of air the building requires. If the building needs just a small amount of heating, the fans will run at a slower speed using only the amount of energy that is necessary. Therefore, a digital control system is a modern and essential step in reducing the environmental footprint of the Education Building.

The Education Building's HVAC system is a dual duct-dual fan system. This means that each supply duct is separated into a hot deck and a cold deck, with a fan in each. The hot deck has its own heating coil while the cold deck has its own cooling coil. Once each airstream is modulated to a set temperature they are combined downstream in a mixing box, and then sent into the area where heating or cooling is required.

The HVAC system is divided into four separate zones. First, a main zone operates from an air handler located in the penthouse. This zone supplies air to the majority of the building including offices, hallways, classrooms and the library. It is divided into two separate and mirror sections: a north system and a south system. A second air handler supplies heating to the gym, locker rooms, and pool. Air is heated to the set temperature then sent to the gym. While exiting the gym it can either be sent to a heat exchanger or into the locker rooms. The heat exchanger is used to preheat the air being supplied to the gym. Finally, once the air is exhausted from the locker rooms it is sent to the swimming pool. The third HVAC zone supplies the Quance Theatre. This zone utilizes a carbon dioxide to modulate temperature within the theatre based on occupancy. The fourth HVAC zone supplies air to a small audio/visual room situated in the basement.

The scope of this project includes an improvement of the current mechanical control system's schedule and sequences in order to optimize the amount of energy being used. The mechanical controls in the Education Building regulate the building's ventilation, space heating/cooling, domestic hot water, and pool. The Office of Sustainability and Facilities Management Division are asking for an evaluation of the current control system in addition to any design recommendations that can be done to improve economic and energy performance of the system.

Several objectives must be completed in order to successfully complete this design project. First, an analysis must be made as to where the current control system can be improved regarding energy efficiency. For this project, the analysis will focus primarily on the HVAC system. Secondly, a quantitative assessment must be made in terms of the reduction of energy consumption. This will involve a comparison between the original mechanical system and the updated system.

Finally, a goal of 15% reduction of energy consumption is set to provide sufficient building sustainability for the future.

Along with the three objectives stated, numerous constraints affect the outcome of this project. First, the updated control system must utilize existing mechanical equipment in the building; therefore, energy savings must come strictly from control adjustments. Secondly, all relevant ASHRAE standards and building codes must be abided. This is to ensure sufficient ventilation and comfort levels are present throughout the Education Building. A third constraint that must be followed is the new control system the U of S will be installing is already selected. The university will be changing the current *Robert Shaw* control system to a *Delta Controls* system. This restricts any company-specific control system to be put in place. Lastly, due to the time constraint of the project an empirical analysis of existing data will only be present throughout fall and winter operation; spring and summer operation cannot be monitored. Thus, any information during this timeframe will have to be estimated.

The deliverables for this project include a report summarizing all applicable information found addressing the assigned objectives. An analysis of present mechanical energy consumption must be shown, highlighting any potential areas of improvement. Also, a breakdown of the updated control sequences for the proposed system is required in the report. This will include an examination of the energy used by the suggested system. Furthermore, a comparison between the current and proposed systems must be made. Lastly, any recommendations for further productivity improvements will be supplied. In addition to this report, the results of the project will be presented at an event hosted by the Office of Sustainability. This event will demonstrate several student projects from across campus focused on refining the University of Saskatchewan's sustainability.

2. Design Alternatives:

Seven alternatives were considered for improving the mechanical control system:

- Filter/Pressure Sensors
- Enthalpy
- CO_2 Sensors
- Nighttime Purge
- Optimum Start
- Set point Adjustment
- Hydronics

2.1.1 Design Alternative- Filter/Pressure Sensors

Fans F70 and F71 filter banks have a pressure differential switch that closes to generate an alarm. The filter/pressure sensors alternative looks at lowering the set point on the alarm on the filters. This means that the filters are changed more regularly which could potentially reduce fan load. This alternative increases the maintenance cost because the filters are replaced more frequently. Potential savings appear if the energy saved by reducing the fan loads was greater than the added cost of replacing the filters more often. See Figure 1 for an example of a differential pressure sensor (DPS- FILT1) across a filter following fan F71. This sensor is connected to alarm AI06, which is one location where this alternative could be applied.

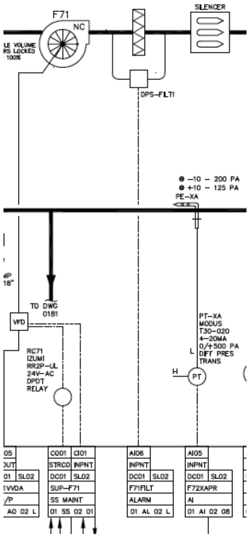

Figure 1: U of S Schematic Showing Differential Pressure Sensor Across Filter

2.1.2 Design Alternative- Enthalpy

The enthalpy alternative involves installing enthalpy sensors at select building locations. Enthalpy sensors are used to measure the humidity of the air in order to heat and cool the air more effectively. Enthalpy sensors can be used as a single sensor on the return air or in both the return air and outside air. This allows the system to drop the minimum outside air when the outside air enthalpy is equal to the return air enthalpy (McDowall et al, 2009). Figure 2 shows an example of how the system can use enthalpy to determine the temperature below 18^{o}C and any moisture contents. A system without enthalpy sensors does not have this level of control of the system. There is currently no humidity control within the education building so this would also have to be a consideration when looking at the enthalpy control alternative.

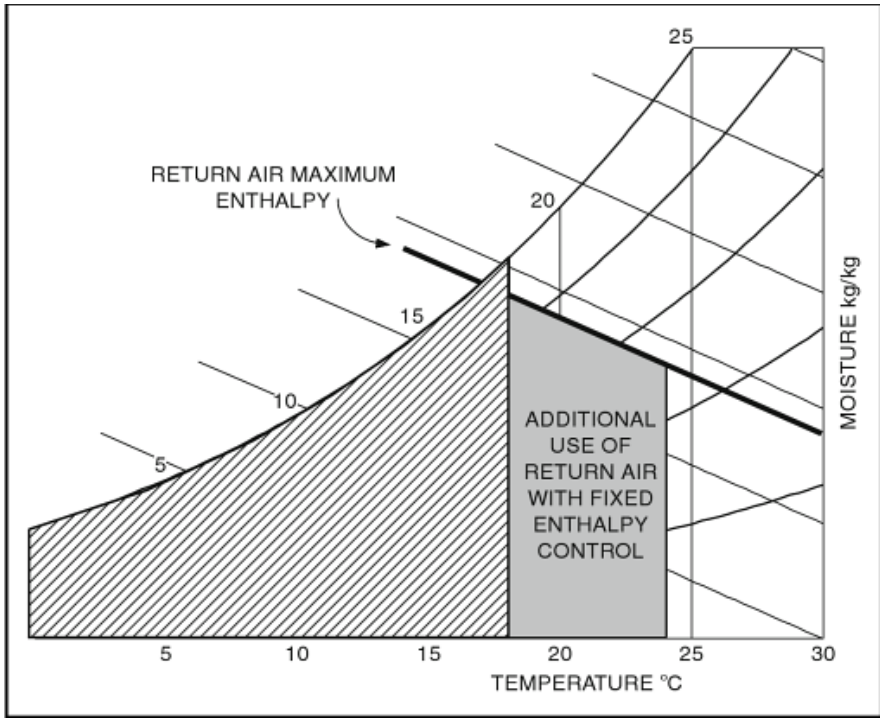

Figure 2: Temperature vs Enthalpy for Switching off Economizer (McDowall et al, 2009)

2.1.3 Design Alternative- CO_2 sensors

The CO_2 sensors alternative involves installing CO_2 sensors in selected building locations. These sensors measure the amount of CO_2 in a given area, and from this determine the amount of people occupying it. The heat gains given off by the people are considered when heating and cooling the area to avoid wasted energy overheating. The area could also be cooled by a certain amount when it is not in use, which is determined by the sensor. Currently, the Quance Theatre is the only area with a CO_2 sensor. Figure 3 shows an example of schematic on how a CO_2 sensor is implemented into the Quance Theatre.

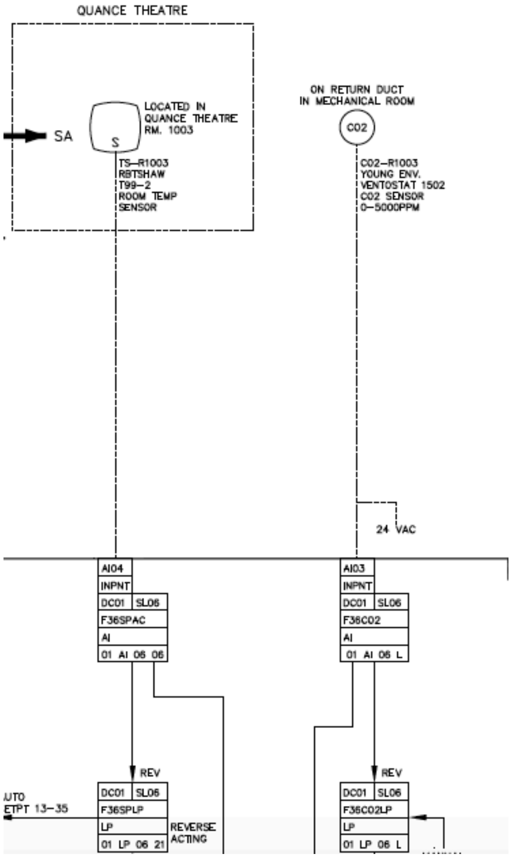

Figure 3: U of S Schematic Showing CO2 Sensor in Quance Area

2.1.4 Design Alternative- Nighttime Purge

The nighttime purge alternative looks at a technique involving opening the outside air dampers and running the fans at night. This provides passive ventilation when the temperature is low enough outside, removing as much heat from the building without using active HVAC cooling. The purpose of this is to bring in cool outside air during the night to delay the start of air conditioning in the morning. Because of Saskatoon's climate this alternative could only be implemented in some of the summer months, when the temperature is high during the day and low at night. Figure 4 shows an illustration of a nighttime purge system and how it removes heat from the building during the night.

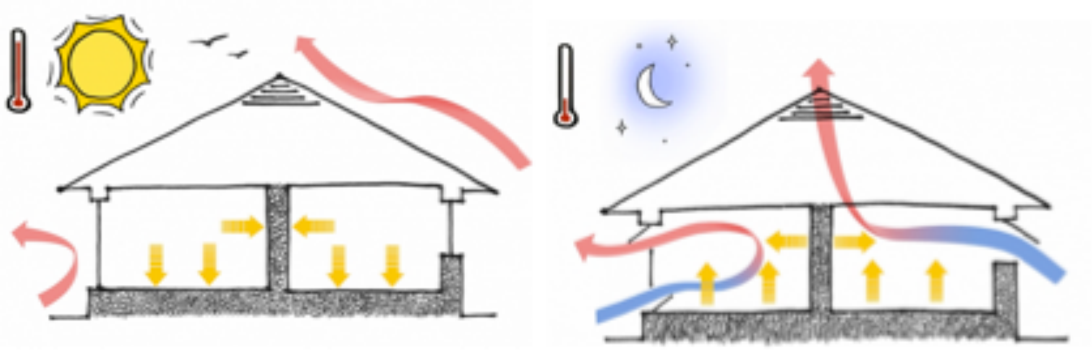

Figure 4: Illustration of Nighttime Purge technique used on a building ("Night-Purge Ventilation", 2015)

2.1.5 Design Alternative- Optimum Start

The Optimum Start alternative looks at optimizing the time the system and starts based on outside temperature as opposed to starting at fixed times. This alternative is possible now that the system is being upgraded from analog to digital controls. The savings from this alternative arise from not running the system when it is unnecessary. This alternative requires an algorithm that takes zone temperature, the outdoor air temperature and time to heat or cool the set point (Optimal Start/Stop of HVAC Systems, 2015). This algorithm approximates the start point of the system. Figure 5 shows potential energy savings due to a delayed start of a system in the morning.

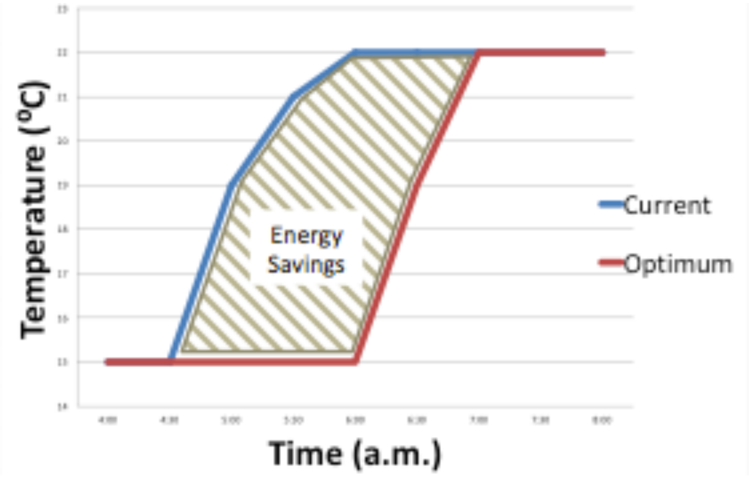

Figure 5: Graph highlighting potential energy savings due to delayed start of system

2.1.6 Design Alternative- Set Point Adjustment

The set point adjustment alternative looks at adjusting the set points of the hot deck and cold deck temperature. By adjusting the cold deck, hot deck, and mixed air temperature set points along with flow rates while maintaining indoor comfort levels, there is potential for large energy savings. Furthermore, the cold deck and hot deck temperatures could be moved closer together in order to maintain indoor temperature while reducing the heating and cooling load.

2.1.7 Design Alternative- Hydronics System

The hydronics system alternative examines areas of the hydronics system. Steam temperature and pump flow rates could be examined in order to find energy savings. Because data was not available on the hydronics system, this was not a viable alternative to be considered.

2.2 Evaluation Matrix

Table 1 shows the evaluation matrix used to determine the selected design alternatives using five criteria to evaluate the seven design alternatives. The score is based on a 1-10 scale, 10 being best and 1 being the worst. The first criteria assessing the alternatives is implementing cost. This measures how much the alternative costs to implement, with cheaper costs resulting in higher scores. The second evaluation criterion is maintenance. This estimates the maintenance cost required to preserve the alternative once it has been implemented. Thirdly, potential savings of the alternatives are evaluated. This is weighted three times heavier than the other criteria because it is crucial to accomplish the objectives of the project. The fourth criterion used is difficulty of analysis, which looks at the quantity of information available as well as the number of assumptions require to be made for the alternative. The difficulty of analysis alternative was weighted by half as it was considered as the least important criteria. The final criterion used to evaluate each alternative is availability of data. This is simply a pass or fail condition based on data obtainability to analyze and implement the alternative. The only alternative to fail the availability of data criteria was the hydronics system alternative; therefore the hydronics system alternative was eliminated as a viable option.

Table 1: Evaluation Matrix Used to Determine Alternatives

Alternatives	**Implimenting Cost (10)**	**Maintanance (10)**	**Potential Savings (x3)**	**Difficulty of Analysis (/2)**	**Availability of Data (Pass/ Fail)**	**Total**
Filter/ Pressure Sensors	8	3	3	7	Pass	27
Enthalpy	4	3	3	5	Pass	21
CO2 Sensors	3	8	6	5	Pass	34
Nighttime Purge*	**9**	**6**	**8**	**7**	**Pass**	**46**
Optimum Start*	**9**	**9**	**7**	**7**	**Pass**	**46**
Setpoint Adjustment*	**10**	**10**	**8**	**7**	**Pass**	**51**
Hydronics System	N/A	N/A	N/A	N/A	FAIL	N/A

Based on the evaluation matrix, the three highest-ranking alternatives were set point adjustment, optimum start and nighttime purge. All of these alternatives have low implementing cost, low maintenance cost, high potential savings as well as available data to examine implementation.

3. Operation of Areas

3.1 Main Area

The penthouse air-handling unit conditions the air for the majority of the University of Saskatchewan Education Building. The supply fans are the largest in the building and can handle up to 90000 cubic feet of air per minute. Air is taken from outside which mixes with return air. Mixed air dampers control the amount of return air that is mixed with outdoor air. The remainder of the return air that is not mixed is exhausted. The mixed air is then directed through one of the two main supply fans, either F70 or F71. Next, the air is split into two different ducts, a cold deck and a hot deck. Air in the cold deck passes through a cooling coil while air in the hot deck passes through a preheat coil then a heating coil. These two ducts combine downstream in mixing boxes before supplying rooms with conditioned air.

3.2 Gym, Locker Rooms, and Pool Area

The air supplied to the gym comes directly from outdoor air. It first passes through a preheat and reheat coil bank, then sent to either the locker rooms or through another heating coil before being directed into the gym. From the gym, air is sent to the locker rooms or to a heat recovery coil. The air sent to the locker rooms is first split into a duel duct system: both have dampers while one duct is equipped with a heating coil. This system modulates to preserve a temperature of 25.5°C in the men's, women's and faculty locker rooms. Next, air returned from the locker rooms is sent through a final heating coil before being supplied into the swimming pool. This heating coil is set to retain the pool exhaust air temperature at 27°C. Finally; air exhausted from the pool is guided back to the heat recovery coil mentioned previously.

3.3 Quance Area

A standalone air-handling unit controls the Quance Theater. The fans run during the weekdays from 7:30 until 23:00 and weekends from 8:00 until 23:00. The supply air consists of a combination of two airflows: outdoor air mixes with return air resulting in overall supply air. The amount of return air that is combined is controlled by a PID loop which modulates the mixed air dampers to achieve a temperature set point. The excess return air not mixed with outdoor air is exhausted. The mixed air temperature set point can be reset by a CO_2 loop. This adjusts the temperature of the mixed air based on the number of people in the room. The mixed air then goes through a heating coil and cooling coil that conditions the air based on the PID loop that is sent feedback from zone temperature.

The Quance Theater is upgraded significantly in comparison to the rest of the Education Building. It uses a PID loop and CO_2 sensor to achieve desired temperatures more accurately than the rest of the building. The Quance Theater is the only room that has a CO_2 sensor. The CO_2 sensor allows the temperature to be adjusted based on occupancy. Because the Quance Theater already has a fairly sophisticated method of temperature control, it was decided to focus our analysis on other areas of the building. A more in depth analysis of the PID loops and set points could be done in an attempt to optimize the current controls, however the cost of analysis may outweigh the benefits as any potential changes will likely be negligible.

4. Method of Analysis

4.1 Establish Baseline

In order to quantify any improvements that are made, an approximation of the system's current energy usage must be calculated. First, weather data for Saskatoon was acquired from the US Department of Energy for 2013. The data shows the outdoor dry bulb air temperature broken down into every hour for the entirety of the year. In order to improve accuracy of results, bin data could be taken from many years and averaged. The outdoor air temperature was then used by the system to set a number of operating temperatures. The following reset tables were given with the current sequences:

Table 2: Reset Points for Hot Deck, Cold Deck and Mixed Air Temperature

OAT (°C)	HD SAT (°C)
Hot Deck	
13	22
-48.7	55
Cold Deck	
OAT (°C)	**MAT (°C)**
30	13.5
-50	19
Mixed Air	
OAT (°C)	**MAT (°C)**
30	13.5
-50	19

These tables were then used to generate a reset graph for the hot deck, cold deck, and mixed air temperature set points. They appear as follows:

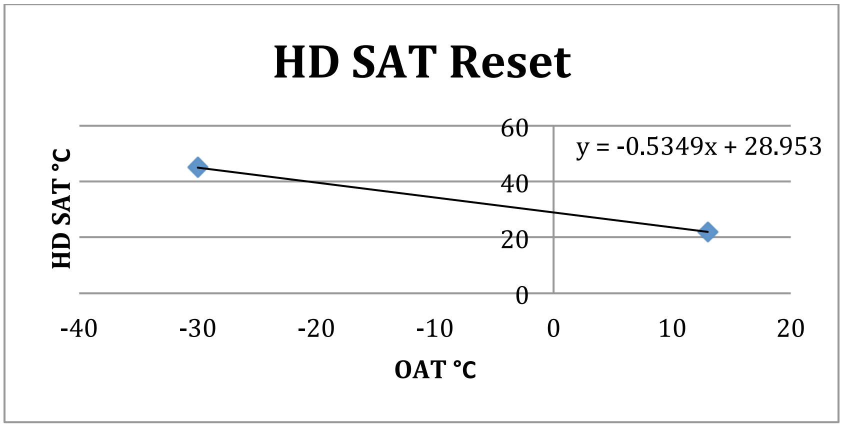

Figure 6: Hot Deck SAT Reset

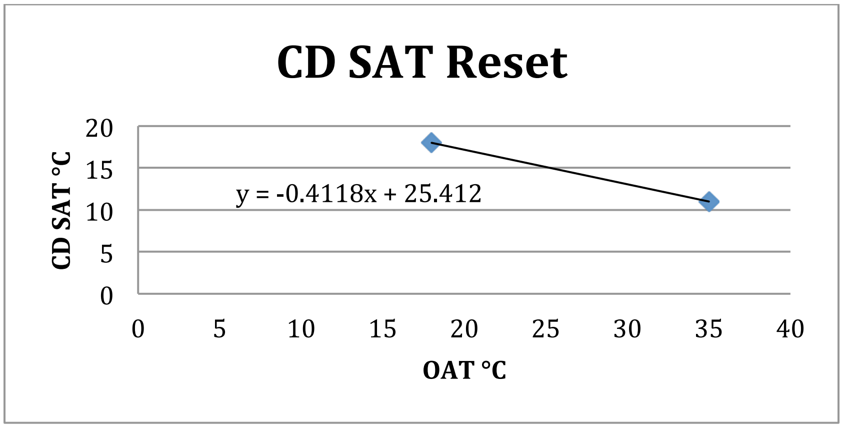

Figure 7: Cold Deck SAT Reset

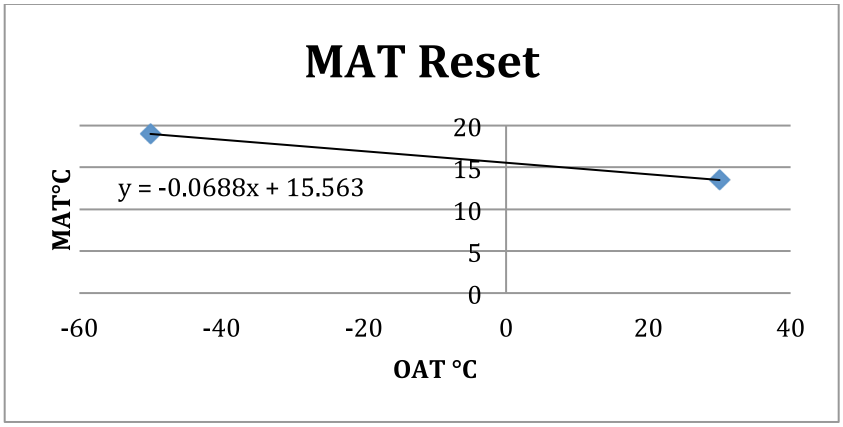

Figure 8: Mixed Air Temperature Reset

The current sequences also give airflow resets for the hot deck and cold deck, which modulate flow rates according to their respective set temperatures.

Table 3: Hot Deck and Cold Deck Flow Rates

HD SAT (°C)	Flow Rate (m^3/s)
55	16.5
22	8.45
CD SAT (°C)	**Flow Rate (m^3/s)**
18	18.4
11	35.2

These tables were then used to generate graphs to get an equation for the relationship. The two graphs are as follows:

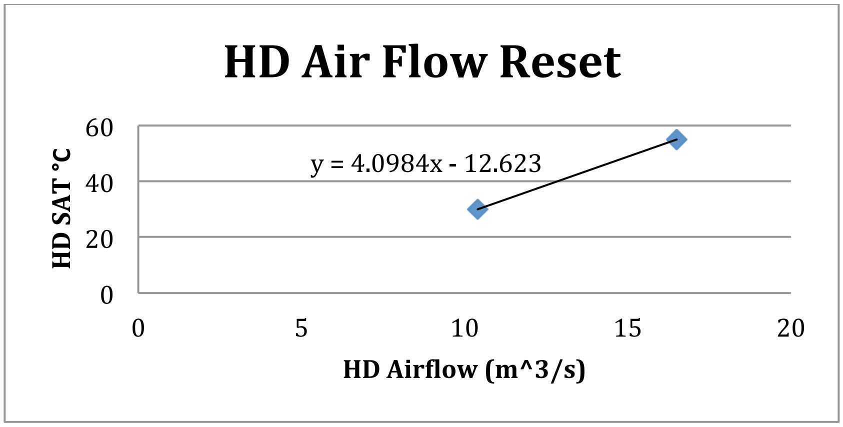

Figure 9: Hot Deck Air Flow Reset

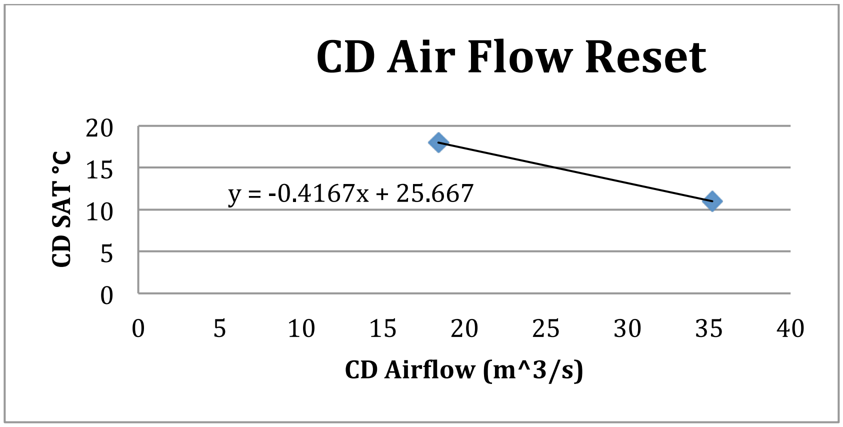

Figure 10: Cold Deck Reset

All equations generated with the Figures 6-10 were then applied to the acquired bin data, resulting in hot deck, cold deck and mixed air temperatures, as well as volumetric flow rates of the hot deck and cold deck for any given time.

The mixed airflow rate was calculated by summing the hot deck and cold deck flow rates. The temperature also needed to be modified because the reset graph is highly inaccurate during summer. The inaccuracy arises when the outdoor air temperature becomes greater than the mixed air reset temperature. An adjustment was made so the mixed air temperature will set to the average of the return air temperature and outdoor air temperature if the set mixed air temperature is less than the outdoor air temperature.

The return air temperature was assumed to be the same temperature as room temperature. The University Facilities Management Division states that the building will be set to stay within the range of 22°C and 25°C. It is very difficult to determine where room temperatures falls within this range without historical data, so in order to obtain a temperature for analysis it was assumed that when outdoor air temperature is less than 23°C, room temperature will be 22°C. If outdoor air temperature is greater than 23°C, room temperature will be 25°C.

There is also a reset currently in the system that states if the return air temperature is less than the outdoor air temperature, the mixed air dampers will set to 50%, otherwise the system modulates return air flow based on outdoor air temperature.

The mass flow rate of the return air then needed to be calculated. This calculation was done by looking at the mixing of air flows, i.e. outdoor air and return air mix to form mixed air, which is then split into hot air and cold air. (See A.10 in Appendix A)

Next, energy input was calculated for both the hot deck and the cold deck. This analyzes the energy required to bring the mixed air temperature to the required hot deck or cold deck temperature (See A.17 in Appendix A).

After the energy input was calculated for the hot deck and cold deck, the schedule the system runs on needs to be considered in order to get the actual energy used. The current schedule is broken into summer and winter modes. The winter mode runs from October 15th to May 15th, while the summer mode extends from May 15th to October 15th. Each mode then has a different schedule for weekends and weekdays. All operating schedules can be seen in Figure 11.

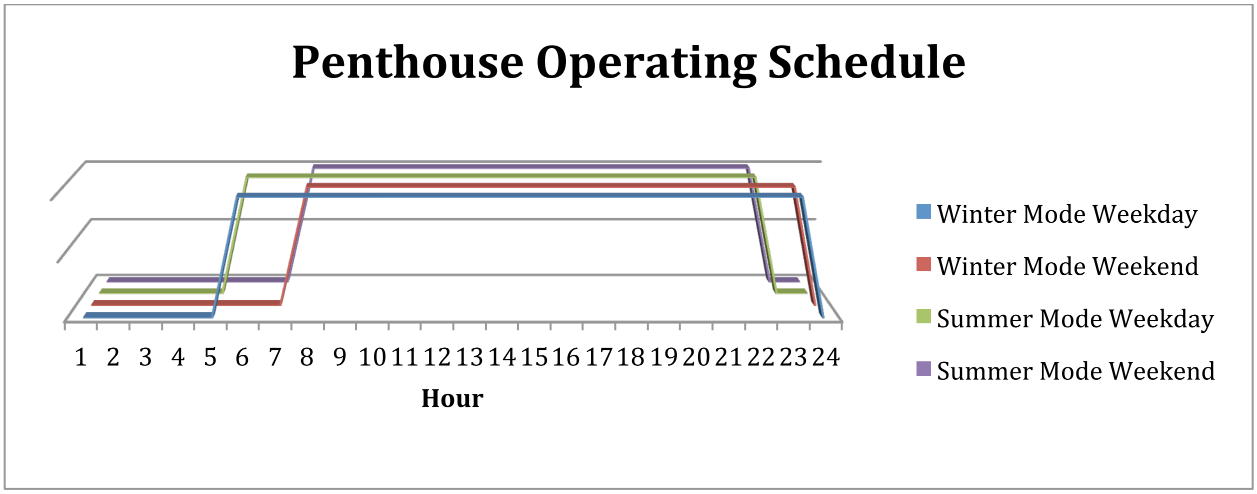

Figure 11: Penthouse Operating Schedule

In the analysis it was assumed that the system never operates at night because there is no historical data showing how long the building takes to heat up or cool off. The current system will turn on if the building temperature drops below 17°C, so when it is very cold in the winter there will likely be some heating at nighttime that is not being considered. A building as large as the education building has a great deal of thermal mass so it will take quite a long time to cool off, therefore the error should be minimal.

Next, the energy was calculated for the fans used by the penthouse system. There are four main fans in the penthouse system: the return fans F70 and F71, and the mixed air fans F69, and F72. Available data included peak load, maximum flow rate and power for each of the fans. It was assumed that the fans will be running at their maximum flow rate when the air flow rate is at its maximum, then the fan power will decrease proportionally as flow rate decreases. It was also given that fans F70/F71 operate at 70% when the flow rate is at its maximum. By using the given fan information along with the calculated flow rates, fan energy consumption can then be calculated. The power of all other fans in the building was then summed up and their energy consumption was calculated. Because most of the remaining fans are exhaust fans, the return airflow rate was used for this calculation. Summing all calculated fan powers and applying the operating schedule results in total fan power. This provides a working model of the current system. From here, adjustments can be made to seek out potential operation improvements.

4.2 Set Point Adjustment

Facilities Management Division states that room temperature must stay within 22°C and 25°C, so indoor room temperature cannot be modified; although, adjustments can be made to the hot deck, cold deck and mixed air temperatures. The hot deck, cold deck, and mixed air all follow reset graphs that have upper and lower limits, therefore a sensitivity study was done for each set point by changing the upper and lower limit of each.

4.3 Optimum Start

Next, the system was modified by implementing an optimum start. Since there is no historical data allowing us to determine duration for the building to heat up, it was assumed that the maximum temperature differential between outdoor air and indoor temperature within the year takes the maximum start time. The maximum start time is two hours since the system starts up at 6:00am and the building opens at 8:00am. It was assumed that the time it takes for the building to heat up will be a ratio of this temperature differential, thus when the temperature differential is half of the maximum, the building will take half of the maximum start-up time which is one hour.

In order to calculate the amount of energy saved by delaying the system start-up, the energy currently being used for the start-up time period (6:00am to 8:00am on a weekday) was summed then multiplied by the percentage of the maximum temperature differential.

4.4 Nighttime Purge

The last method of improvement that was tested was nighttime purge. Implementing a nighttime purge would lower the building's temperature by running the fans when it is colder outside than it is inside. It was assumed that running the fans for two hours would be adequate time to cool the building. Cooling the building during the night will delay the start of the fans until later in the morning. This means that the fans will be off for two hours when they are normally running, so the power consumed by running the fans at night will be offset by delaying fan start-up prior to opening the building. It can be expected that the building will cool to approximately 20ºC utilizing nighttime purge, and the cooling will not turn on until room temperature has risen to 25ºC. It should be noted that cooling to 20ºC is below the lowest allowable temperature specified by Facilities Management Division, however this would directly increase energy savings. Also, ASHRAE standards state that comfort will not be compromised unless temperature drops below 19ºC. Savings are calculated assuming cooling could be delayed until 10:00am.

Nighttime purge is only effective if there is significant cooling energy used throughout the day. Since the highest allowable room temperature is 25ºC, the temperature needs to reach a value higher than that for there to be significant cooling. From climate data over the last 30 years the average daily high is 22.4°C in June, 25.3°C in July, 24.9°C in August, and 19.3°C in September as seen in Figure 12. While there will undoubtedly be days in June and perhaps May or September that reach a temperature higher than 25°C, it was assumed that nighttime purge will only be effective in July and August. This will be offset by the fact that there will be some days in July and August where the temperature does not reach a value above 25°C.

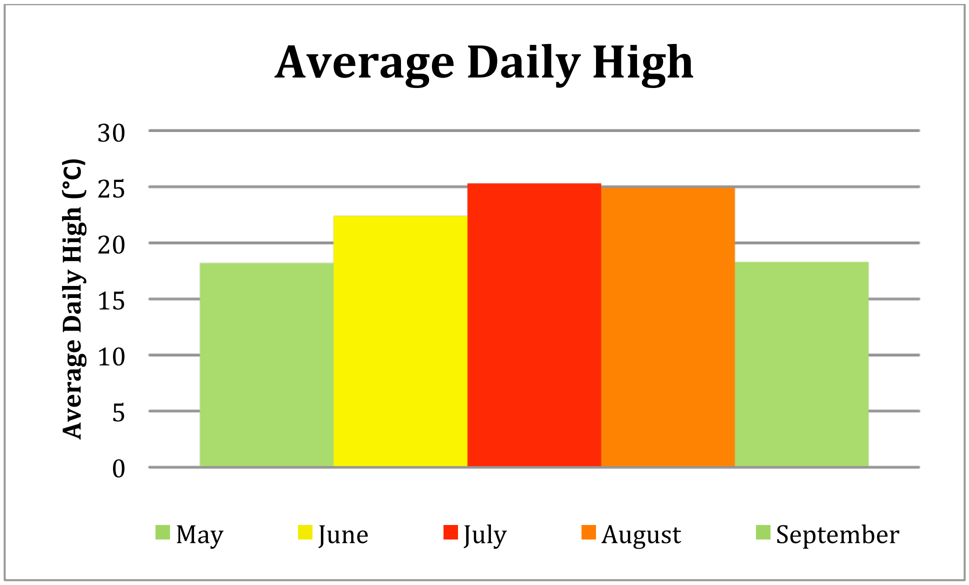

Figure 12: Average Daily High for Education Building

5. Final Design- Analysis of Alternatives

5.1 Main Area Design Alternatives

5.1.1 Set point Adjustment

By adjusting set points in the penthouse air hander, a large impact on annual energy consumption is achieved. This is done using an excel file that models the energy use within the main area. Parameters adjusted within this area include upper and lower hot deck temperature, upper and lower cold deck temperature, and upper and lower mixed air temperature. Room temperature cannot be adjusted because Facilities Management Division has specified that room temperature be at 22°C in the winter and 25°C in the summer. Table 4 shows the adjustments made to the hot deck reset schedule. The current system modulates between 55°C and 22°C.

Table 4: Hot Deck Upper and Lower Adjustment

Hot Deck Upper and Lower Adjustment		
HD Upper SAT	**Yearly Energy Consumption (MWh)**	**% Change**
53	1955.44	-1.454
54	1969.87	-0.727
55	1984.29	0
56	1998.71	0.727
57	2013.13	1.453
HD Lower SAT	**Yearly Energy Consumption (MWh)**	**% Change**
20	1901.76	-4.159
21	1941.77	-2.143
22	1984.29	0
23	2028.44	2.225
24	2072.80	4.461

Figures 13-16 show how changing the temperature set points of the hot decks upper and lower limits affect yearly energy consumption. It can be seen that energy savings can be made by lowering both of these temperature limits. Reducing the hot deck upper temperature by 1^{o}C can reduce energy consumption by 0.72% and raising the hot deck lower temperature by 1^{o}C can reduce energy consumption by 2.14%.

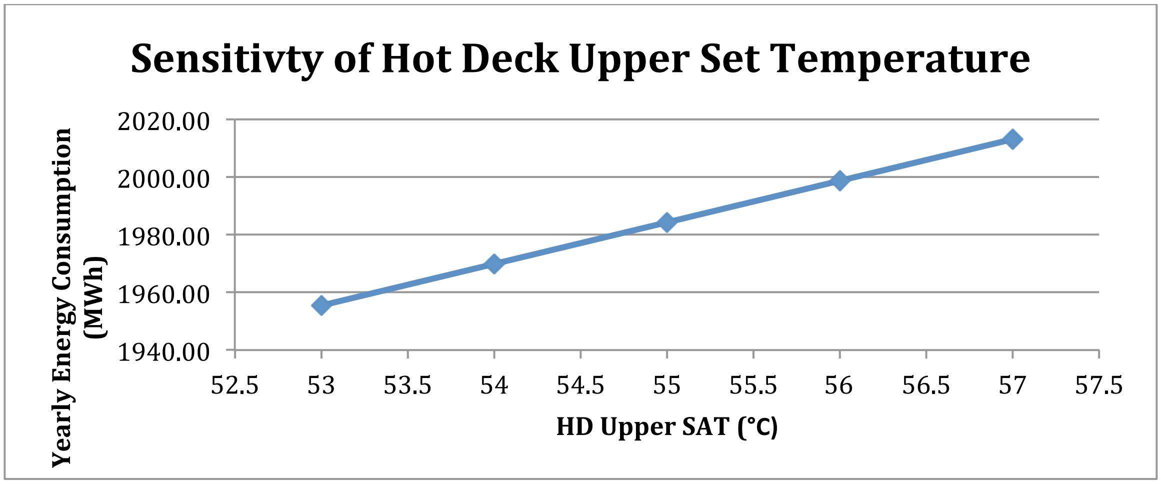

Figure 13: Sensitivity of Hot Deck Upper Set Temperature Yearly Energy Consumption

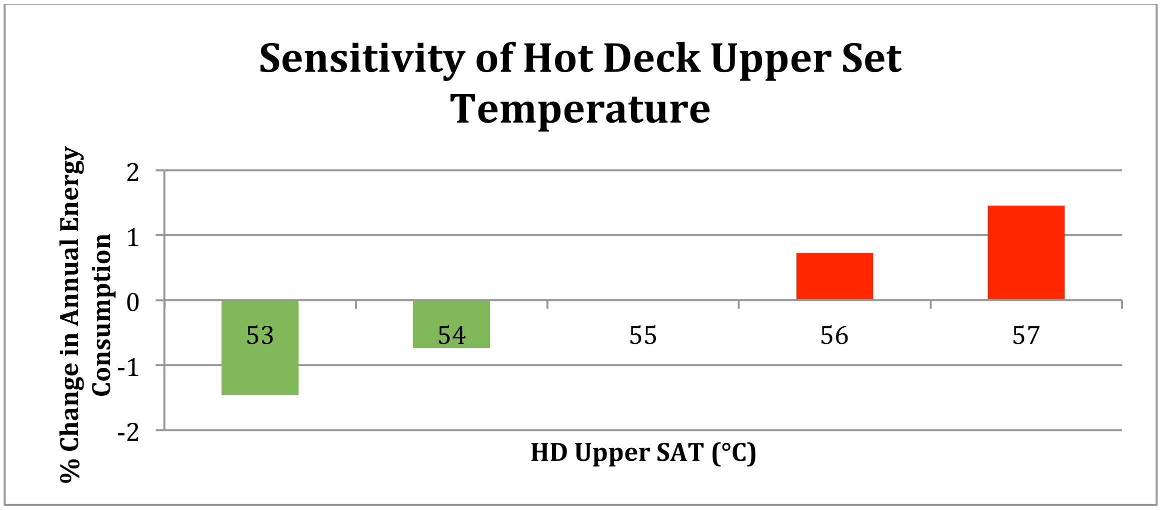

Figure 14: Sensitivity of Hot Deck Upper Set Temperature %Change

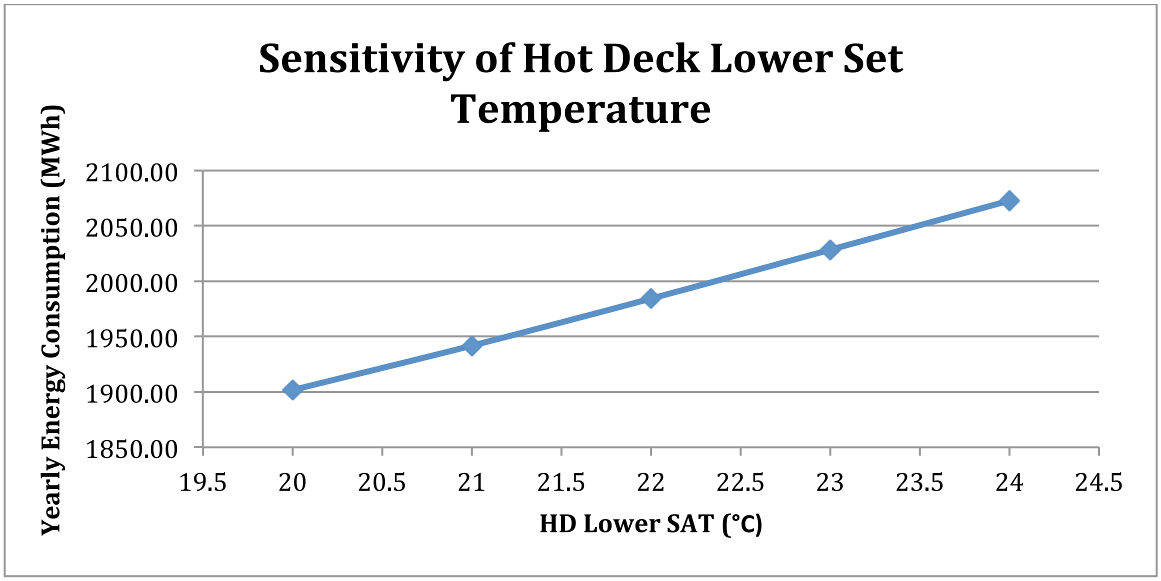

Figure 15: Sensitivity of Hot Deck Lower Set Temperature Yearly Energy Consumption

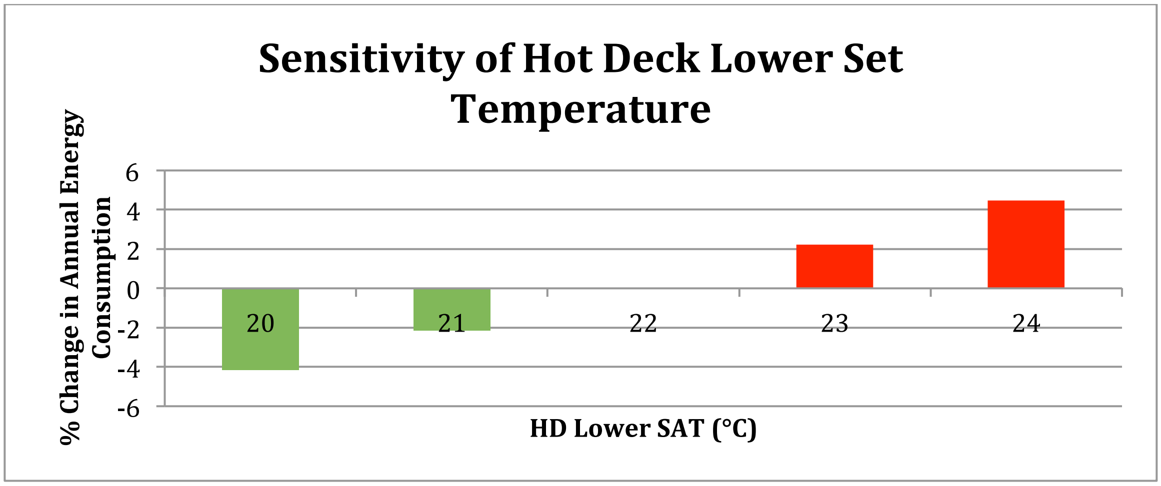

Figure 16: Sensitivity of Hot Deck Lower Set Temperature % Change

Similar to the adjustments made for the hot deck, the cold deck limits are also modified. From the adjustments made in Table 5, it can be seen that increasing both values saved energy. Increasing the upper set point had a much larger impact on energy savings.

Table 5: Cold Deck Upper and Lower Adjustment

Cold Deck Upper and Lower Adjustment		
CD Upper SAT	**Yearly Energy Consumption (MWh)**	**% Change**
16	2062.83	3.958
17	2016.47	1.622
18	1984.29	0
19	1956.85	-1.383
20	1935.38	-2.465
CD Lower SAT	**Yearly Energy Consumption (MWh)**	**% Change**
9	1998.36	0.709
10	1991.32	0.354
11	1984.29	0
12	1977.26	-0.354
13	1970.22	-0.709

Figure's 17-20 show the sensitivities of the upper and lower limits of the cold deck compared to the yearly energy consumption and percent change in annual energy consumption. It is seen that raising the cold deck upper temperature by 1°C can reduce energy consumption by 1.38% and lowering the cold deck lower temperature by 1°C can reduce energy consumption by 0.35%.

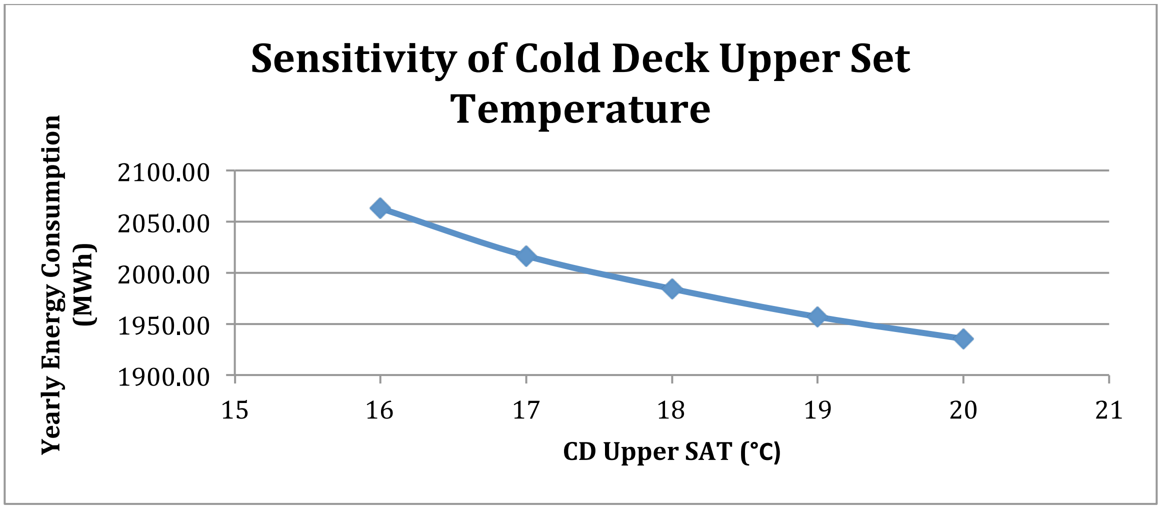

Figure 17: Sensitivity of Cold Deck Upper Set Temperature Yearly Energy Consumption

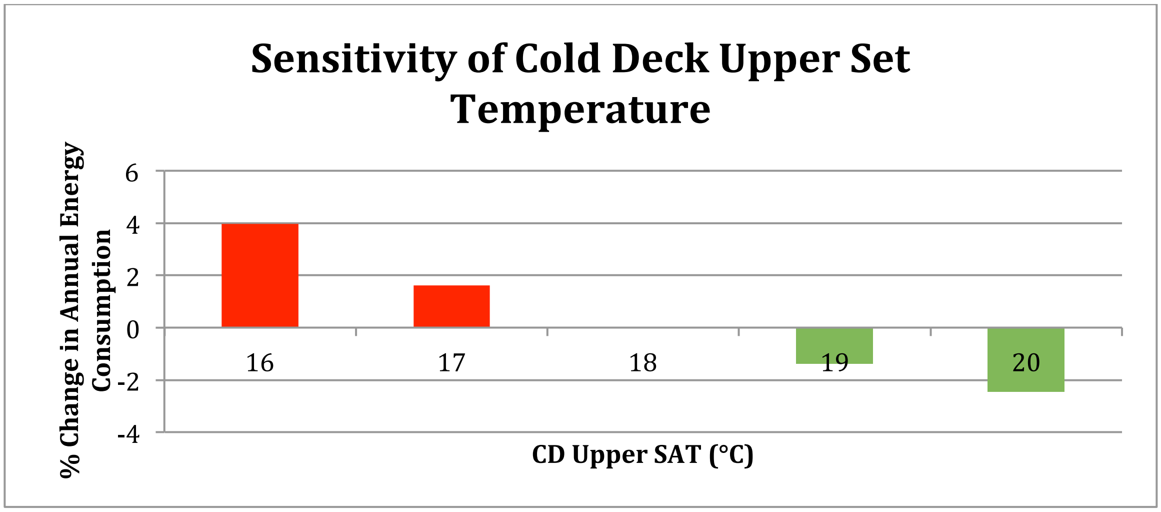

Figure 18: Sensitivity of Cold Deck Upper Set Temperature % Change

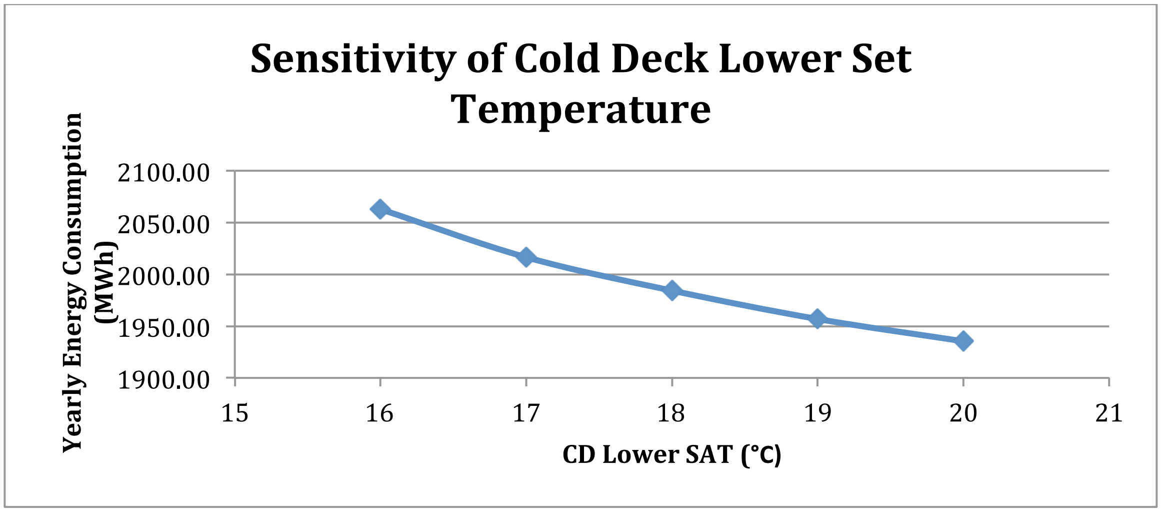

Figure 19: Sensitivity of Cold Deck Lower Set Temperature: Yearly Energy Consumption

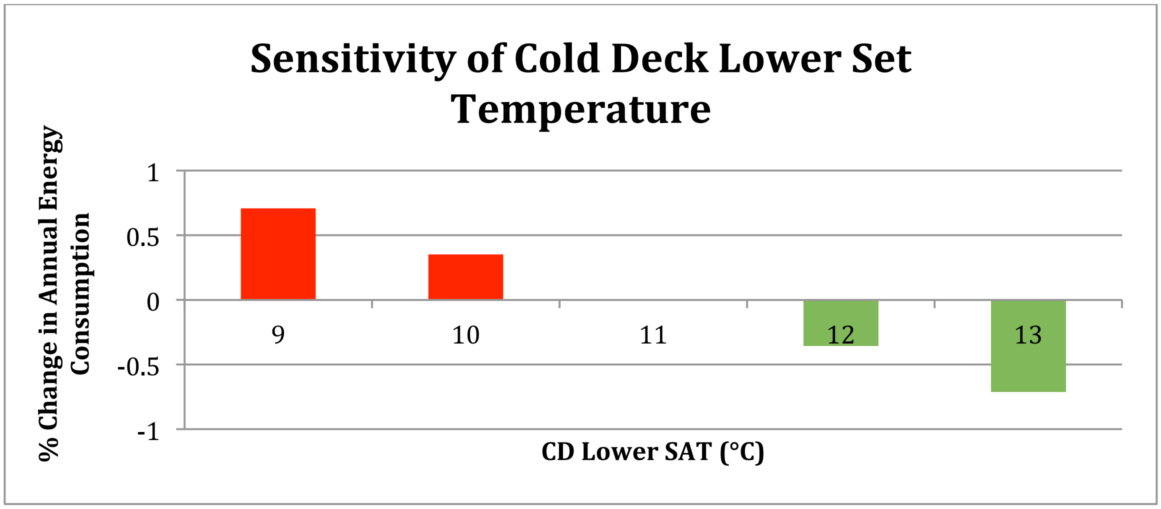

Figure 20: Sensitivity of Cold Deck Lower Set Temperature % Change

The next parameter that is varied is the mixed air set points. It is found that increasing both the upper and lower limits lowers the yearly energy consumption.

Table 6: Mixed Air Upper and Lower Adjustment

Mixed Air Upper and Lower Adjustment		
Mixed Lower	Yearly Energy Consumption (MWh)	% Change
10	2031.45	2.377
12	2005.02	1.045
13.5	1984.29	0
15	1963.56	-1.045
17	1938.19	-2.323
Mixed Upper	Yearly Energy Consumption (MWh)	% Change
15	2062.78	3.956
17	2023.21	1.961
19	1984.29	0
21	1952.77	-1.589
23	1936.69	-2.399

Figure's 21-24 show the sensitivities of the upper and lower limits of the mixed air compared to the yearly energy consumption and percent change in annual energy consumption. It is seen that raising the mixed air upper temperature by

1.5°C can reduce energy consumption by 1.04% and raising the mixed air lower temperature by 2°C can reduce energy consumption by 1.5%.

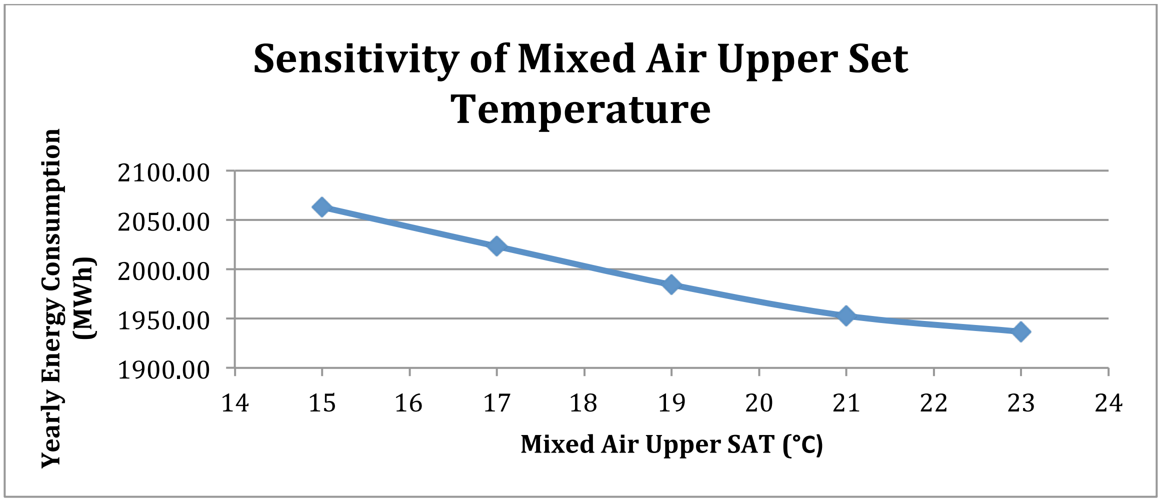

Figure 21: Sensitivity of Mixed Air Upper Set Temperature Yearly Energy Consumption

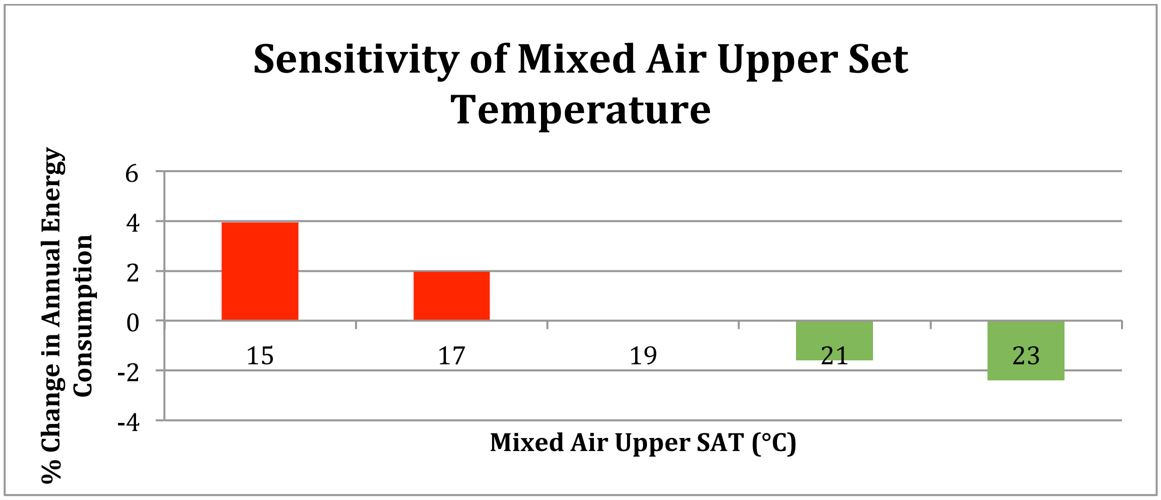

Figure 22: Sensitivity of Mixed Air Upper Set Temperature % Change

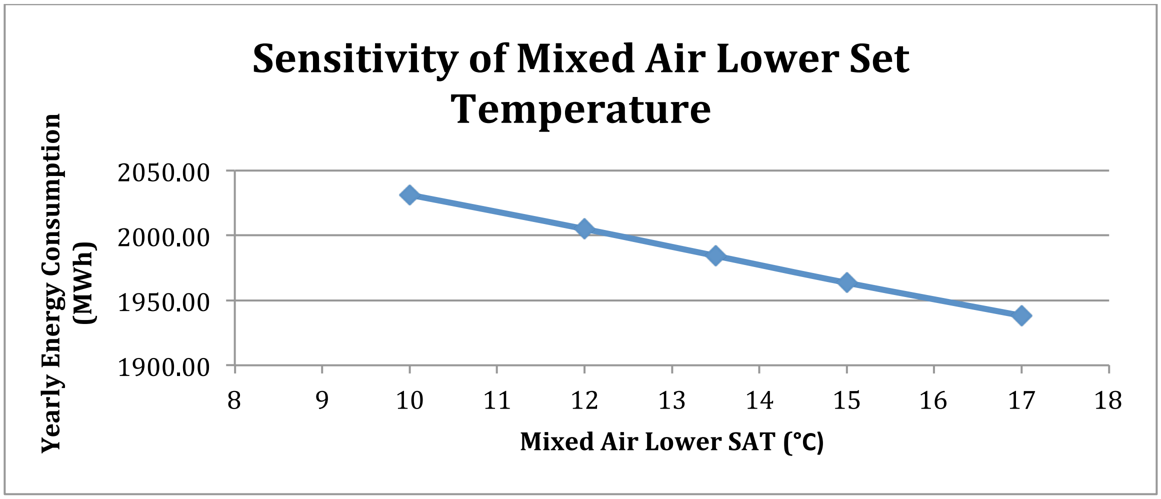

Figure 23: Sensitivity of Mixed Air Lower Set Temperature Yearly Energy Consumption

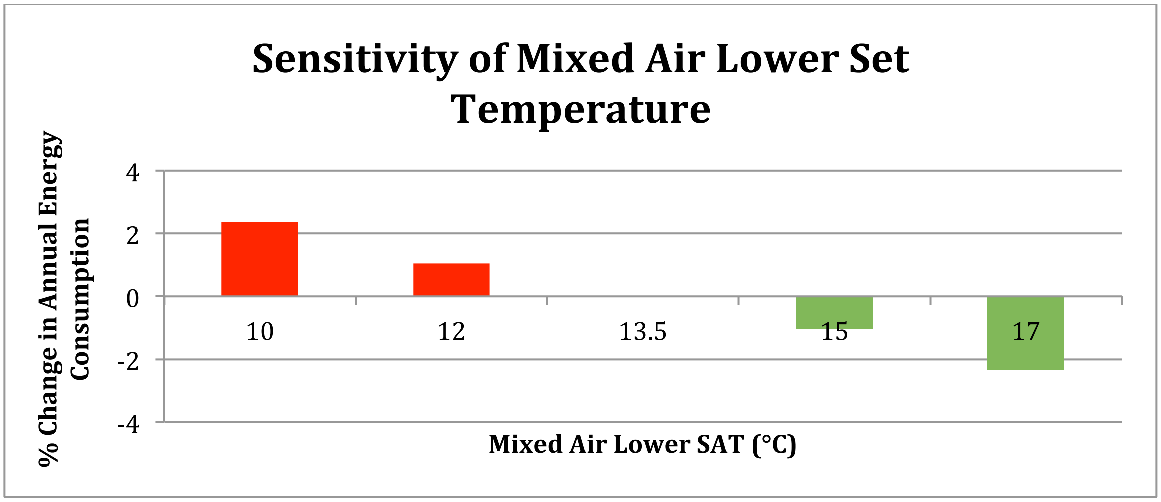

Figure 24: Sensitivity of Mixed Air Lower Set Temperature % Change

By looking at all of the sensitivity studies done for each of the six set points, it is shown that adjusting each of them can save energy. Making all appropriate adjustments and combining the results illustrate an overall reduction in energy. Table 7 shows the effect of adjusting all set points.

Table 7: Total Main Area Variation of Set points, Energy and Cost Saved

Total Main Area Variation of Set points			
Variation in Set points (°C)	% Change Energy Reduction	Energy Saved MWh	Cost Saved
0	0.00	0	$0.00
1	6.21	123.250	$8,011.25
2	7.86	155.990	$10,139.35

Figures 25-26 show results for set point adjustment in the penthouse area. A rate of $0.065/kWh is used to determine the cost savings of the system. It is shown in Figure 25 that changing the set points by 1^{o}C can save 6.21 % energy consumption and $8,011.25 in cost savings. The slope between percent reduced energy consumption and change in set points is much steeper between 0^{o}C and 1^{o}C than between 1^{o}C and 2^{o}C. This indicates that diminishing returns can be expected when adjusting the system more than two degrees.

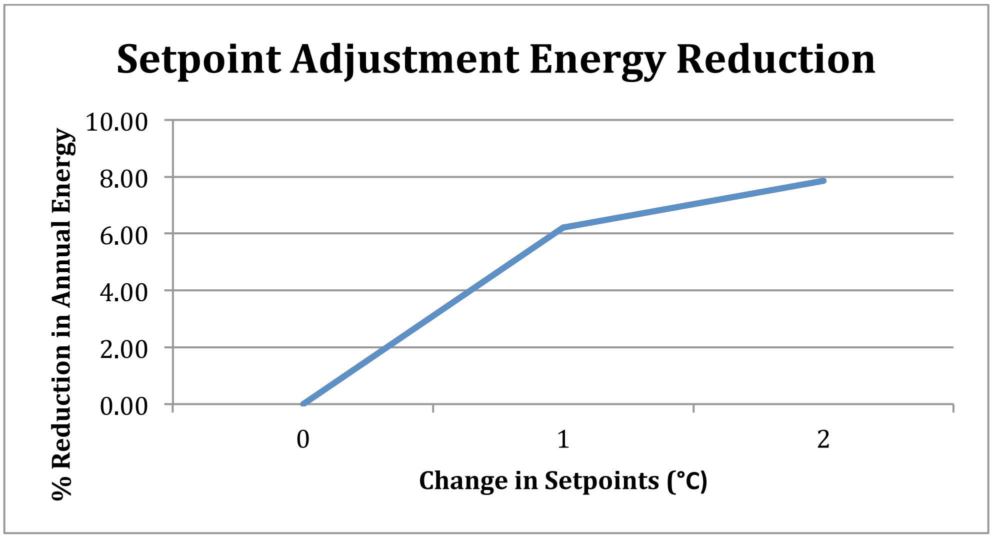

Figure 25: Total Main Area Set point Adjustment % Energy Reduction

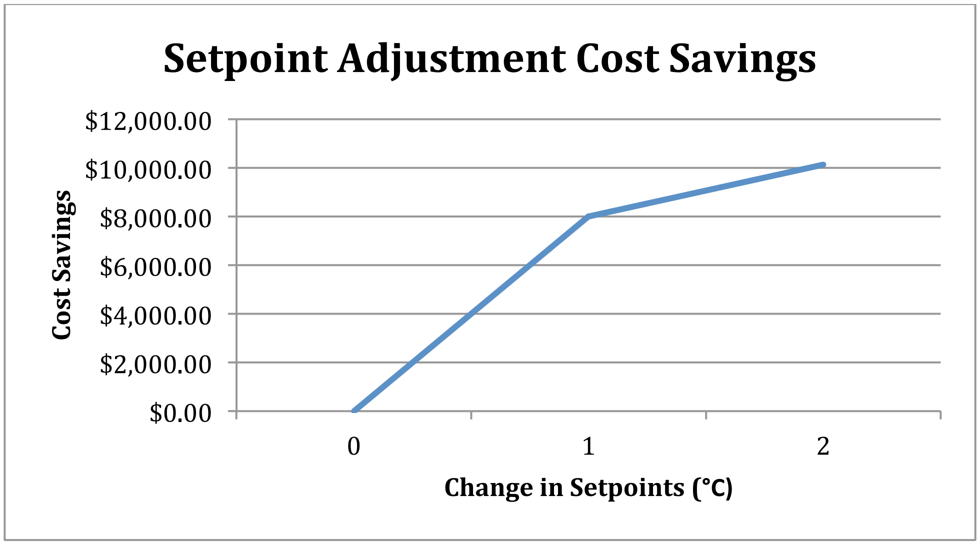

Figure 26: Set point Adjustment Cost Savings

There is no way of verifying if adjusting the set points will negatively affect the comfort of the building occupants. The only way to tell is to make the changes slowly and see if comfort is affected. It is possible that some of the changes will negatively affect comfort making them unfeasible, but it is also possible that larger adjustments could be made to increase savings without affecting comfort. All that is known is that the closer the system remains to the current set points the more feasible the change is.

5.1.2 Optimum Start

The current system was modeled giving a baseline for energy consumption so that changes could be made to see potential improvements. The current system uses 7143.38 GJ of energy annually using this model. The total energy consumption accounts for the heating, cooling and fan power throughout the course of the year. The design does not account for latent heat from moisture content within air because there are no humidity sensors or humidity regulating equipment in the education building. Also, this total does not account for gains from lighting, occupancy, and plug load, which reduces the annual heating energy, thus making our saving somewhat more conservative than actual.

The model calculates annual heating energy to be 2793.67 GJ, the annual cooling energy to be 678.65 GJ and the annual cooling energy to be 678.65 GJ. Figure 27 illustrates the energy use is broken up as percentages.

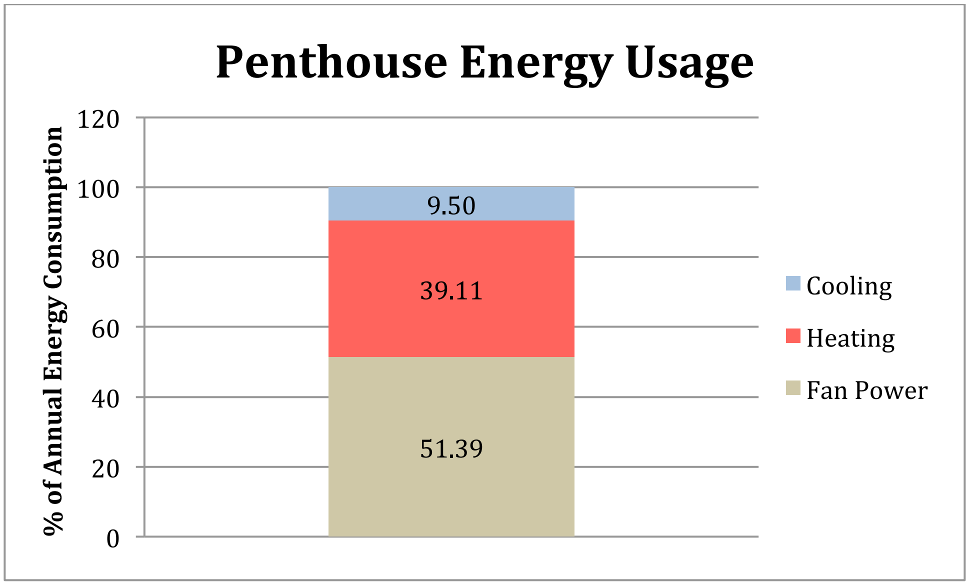

Figure 27: Penthouse Energy Use

Fan power accounts for the majority of energy usage while heating is a close second. Cooling makes up a much smaller portion of the annual energy consumption at 9.50%

5.1.3 Nighttime Purge

Nighttime purge is implemented with the intention of lowering the cooling energy required by the system. By delaying cooling five hours for the months of July and August the cooling energy was improved from 678.65 GJ to 655.69 GJ. This is a mere 3.38% reduction in cooling energy alone, and a 0.32% reduction in total annual energy.

By implementing an optimum start for the system, the annual energy consumption is reduced from 7143.38 GJ to 6699.68GJ. This is a reduction of 443.7 GJ which equates to a 6.21% reduction in annual energy use.

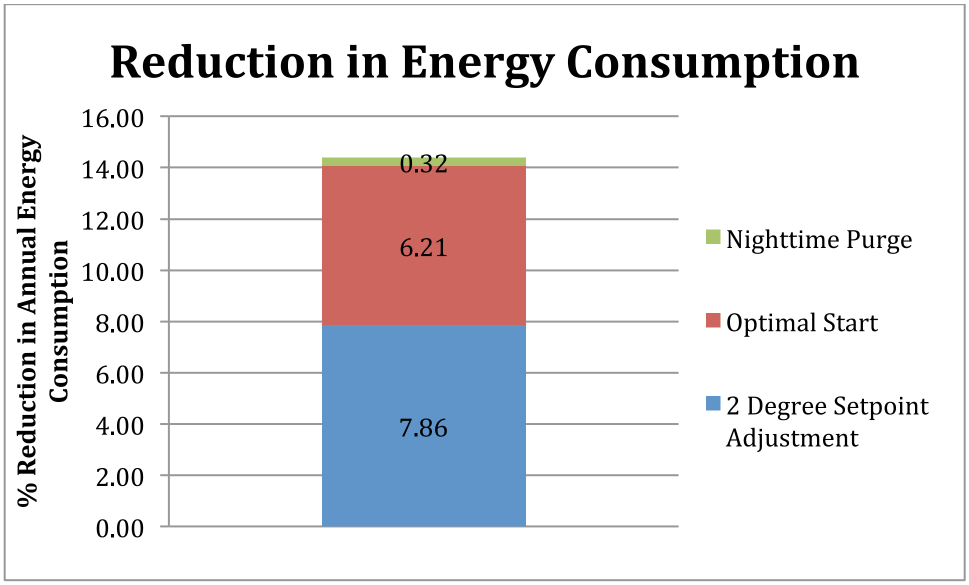

Figure 28: Reduction in Energy Consumption

When all alternatives are combined a total energy reduction of 14.39% can be obtained. Set point adjustment makes up the largest portion of this at 7.86%, followed by optimal start at 6.21%. Nighttime purge had the smallest contribution at 0.32%.

5.1.4 Verification

In order to get some verification of the energy calculations the total electrical energy of the Education building was calculated. Using an average of 10968 kWh for a weekday and 9251 kWh for a weekend, a yearly energy consumption of 3835975 kWh was approximated. Based on our model the total yearly energy to heat, cool, and run the fans is 1984289 kWh. This is around 51% of the total energy used by the building. The remaining energy would go to heating, cooling and fans in the other areas as well as plug loads, lighting etc.

5.2 Gym, Locker Room and Pool Heat Recovery

The heat recovery system utilizes return air from the pool and gym to preheat the outdoor air being supplied to the gym. The warm return air passes through a heat exchanger, which heats up water. This water is sent to the preheat coil on the gym supply air duct, which heats the outdoor air. This type of arrangement reduces the system's energy consumption because it makes use of previously heated return air to heat the supply air. For this heat recovery to work most effectively, the air is to be heated as close to the gym set point temperature as possible, resulting in the heating coils introducing minimal new energy into the air. Ideally, it is recommended the preheat temperatures to follow a relation as shown in Figure 29, assuming a heat recovery efficiency of 40%. In winter mode, which extends from October 15th to May 15th, the return air is set at 22°C. In summer mode, ranging from May 15th to October 15th, return air is 25°C.

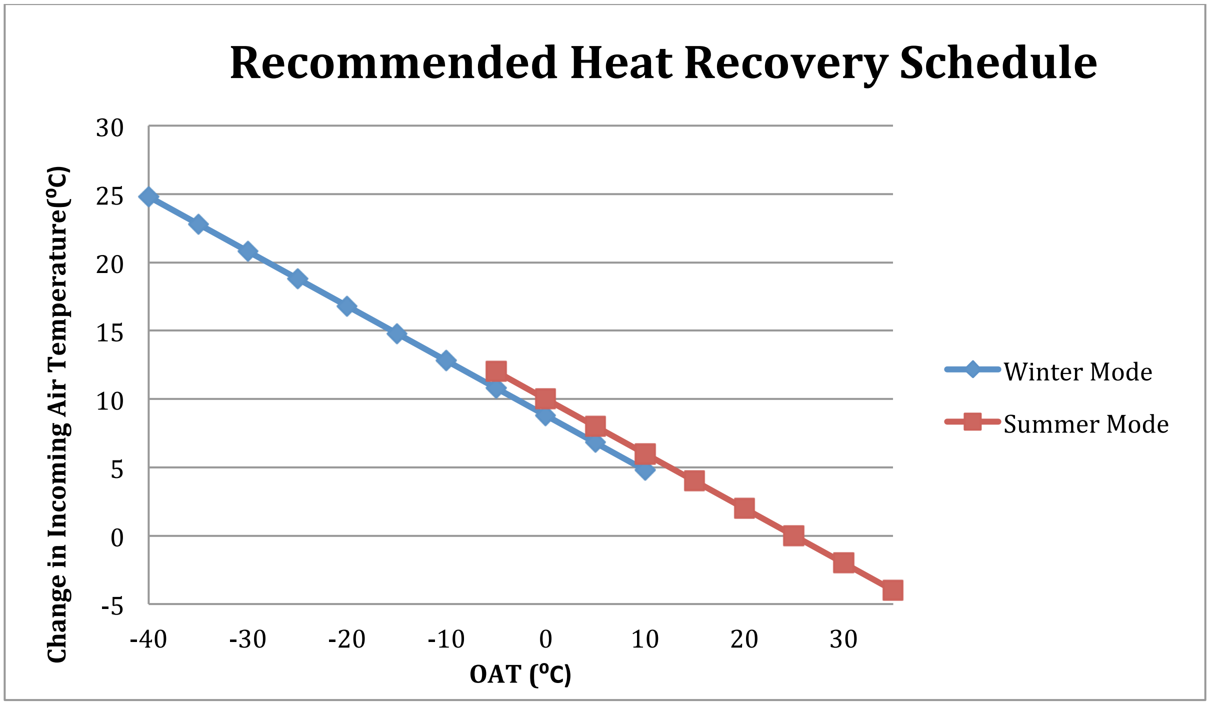

Figure 29: Gym, Locker Room and Pool Recommended Heat Recovery Schedule

The change in outdoor air temperature is calculated using the relation given in Appendix A. This relation is recommended because the preheat coil is operating at max workload at all times to recover the greatest amount of energy, reducing heating costs. In addition, the more the preheat coil heats the incoming air, the larger the energy savings will be; therefore, the most energy is saved when the difference in return air and outdoor air temperature is at its largest. Also, since there is no temperature change when outdoor air is 25ºC, there is no energy recovered because there is no difference in temperature between outdoor air and return air. Lastly, at any temperature above 25ºC, the return air is at a lower temperature than the outdoor air therefore the recovered energy is cooling the supply air instead of heating it.

6. Cost Estimate

Due to the nature of the alternatives, there is no material cost. The only cost the alternatives require is time of a specialist to program and implement the changes within the control system. There is also wages accumulated by our project group over the course of the semester. Table 8 illustrates a breakdown of hours, rate and cost from both cost of implementing the alternatives as well as the cost for the design of the project. Table 9 shows the hours as cost broken down by cost codes for Group 3. From Table 8, it is seen that the cost to implement the alternatives is $675 and the cost for Group 3 hours is $39,904. See Appendix B for the timesheet.

Table 8: Project Cost

Project Cost			
Cost Implementing Alternative's			
Alternative	Hours	Rate	Cost
Set point Adjustment	2.5	$150.00	$375.00
Optimum Stop/Start	1	$150.00	$150.00
Night time Purge	1	$150.00	$150.00
Total			**$675.00**
Cost Group Design			
Group 3	344	$116.00	**$39,904.00**

Table 9: Group 3 Hours and Cost

Group 3 Hours and Cost			
Category	**Code**	**Hours**	**Cost**
Planning	10	38	$4,408.00
Research	11	30	$3,480.00
Meeting	12	56	$6,496.00
Design	13	44	$5,104.00
Drawing	14	0	$0.00
Rep/ Pres	15	114	$13,224.00
Consult	16	0	$0.00
Analysis	17	62	$7,192.00
Check	18	0	$0.00
Other	19	0	$0.00
Wage Rate			$116.00
	Total	**344**	**$39,904.00**

7. Standards, Health & Safety

7.1 Standard Operation

To regulate building temperature throughout campus, the University of Saskatchewan's Facilities Management Division provides an indoor temperature guideline that was submitted as of April 4, 2014. These procedures also follow the objectives of the Climate Action Plan and Operational Budget Adjustments. This Indoor Temperature Guideline splits time between winter and summer seasons. The summer season ranges from mid-May to mid-October; alternatively, the winter season extends from mid-October to mid-May. The hours in the day are also separated into occupied and unoccupied hours. Occupied hours are defined as operating hours such as when rooms are reserved for classes or events; otherwise, the building is considered unoccupied; this includes evenings, weekends and holidays.

During occupied hours, a target temperature of 21°C is set for the winter months and 24°C for the summer months where air temperature is regulated. These spaces are permitted to range up to 1°C, although because of the large outdoor air temperature variance in spring and fall actual temperatures may have a larger error. This target temperature meets the ANSI/ ASHRAE Standard 55-2010 and Thermal Environmental Conditions for Human Occupancy. The Can/CSA z412-00 (R2011) Office ergonomics standard references the Thermal Environmental Conditions for Human Occupancy.

During unoccupied hours, a target temperature of 18°C is set for the winter months and 27°C for the summer months where HVAC equipment operates. The purpose of temperature set points is to allow the university to save energy during unoccupied hours. The temperature can vary greatly during this time.

7.2 Health and Safety

Safety Resources at the University of Saskatchewan deal with Air Quality Measurement and Assessment. When measuring the air quality within the building, Saskatchewan Occupational Health and Safety Regulations as well as relevant MSDS's, ACGIH and NIOSH recommendations are used. Accepted exposure values are measured in the area after it is monitored for a specific amount of time, typically 8 hours; actions are then recommended depending on the results of the test. These actions include rebalancing of an area, or installation of engineering controls, administrative controls or personal protective equipment.

Additionally, a number of the areas in the University of Saskatchewan Education Building contain asbestos that can cause fibrosis in lung tissue when inhaled. Caution and proper safety equipment must be used when working in these areas. Air quality must also be considered in order to ensure the health of occupants using the building. Any airborne contaminants such as dust or smoke should be eliminated in order to maintain the health of occupants. Bioaerosols such as bacteria and fungi can exist with appropriate air temperature and humidity. The composition of air must be maintained at a standard level keeping contaminants such as acrolein and carbon monoxide below a certain level measured in parts per million. Refer to Table 4 Comparison of Indoor Environment Standards and Guidelines page 10.11 in 2013 ASHRAE HANDBOOK for these standards.

8. Conclusion and Recommendations

The Education Building can be broken up into four zones; the gym, locker room, and pool system, the penthouse/main area, the Quance Theatre, and the Audio/Visual Room. The Audio/Visual Room was neglected due to its small size. The Quance Theatre has already been significantly optimized; it contains sophisticated operation measures that utilize PID loops and CO_2 sensors. For this reason the Quance system is not modeled or analyzed.

8.1 Gym, Locker Room and Pool Area

A recommendation is made in terms of the heat recovery schedule for the gym, locker room, and pool zone. For this system to work most effectively, it is necessary for the preheat coil to work at max capacity at all times, heating the incoming outdoor air as much as possible using return air. This maximizes the amount of energy being recovered while minimizing heating coil energy usage. The largest amount of energy is saved when the difference in outdoor air and return air temperature is at its greatest. In winter mode, when return air is 22°C, the incoming air is heated 24.8°C when the outdoor temperature is -40°C, whereas incoming air is only heated 12.8°C when outdoor air is -10°C.

This recommendation also cools the outdoor air during the summer, when the outdoor air temperature is greater than the 25°C return air. For example, when outdoor air temperature reaches 35°C, it will be cooled 4°C by the return air. The only point where the heat recovery system is saving zero energy is when the outdoor air temperature matches the return air temperature, i.e. 25°C.

This is based on the assumption that the heat recovery system does not currently work at max capacity. Using a heat recovery efficiency of 40% reduces the amount of heating energy that must be consumed on outdoor air by 40%, which results in significant energy savings.

8.2 Penthouse/Main Area

The penthouse is modeled using information given on the schedules, control schematics and equipment data. When combined with historical weather data, energy consumption can be calculated. The annual energy consumption is calculated to be 7,143 GJ. The majority of this energy is fan power at 51%, closely followed by heating energy at 39%, while cooling energy makes up the remainder. From these results it can clearly be seen that improvements in heating operating will likely be more impactful than cooling operation.

Set point adjustment proved to be a very effective method of lowering annual energy consumption. By modifying the hot deck, cold deck and mixed air operating temperatures the system can potentially be run more effectively. A 1°C change in all of these parameters results in a 6.21% reduction of annual energy consumption. Further changing these values another degree decreases annual energy consumption by 7.86%. This suggests that there are diminishing returns from further varying these set points. The largest issue with adjusting the set points is that is it very difficult to confirm if the comfort of the building occupants will be affected by these changes. It is possible that lowering the maximum hot deck temperature 2°C will result room temperature to drop below the allowable limit of 22°C. It is also possible that the set points could be changed more than 2°C without affecting the comfort, resulting in an even larger reduction in energy consumption. The only way to verify if the building comfort level is satisfactory following a change in set point is to incrementally change the set point then check that comfort is maintained.

The most effective set point adjustment made, is to reduce the lower temperature of the hot deck, i.e. the temperature the hot deck will be set to in the summer. By lowering this temperature 2°C, from 22°C to 20°C, annual energy consumption is reduced by 4.16%. The second most effective set point adjustment is to increase the cold deck upper temperature; increasing this value from 18°C to 20°C results in a 2.46% reduction in energy consumption.

Following set point adjustment, the most effective method of reducing energy consumption is introducing an optimal start. The optimal start reduces the annual energy consumption from 7143.38 GJ to 6699.68 GJ. This is a reduction of 443.7 GJ, which equates to a 6.21% reduction in annual energy use. Unlike adjusting the set points, implementing an optimum start does not take extended user input.

Nighttime purge only proves to reduce energy consumption by 0.3%. This is rather insignificant and makes this option unappealing. Saskatoon has a very cool climate so there is very little cooling done throughout the year. The annual cooling energy consumption is over four times smaller than the annual heating energy consumption, meaning there are few days when a nighttime purge would be viable. While it may still be worth implementing due to the small amount of labour required, nighttime purge proves to be less effective than anticipated.

When all alternatives are combined a 14.39% reduction in total annual energy consumption is attained for the penthouse. This result is marginally below the objective given by the Department of Sustainability of a 15% energy reduction.

8.3 Recommendations

The improvements made to the penthouse can also be applied to the gym, locker room, and pool system where similar results can be expected. These enhancements can also be applied to the Quance Theatre, but likely not have a large impact since the CO_2 sensors are currently reducing the heating.

9. References:

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10. Appendices

Appendix A- Sample Calculations

A.1 Sample Calculation- Gym Heat Recovery Temperature Change ΔT_{HR}

$\Delta T_{HR} = \eta(T_R - T_O)$

η = heat transfer effectiveness [%]

T_R = return air temperature [°C]

T_O = outdoor air temperature [°C]

$\Delta T_{HR} = 0.4(22^oC-(-40^oC))$

$\Delta T_{HR} = 24.8^oC$

A.2 Sample Calculation- Air Density:

$$\rho_{air} = \frac{P_{ambient}}{R(T_{HD} + 273.15)}$$

$P_{ambient}$ = atmospheric pressure (measured to be 102800) [Pa]

R = specific gas constant [J/Kg*K]

T_{HD} = hot deck temperature (both limits) [^{0}C]

$$\rho_{air} = \frac{102800Pa}{\left(287\frac{J}{kgK}\right)(41.82^\circ C + 273.15)}$$

$$\rho_{air} = 1.14\frac{m^3}{kg}$$

A.3 Sample Calculation- Hot Deck Temperature:

=(slope of HD SAT RESET * OUTDOOR AIR TEMP)+(intercept of HD SAT RESET)

$=(-0.535 * (-24.05^0C))+28.953$

$=41.82^0C$

See figure 6

A.4 Hot Deck Temperature Lower Limit:

If HOT DECK TEMPERATURE is greater than 55^{0}C, return 55^{0}C, otherwise return HOT DECK TEMPERATURE

A.5 Hot Deck Temperature Both Limits:

If HOT DECK TEMPERATURE LOWER LIMIT is less than 22^{0}C, return 22^{0}C, otherwise return HOT DECK TEMPERATURE LOWER LIMIT

A.6 Sample Calculation- Hot Deck Air Flow Rate:

=(HOT DECK TEMPERATURE BOTH LIMITS – intercept of HOT DECK AIRFLOW RESET)/slope of HOT DECK AIRFLOW RESET

$$=\frac{41.82°\text{C}-(-12.640)}{4.099}$$

$$=13.28\frac{m^3}{s}$$

See Figure 9

A.7 Sample Calculation- Hot Deck Mass Flow rate:

=(HOT DECK AIR FLOWRATE)(HOT DECK AIR DENSITY)

$$=\left(13.28\frac{m^3}{s}\right)\left(1.14\frac{kg}{m^3}\right)$$

$$=15.11\frac{kg}{s}$$

A.8 Sample Calculation- Mixed Air Temperature:

=(slope of MAT RESET * OUTDOOR AIR TEMPERATURE) + intercept of MAT RESET

=(-0.069 * (-24.05^{0}C)) + 15.563

=17.2^{0}C

See figure 8

A.9 Return Air %:

If OUTDOOR AIR TEMP is greater than INDOOR RETURN AIR TEMP, return 0.5, otherwise return 0

A.10 Sample Calculation- Mass Flow rate Return Air:

=((HOT DECK MASS FLOWRATE + COLD DECK MASS FLOWRATE)*(ACTUAL MIXED AIR TEMP - OUTDOOR AIR TEMP))/((INDOOR RETURN AIR TEMP – ACTUAL MIXED AIR TEMP)+(ACTUAL MIXED AIR TEMP – OUTDOOR AIR TEMP))

$$=\frac{\left(\left(15.11\frac{kg}{s}+22.64\frac{kg}{s}\right)(17.22°C-(-24.05°C))\right)}{((22°C-17.22°C)+(17.22°C-(-24.05°C)))}$$

$$=33.82\frac{kg}{s}$$

A.11 Return Airflow:

If RETURN AIR % = 0.5, return (0.5*TOTAL MIXED AIR FLOWRATE), otherwise return (MASS FLOWRATE RETURN AIR / INDOOR AIR DENSITY)

A.12 Mixed Air Temperature Upper Limit:

If MIXED AIR TEMPERATURE is greater than 19^{0}C, return 19^{0}C, otherwise return MIXED AIR TEMPERATURE

A.13 Mixed Air Temperature Both Limits:

If MIXED AIR TEMPERATURE UPPER LIMIT is less than 13.5^{0}C, return 13.5^{0}C, otherwise return MIXED AIR TEMPERATURE UPPER LIMIT

A.14 Actual Mixed Air Temperature:

If MIXED AIR TEMPERATURE BOTH LIMITS is less than OUTDOOR AIR TEMPERATURE return ((INDOOR RETURN AIR TEMP + OUTDOOR AIR TEMP)/2), otherwise return MIXED AIR TEMPERATURE BOTH LIMITS

A.15 Sample Calculation- Total Mixed Air Flowrate:

=HOT DECK AIR FLOWRATE + COLD DECK AIRFLOW RATE

$$= 13.28\frac{m^3}{s} + 18.40\frac{m^3}{s}$$

$$= 31.68\frac{m^3}{s}$$

A.16 Indoor Return Air Temperature:

If OUTDOOR AIR TEMPERATURE is less than 22^{0}C, return 22^{0}C, otherwise return 25^{0}C

A.17 Sample Calculation- Heating Energy:

$$\dot{E}_{heat} = c_p \dot{V}_{HD}(T_{HD} - T_{mixed(actual)})$$

c_p = specific heat capacity of air [kJ/kg^{0}K]

$\dot{V}_{HD}$ = hot deck volumetric flow rate [m^3/s]

T_{HD} = hot deck temperature (both limits) [^{0}C]

$T_{mixed(actual)}$ = actual mixed air temperature [^{0}C]

$$\dot{E}_{heat} = (1.005\frac{kJ}{kg°K})(13.28\frac{m^3}{s})(40.62°C - 19.22°C)$$

$$\dot{E}_{heat} = 285.69\frac{kJ}{s}$$

A.18 Heating Energy with Schedule:

Returns a 0 when the fans are off, returns Heating Energy in $\frac{GJ}{hr}$ when fans are on.

A.19 Sample Calculation- F70/F71 (Mixed) Load:

$$L_{mixed}\% = \frac{\dot{V}_{mixed(total)}}{\dot{V}_{mixed(total),\max}} \times 100\%$$

$\dot{V}_{mixed(total)}$ = total mixed air volumetric flow rate [m^3/s]

$\dot{V}_{mixed(total),\max}$ = maximum total mixed air volumetric flow rate [m³/s]

$$L_{mixed}\% = \frac{31.68\frac{m^3}{s}}{43.06\frac{m^3}{s}} \times 100\%$$

$$L_{mixed}\% = 74\%$$

A.20 Sample Calculation- Maximum Energy Consumption of F70 and F71:

$$\dot{E}_{F70/71} = hp * L_{\max}$$

Hp = horsepower [hp]

L_{max}=max load (70%)

$$\dot{E}_{F70/71} = 200 * 70\%$$

$$\dot{E}_{F70/71} = 140hp$$

$$\dot{E}_{F70/71} = 0.375833\frac{GJ}{hr}$$

A.21 Sample Calculation- Energy Consumption of F70 and F71:

$$\dot{E}_{F70/71} = \dot{E}_{F70/71,\max} L_{mixed}\%$$

$\dot{E}_{F70/71,\max}$ = maximum energy consumption of F70 and F71 [GJ/hr]

$L_{mixed}\%$= F70/F71 (mixed) load [%]

$$\dot{E}_{F70/71} = (0.375987\frac{GJ}{hr})(0.76)$$

$$\dot{E}_{F70/71} = 0.28\frac{GJ}{hr}$$

A.22 Sample Calculation- Penthouse Fan Power:

$$\dot{E}_{penthouse} = \dot{E}_{F70/71} + \dot{E}_{F69/72}$$

$\dot{E}_{F70/71}$ = energy consumption of F70 and F71 [GJ/hr]

$\dot{E}_{F69/72}$ = energy consumption of F69 and F72 [GJ/hr]

$$\dot{E}_{penthouse} = 0.28\frac{GJ}{hr} + 0.25\frac{GJ}{hr}$$

$$\dot{E}_{penthouse} = 0.53\frac{GJ}{hr}$$

A.23 Sample Calculation- Total Fan Power:

$$\dot{E}_{total(fans)} = (\dot{E}_{other} + \dot{E}_{penthouse}) \times S_{on/off}$$

$\dot{E}_{other}$ = energy consumption of other fans [GJ/hr]

$\dot{E}_{penthouse}$ = energy consumption of penthouse fans [GJ/hr]

$S_{on/off}$ = check to find if fan schedule on or off

$$\dot{E}_{total(fans)} = (0.23\frac{GJ}{hr} + 0.55\frac{GJ}{hr}) \times 1$$

$\dot{E}_{total(fans)} = 0.77\frac{GJ}{hr}$

A.24 Sample Calculation- Total Energy:

$\dot{E}_{total} = \dot{E}_{other} + \dot{E}_{penthouse} + \dot{E}_{heat} + \dot{E}_{cool}$

$\dot{E}_{other}$ = energy consumption of other fans [GJ/hr]

$\dot{E}_{penthouse}$ = energy consumption of penthouse fans [GJ/hr]

$\dot{E}_{heat}$ = energy consumption of heating coils [GJ/hr]

$\dot{E}_{cool}$ = energy consumption of cooling coils [GJ/hr]

$\dot{E}_{total} = 0.22\frac{GJ}{hr} + 0.53\frac{GJ}{hr} + 1.03\frac{GJ}{hr} + 0\frac{GJ}{hr}$

$\dot{E}_{total} = 1.78\frac{GJ}{hr}$

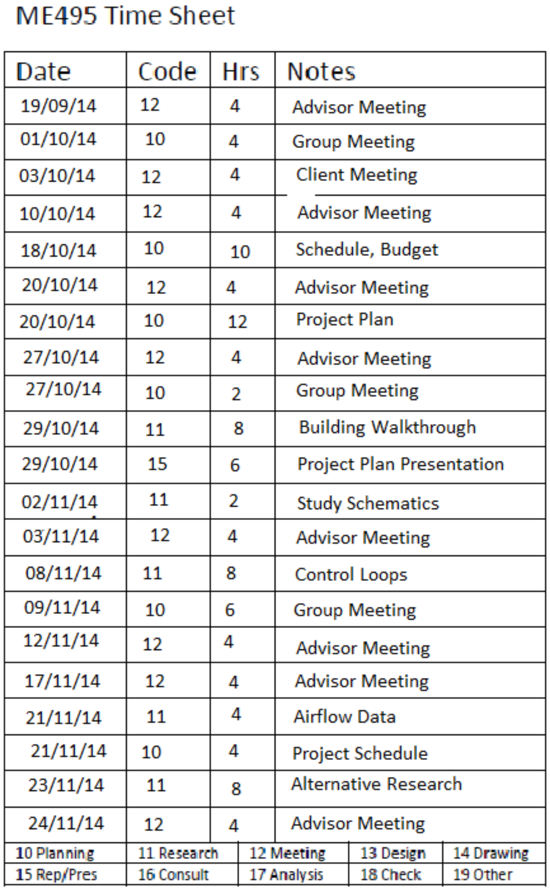
A.25 Schedule On/Off:

Utilizes fan schedule during winter/summer and weekend/weekday to interpret if fans are running. Off returns a 0 while on returns a 1.

A.26 Total Energy with Schedule:

Returns a 0 when the fans are off, returns Total Energy in $\frac{GJ}{hr}$ when fans are on.

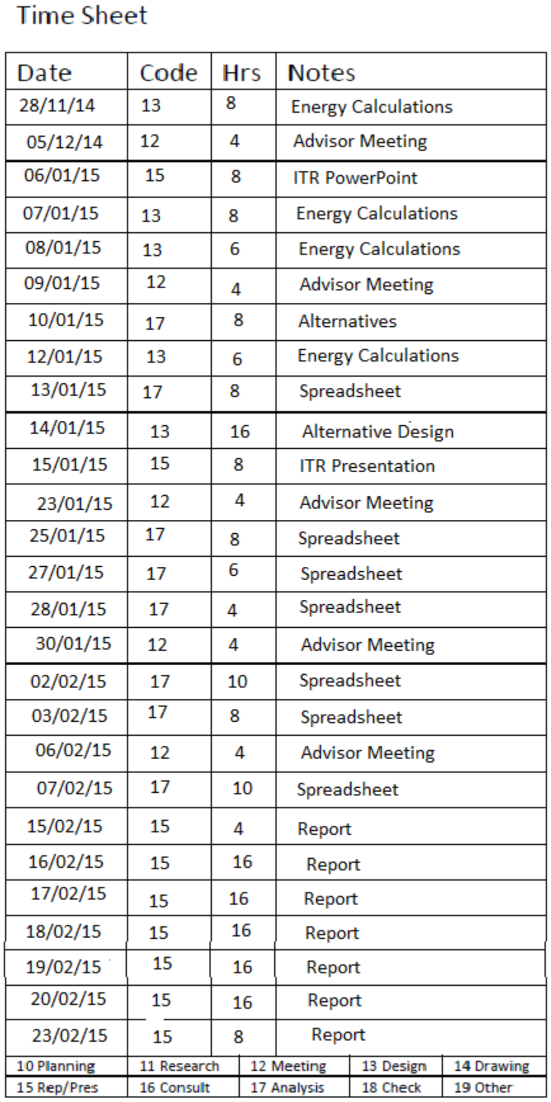
Appendix B- Timesheet



ME495 Time Sheet

Date	Code	Hrs	Notes
19/09/14	12	4	Advisor Meeting
01/10/14	10	4	Group Meeting
03/10/14	12	4	Client Meeting
10/10/14	12	4	Advisor Meeting
18/10/14	10	10	Schedule, Budget
20/10/14	12	4	Advisor Meeting
20/10/14	10	12	Project Plan
27/10/14	12	4	Advisor Meeting
27/10/14	10	2	Group Meeting
29/10/14	11	8	Building Walkthrough
29/10/14	15	6	Project Plan Presentation
02/11/14	11	2	Study Schematics
03/11/14	12	4	Advisor Meeting
08/11/14	11	8	Control Loops
09/11/14	10	6	Group Meeting
12/11/14	12	4	Advisor Meeting
17/11/14	12	4	Advisor Meeting
21/11/14	11	4	Airflow Data
21/11/14	10	4	Project Schedule
23/11/14	11	8	Alternative Research
24/11/14	12	4	Advisor Meeting

10 Planning	11 Research	12 Meeting	13 Design	14 Drawing
15 Rep/Pres	16 Consult	17 Analysis	18 Check	19 Other



Time Sheet

Date	Code	Hrs	Notes
28/11/14	13	8	Energy Calculations
05/12/14	12	4	Advisor Meeting
06/01/15	15	8	ITR PowerPoint
07/01/15	13	8	Energy Calculations
08/01/15	13	6	Energy Calculations
09/01/15	12	4	Advisor Meeting
10/01/15	17	8	Alternatives
12/01/15	13	6	Energy Calculations
13/01/15	17	8	Spreadsheet
14/01/15	13	16	Alternative Design
15/01/15	15	8	ITR Presentation
23/01/15	12	4	Advisor Meeting
25/01/15	17	8	Spreadsheet
27/01/15	17	6	Spreadsheet
28/01/15	17	4	Spreadsheet
30/01/15	12	4	Advisor Meeting
02/02/15	17	10	Spreadsheet
03/02/15	17	8	Spreadsheet
06/02/15	12	4	Advisor Meeting
07/02/15	17	10	Spreadsheet
15/02/15	15	4	Report
16/02/15	15	16	Report
17/02/15	15	16	Report
18/02/15	15	16	Report
19/02/15	15	16	Report
20/02/15	15	16	Report
23/02/15	15	8	Report

10 Planning	11 Research	12 Meeting	13 Design	14 Drawing
15 Rep/Pres	16 Consult	17 Analysis	18 Check	19 Other

Appendix C- Attached USB Electronic Files

List of files included on attached USB:

Excel Sheets:

- Gym Heat Recovery
- Penthouse Model
    - This is the model used to evaluate the main area

Schematics:

- F59 Lockers and F61 Pool Supply Air Systems
- F70 Building
- F70 Penthouse Supply Air System Mechanical Layout
- F71 Penthouse Supply Air System
- Gym Supply and Exhaust Air System
- Quance Supply Air System

Other:

- Education Sequences
- Equipment Schedules
- Electrical Meter Data
- Fan Power Data