Mechanical Project Proposal

Proposal of Alternative Systems

Des Places Residence Hall

Duquesne University

Pittsburgh, PA

DUQUESNE UNIVERSITY

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Executive Summary

Des Places Residence Hall is a new LEED Certified dormitory building on the campus of Duquesne University in Pittsburgh, PA. The building receives chilled water and steam from central plants on campus. The steam is immediately converted into hot water that serves the domestic and mechanical heating loads for the building. Des Places is conditioned and mechanically ventilated by a dedicated outdoor air system. An energy recovery unit in the penthouse provides all of the necessary ventilation and meets the latent loads of the building. A parallel system of four-pipe fan coil units meets the sensible heating and cooling loads in each space.

The purpose of this proposal is to redesign Des Places to minimize the buildings energy consumption and emissions footprint and possibly create a more comfortable environment for the buildings occupants. One design alternative outlined in this report is replacing the fan coil units in the existing DOAS system with chilled beams and baseboard radiators. A solar hot water system is also outlined in this report as an alternative way to meet the entire heating load for the domestic hot water system. Increasing the size of all of the bedroom windows is also examined for the purpose of increasing natural daylighting. The use of solar shading will be evaluated as a way to reduce the increased solar heat gain on the building envelope as a result of the redesigned glazing.

All of these proposed changes will affect other systems in the building and will require a significant amount of integration in both the design and construction phase. The impact of the solar thermal system and the automated solar shading on the structural and electrical systems will be evaluated in detail. The proposed structural and electrical evaluations for Des Places are outlined in detail in this report.

In order to analyze all of the proposed systems effectively, several programs will be used. These programs will include Autocad, Microsoft Excel, PHEONICS CFD software and Trane TRACE 700 energy modeling software. All of these tools will be essential in completing a thorough evaluation and design of the proposed systems.

System Description

Introduction

Des Places Residence Hall is a 13 story, 131,000 square foot mixed use dormitory building for Duquesne University in Pittsburgh, Pennsylvania. The building primarily consists of student living space, with offices on the first and second floor, conference space on the twelfth floor and mechanical space on the first floor and thirteenth floor penthouse. The total estimated budget for the project is $27,535,000. Des Places was designed to provide comfortable and modern living space to its student occupants while at the same time minimizing its energy use. The building was designed to achieve a minimum of LEED certification upon its completion and it will achieve this through the implementation of efficient mechanical and electrical systems, energy saving controls, high efficiency lighting fixtures and sustainable construction practices.

Design Objectives and Requirements

There were several objectives that drove the design of the mechanical system for Des Places. Duquesne University wanted a system that could provide fast responding individual control for all of the occupied spaces in the building and the system had to meet the prescribed standards given by the 2009 edition of the National Mechanical Code and the National Plumbing Code. Des Places was designed in accordance with ASHRAE Standards 62.1 and 90.1 as well, and therefore the building is designed to meet all of the energy, ventilation, temperature and humidity requirements prescribed in these documents. The University also required that the building achieve a minimum of LEED certification upon its completion. After considering several alternatives, the mechanical engineers decided to use individual fan coil units to condition each room, and a dedicated OA air handling unit to deliver the required amount of ventilation to each space.

Site and Budget

The site of Des Places is located on Duquesne University's campus in Pittsburgh, Pennsylvania. There is an existing dormitory building on the site that will need to be demolished before the construction of Des Places can begin. The site is along the eastern edge of Duquesne's campus with a busy urban street that acts as the dividing line between campus property and a residential area. Because of the urban environment surrounding Duquesne, the building was designed with security in mind. Certain precautions were made to ensure the safety of students living in the building, such as a limited amount of entrances, card access and security cameras. The building will get its steam for heating and chilled water for cooling from central plants that service all of the buildings on campus. The site is immediately adjacent to an athletic field to the west, academic buildings to the north and a smaller street that runs through campus on the south. An improvement to the existing landscaping and exterior lighting around Des Places is included in the scope of the project. The total budget for the project was set at approximately $30,000,000. The estimated cost for the construction and design of Des Places was $27,535,000, so the building should be within budget with some extra money for various improvements, if the construction process goes according to plan. Des Places has been designed to be as energy efficient as possible while staying within the budget. Although it will still be able to achieve a LEED certification, improvements to the buildings overall efficiency could be made if more money was available.

System Design and Equipment Summaries

All of the rooms in Des Places except for the data rooms, electrical rooms and the conference room on the 12th floor will be fully conditioned by individual four-pipe fan coil units. There are 257 FCUs throughout the building that range in size from 300 CFM to 1200 CFM. All of these units are connected to separate hot water and chilled water pipes and are equipped with thermostats so that occupants can have direct control of the temperature in each space. They are also equipped with motion sensors so that they can change from occupied to unoccupied mode and automatically shut themselves off when the room is empty. Duquesne University required that Whalen fan coil units be used for Des Places, because they have had them installed in other buildings and have found that they are especially reliable and easy to maintain.

A one-hundred percent outdoor air, energy recovery unit capable of providing 20,600 CFM of supply air provides all of the required ventilation needed for the building, in accordance with ASHRAE Standard 62.1. The ERU also exhausts all of the public and private bathrooms in the building and conditions the electrical rooms and data rooms. ERU-1 uses a desiccant energy wheel to transfer latent and sensible heat between the incoming outdoor air stream and the outgoing exhaust air from the bathrooms and data rooms.

The chilled water supply for the building is piped directly into the mechanical room on the first floor from a central plant on campus. The chilled water comes into the building at 45 ^{o}F and is sent back to the plant at 57 ^{o}F after it passes through the various loads in Des Places. A central plant also provides steam to the building at a pressure of 50 lbs and a velocity of 6,000 fpm. The steam is converted to hot water at 140 ^{o}F by two heat exchangers arranged in parallel before it is distributed throughout the building. Both the chilled water and hot water is circulated throughout the building in the same variable primary flow pumping arrangements. For both the hot water and chilled water systems, two pumps arranged in parallel deliver water to all of the fan coil units and one pump on a branch circuit delivers water to the unit heaters and energy recovery unit. The two pumps servicing the fan coil units have a capacity of 480 gpm each for the chilled water and 180 gpm each for the hot water. The single pump servicing the unit heaters and ERU-1 has a capacity of 120 gpm for the chilled water and 175 gpm for the hot water.

The main electrical feed will be provided through an existing Duquesne Light manhole on the site, using a 23 KV cable. This cable will connect to a 23 KV Duquesne Light pad mount transformer, that will bring the power supply down to a 277/480 V, three phase, four wire cable. Emergency power is supplied by 250 KW, 277/480 V diesel powered generator.

Design vs. Computed Block Loads

The entire building was modeled and simulated using Trane Trace 700. For this report the capabilities of the fan coil units and the energy recovery unit will be discussed and compared to the modeled heating and cooling loads and required airflows for the building, as calculated in Trace. Table 10 below summarizes the total cooling load, heating load and supply airflow for the entire building and compares it to the heating capability, cooling capability, and total supply airflow of all the fan coil units in the building. This table also compares the total ventilation airflow calculated in Trace to the maximum amount of outdoor air coming from the energy recovery unit. Table 11 uses a few sample rooms and blocks and makes the same comparisons as Table 10, using the calculations performed by Trace for those individual rooms or blocks. The total heating and cooling capability as well as the supply airflow for the FCUs was attained from the fan coil unit schedule in the mechanical drawings. The total outdoor airflow supplied to the building by ERU-1 was found in the energy recovery unit schedule. The outdoor airflow supplied to each room or block was found by adding up the total CFM coming out of all of the supply registers in that space. The airflow coming out of the supply diffusers is an accurate estimate of the total designed ventilation airflow, because all of the supply ductwork in the building connects to ERU-1 in the penthouse, which brings in 100% outdoor air.

Comparisons by System								
	Cooling		Heating		Supply Airflow		Ventilation Airflow	
	Design (MBh)	Modeled (MBh)	Design (MBh)	Modeled (MBh)	Design (CFM)	Modeled (CFM)	Design (CFM)	Modeled (CFM)
Fan Coil Units	2,421	1,452	3,624	1,200	92,100	51,266	20,600	17,667

Table 1: *Design vs. modeled load comparison by system*

Comparisons by Rooms and Blocks								
	Cooling		Heating		Supply Airflow		Ventilation Airflow	
	Design (MBh)	Modeled (MBh)	Design (MBh)	Modeled (MBh)	Design (CFM)	Modeled (CFM)	Design (CFM)	Modeled (CFM)
211A - Bedroom A	8.1	2.9	12	1.6	300	111	45	28
304B-1104B - Bedrooms	72.9	24.9	108	14.1	2700	964	405	243
1202-Lounge	21.8	18.5	27	13.4	800	650	230	202

Table 2: *Design vs. modeled load comparison for sample rooms and blocks*

Table 10 shows that the designed heating and cooling capability of the fan coil units in Des Places far outweighs the total designed heating and cooling loads. This large discrepancy gives the appearance of either a poor energy model or some significant errors made during the design process. However there is a justification for the fan coil units being so oversized in comparison to the loads. According to Tony Valenza, a mechanical engineer for CJL Engineering who worked on the Des Places project, Duquesne University specifically required the use of Whalen fan coil units to heat and cool the building. The owner wanted fan coil units in each room, so that the students could have personalized control of the temperature in whatever space they were occupying. Furthermore they specifically required Whalen units, because they had used them in other buildings and found that they were very reliable. The smallest fan coil unit that Whalen makes has a heating coil capacity of 12 MBh and a cooling coil capacity of 8.1 MBh. The vast majority of rooms in Des Places had calculated loads that were far less than these values. This trend can clearly be seen in Table 11, with the individual bedroom and the block of similar bedrooms. Therefore most of the rooms in the building had FCUs that were oversized, and these all added up to make a building design load that was much larger than the modeled load.

Another reason for the discrepancy between the design load and the modeled load for the building was the fact that the templates made for all of the rooms and blocks in the Trace model, used internal loads that described typical usage for that type of space. In the actual design of the building, the engineers were more cautious and designed for a worst case scenario so that the heating and cooling loads in each space would not exceed the capability of the fan coil unit. This resulted in the use of fan coil units that were slightly oversized even in the rooms that had heating and cooling loads that surpassed the capability of the smallest available Whalen FCU. This design strategy is seen in the comparison of designed and modeled loads for room 1202 in Table 11.

The design and modeled supply airflow for the building differ greatly for the same reason as the heating and cooling loads. Most of the spaces have oversized FCUs because their required supply airflow is far less than 300 cfm, the amount produced by the smallest Whalen fan coil unit. This scenario was true for 227 out of a total of 264 FCUs used in Des Places.

The required ventilation found by the Trace model was much closer to the total ventilation delivered in the actual design of Des Places, because the ventilation in the building relied on a completely separate system. The energy recovery unit brings in 20,600 cfm of outdoor air into the building. This is only 14% more than the required amount of outdoor air found by the energy model. The designers were not limited in choosing an ERU like they were with the fan coil units, so they could choose a unit that closely matched the amount of outdoor air that they found in their energy model.

Mechanical System Evaluation

The mechanical system for Des Places is designed to be both simple and energy efficient at the same time. The combination of the fan coil units for conditioning and the energy recovery unit for ventilation make the overall system easy to maintain, while still achieving the goals set forth by the owner. Various technologies and controls were added to this building at a reasonable cost to reduce its energy use and earn Des Places at least a LEED certification.

The estimated construction cost of the mechanical system is $2,827,770 which comes out to $21.52 a square foot. The mechanical system will take up 10.2% of the buildings total cost, which is relatively inexpensive. The mechanical and electrical systems take up 8,951 ft^2 in Des Places, which is only 6.8% of the buildings total square footage. The minimal space requirement is primarily because all of the conditioning is done with fan coil units, which reduces the duct sizes needed for the energy recovery unit. There is also less mechanical equipment in the building than usual because Des Places receives district heating and cooling from two central plants off site.

The energy use for the building is dominated by primary heating and cooling. Each entity uses roughly the same amount of energy and each one accounts for about 30% of the buildings total usage. The predicted annual operating cost for Des Places is $95,663 which comes out to only $0.73 a square foot. Not only is the operating cost very low for this building, but the maintenance costs should be kept to a minimum as well, because the system is relatively simple and the maintenance staff have a good amount of experience with the Whalen fan coil units used in Des Places.

The mechanical system that was designed for Des Places succeeds in meeting the goals and requirements set forth by the owner, Duquesne University. The building meets all of the ventilation requirements set forth in ASHRAE Standard 62.1 and the energy standards in ASHRAE 90.1. Des Places should easily earn a LEED certification and has the potential to become a LEED Silver building upon its completion. The mechanical system accomplishes all of this with a relatively low first cost and easy maintainability into the future.

Proposed Alternative Systems

The current mechanical system for Des Places successfully meets ASHRAE Standards 62.1 and 90.1 and saves more energy than the baseline building design given in Standard 90.1. It also will help the building achieve a minimum of LEED certification with the possibility of earning LEED Silver. Despite all of the successes of the current mechanical system, there are several alternatives and additions that could be made to make the system run more efficiently, have a lower operating cost and carbon footprint and even make the occupied spaces more comfortable for the buildings occupants. All of these design alternatives can be implemented easily into the overall design of the building and will be analyzed for their feasibility in Des Places. In this report the following alternatives will be proposed to improve the mechanical system of Des Places: a solar hot water system, a dedicated outdoor air system with chilled beams and larger windows equipped with solar shading.

Dedicated Outdoor Air System (DOAS) with Chilled Beams

Dedicated outdoor air systems use 100% outside air to mechanically ventilate a building. In an ideal DOAS system an energy recovery unit provides all of the ventilation air required at constant volume and meets the latent load of the outside air coming into the unit and the latent load of the spaces that it conditions. An entirely separate system meets the sensible loads in the building. There are several different alternatives for the sensible system, such as fan coil units, radiant panels in the ceiling, chilled beams, or a more conventional VAV system. The two systems operate in parallel to adequately meet the designed heating and cooling loads of each space in the building. A properly designed DOAS system can save a considerable amount of energy over more conventional methods of air conditioning while supplying the correct amount of ventilation air, as prescribed in ASHRAE Standard 62.1. A DOAS system should specifically reduce the amount of energy a building consumes by lowering fan energy consumption, lowering the load on the cooling coil and reducing chiller energy consumption.

Des Places already uses a dedicated outdoor air system that is fairly efficient, especially when compared to the baseline building (Des Places consumes 22% less energy than the base building designed in accordance with Appendix G of ASHRAE Standard 90.1). Even though the existing mechanical system performs well it could be improved by replacing the fan coil units with chilled beams and baseboard radiators. Energy modeling and economic analysis have shown that radiant cooling panels are the best choice for a parallel sensible system (Jeong, Mumma and Bahnfleth 627-636). This would be especially true for Des Places because 227 out of a total of 264 fan coil units used in the building are oversized. This is because the owner required that

Whalen fan coil units be used for the building for maintenance reasons. Most of the rooms in Des Places have a heating and cooling load that is far less than the heating and cooling capacity of the smallest available Whalen unit. Therefore these oversized units will almost always be running at part load, which will make them run less efficiently. If chilled beams and baseboard radiators were used as the parallel sensible system, they could be custom sized for each room so that their heating and cooling capacity closely matched the demands of the space. Then they would be running at or near one-hundred percent of their capacity where they are most efficient.

Chilled beams and radiators can also improve the occupants comfort level by creating a thermally uniform space while producing little to no mechanical noise in the room they are conditioning. This type of system takes advantage of the natural buoyancy effects of air by placing the heat source at the lowest vertical height of the room and the cold source at the highest height in the room. Because cold air naturally sinks and hot air rises, the cooling effect from the chilled beams and the heating effect from the radiators is naturally stratified throughout the room. In order for a fan coil unit to produce the same effect, it has to force hot or cold air out of the unit at a high enough flow rate to forcefully spread the conditioned air throughout the space. This method does not always create a uniform temperature in the space and the fan that is used to blow the air out of the fan coil unit consumes additional energy and can create enough noise in the space to be annoying to the occupants.

Solar Hot Water Collection

Solar hot water collection is a fairly recent technology that has gained more popularity over the last decade as an effective way to offset space heating energy use or domestic hot water heating in a building. Solar hot water heating is done by absorbing thermal energy from the sun and converting it into usable heat. The thermal heat is usually absorbed by water or a freeze resistant water mix. The figure below shows a basic schematic of this process. In this illustration of a closed loop system the solar hot water is being used to offset the energy consumption of a boiler by preheating the boiler supply water.

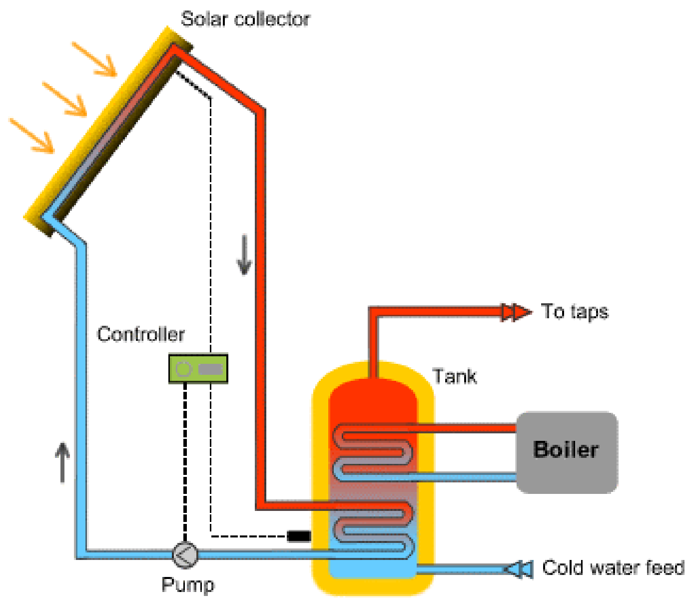


Figure 1: *Basic schematic of a solar hot water system*

Currently there is an array of photovoltaic direct current electricity panels on the roof of Des Places. These photovoltaic panels only provide 1% of the buildings total electrical use and are largely there for the purpose of earning one LEED point under EA Credit 2: On-Site Renewable Energy. A solar hot water array would be a much more efficient and more productive system for Des Places for several reasons. The first and possibly the most important reason is that solar hot water collectors are usually more than three times as efficient as photovoltaic panels in producing energy from the sun. This is largely due to the fact that PVs store direct current electricity and this DC power has to be converted to AC power before it can actually be used by the building. During this conversion a large amount of energy is lost which consequently makes the system much less efficient.

If all of the available space on the 12th floor roof and mechanical penthouse roof was utilized for hot water solar panels a system could be sized to meet the hot water heating load for the entire domestic water system. There are several different design choices that would have to be made for a thermal water system such as deciding between a closed loop and open loop system and whether to use flat plate collectors, evacuated tubes or concentrating collectors as the solar energy absorbers. All of these decisions will be made after more research is done to determine what type of system best fits Des Places.

Incorporating solar hot water heating into the mechanical system of Des Places will significantly improve upon the energy savings of the existing PV array and will reduce the amount of steam that the building requires from the central plant on campus. This will consequently increase the buildings energy performance over the baseline building, which will result in earning more LEED credits and having a smaller emissions footprint. This system should be able to meet the entire domestic water heating load which will eliminate the need for the steam water heater or at least significantly reduce the size of the heater.

Redesign of Building Envelope

Each bedroom and private living room in Des Places has one window that is four feet wide and five feet tall. The smallest exterior wall for a bedroom in Des Places is nine feet wide and ten feet tall. Therefore each of these windows could be much larger, which would allow more natural daylight into each private room. The increase in natural daylighting could eliminate or reduce the need for artificial light in the room during the day and create a more desirable environment for students occupying the spaces. Studies have shown that buildings with a large amount of natural daylighting result in occupants that are more productive, focused and are happier with their surroundings (Ella MacKenna). Increasing the natural daylighting can also earn additional LEED credits for Des Places (Credits 8.1 and 8.2 of the Indoor Environmental Quality section). If all of the 4' by 5' windows were increased in size, this would greatly increase the solar heat gain on the building envelope which would increase the total cooling load for the building.

The increased solar load on the building could be reduced with a couple of different strategies. One way would be to find glazing with a higher U-Value than what is currently being used. Another design alternative would be to use some kind of automated or manually controlled solar shading device, to both reduce the glare coming into the room and cut down on the solar heat gain through the window. Solar shading like the type shown below is one of the more simple and practical options for individual windows like the ones being proposed for Des Places and they can be controlled automatically by an electronic motor or manually by the occupant.

Figure 2: *Example of solar shading used in a room*

At least one or both of these energy saving strategies will be used to reduce the solar heat gain on the envelope of the building. Ultimately the final decision will be made after more research is done to assess whether or not the initial cost is worth the energy savings for each course of action.

Breadth Topics

Electrical

The electrical distribution system for Des Places will have to be reevaluated based on the proposed changes being made in the design of the building. The first change to the electrical system is the loss of the photovoltaic panels on the 12th floor roof, as a result of the solar hot water system replacing them. This array of PVs accounted for 1% of the buildings total electricity supply. There will also be an increase in the buildings electrical use if automated solar shades are used for all of the bedroom and living room windows. Each one of these solar shades will be driven by a small electric motor. Although the electrical demand of each motor will be very small, hundreds of motors will be needed for all of the windows. The total electrical consumption of all of these motors could have an impact on the electrical distribution system for the building. An energy analysis will have to be performed to see if the initial cost and electrical consumption of the automated solar shading is worth the reduction in solar heat gain. An electrical analysis will be done and compared to the current design to ensure all of the necessary electrical loads are met.

Structural

The addition of solar hot water collectors on the 12th floor roof and on top of the penthouse will increase the dead load for both of these roof structures. The increased load from these solar arrays will have to be determined and the existing structural system will need to be reevaluated to determine if it can safely hold the additional weight. The superstructure of Des Places consists of steel framing made with ASTM A50 carbon steel. The roofs of both the 12th Floor and penthouse are supported by an orthogonal grid of wide flange beams. This roof structure will most likely have to be redesigned to meet the additional load of the solar thermal system.

MAE Course Related Study

In order to fulfill the MAE requirements for Senior Thesis, graduate level courses must be incorporated into the redesign of Des Places. Material from the following courses will be utilized in the proposed changes to fulfill this requirement. In AE 558 (Centralized Heating) the topics of life cycle cost analysis and payback period was covered to evaluate whether the energy savings from a heating system was worth its initial cost. A detailed life cycle cost analysis will be performed for the solar hot water system to determine what it's payback period will be and to ultimately decide if it saves enough energy to justify its initial cost. Knowledge learned from AE 557 (Centralized Cooling) will be used when evaluating the alternative chilled beam system and in determining the reduced load on the central chiller plant as a result of changing the buildings cooling system from fan coil units to chilled beams. AE 559 (Computational Fluid Dynamics in Building Design) will be taken next semester during the redesign of Des Places. This class covers the basic principles behind computational fluid dynamics and shows students how to create CFD models using the software package PHOENICS. This software package will be used to create two basic models of a typical bedroom in Des Places. One model will use chilled beams and baseboard radiators to condition the space and the other will use a fan coil unit. These models will be compared to assess how the hot and cold air moves through the space for each alternative and will show which system creates a more uniform temperature throughout the room.

Tools For Analysis

Several different computer programs and standards will be used to analyze the benefits of the proposed mechanical systems and changes to the building envelope of Des Places. ASHRAE Standards will be used in the design of the proposed alternatives. All of the thermal, ventilation and air quality requirements given in these standards will be met for the revised dedicated outdoor air system.

Energy modeling will also be a valuable tool in comparing the buildings energy use before and after all of the proposed changes are made. Trane TRACE 700 will most likely be the software of choice because the existing building and the ASHRAE baseline building are already modeled using this program. Separate models will be made for all of the proposed changes given above and one final energy model will combine all of the revised aspects of the building. All of these models will be compared to the ASHRAE base building (as prescribed in ASHRAE Standard

90.1) and the existing building to assess the annual and monthly energy savings of each proposed alternative.

PHEONICS computational fluid dynamics software will be used to compare the airflow and temperature distribution between a typical bedroom using a fan coil unit for sensible heating and cooling and a bedroom using chilled beams and a baseboard radiator. This analysis will either prove or disprove the theory that chilled beams create a more comfortable, thermally uniform space than fan coil units while producing little to no mechanical noise.

Microsoft excel will be used to perform necessary calculations, organize data and create graphical comparisons of different system performances. This program will be used to carry out tasks such as the life cycle cost analysis for the solar hot water system and solar shading. Excel could also be used in conjunction with weather data and manufacturer's data to size the solar thermal system.

Autocad will be used to show the redesign of the electrical distribution system for Des Places if any changes need to be made. This program can also show the new roof structure for the 12th floor and penthouse, if the steel framing needs to be redesigned to meet the added load of the solar collectors.

Appendix A

List of Tables and Figures

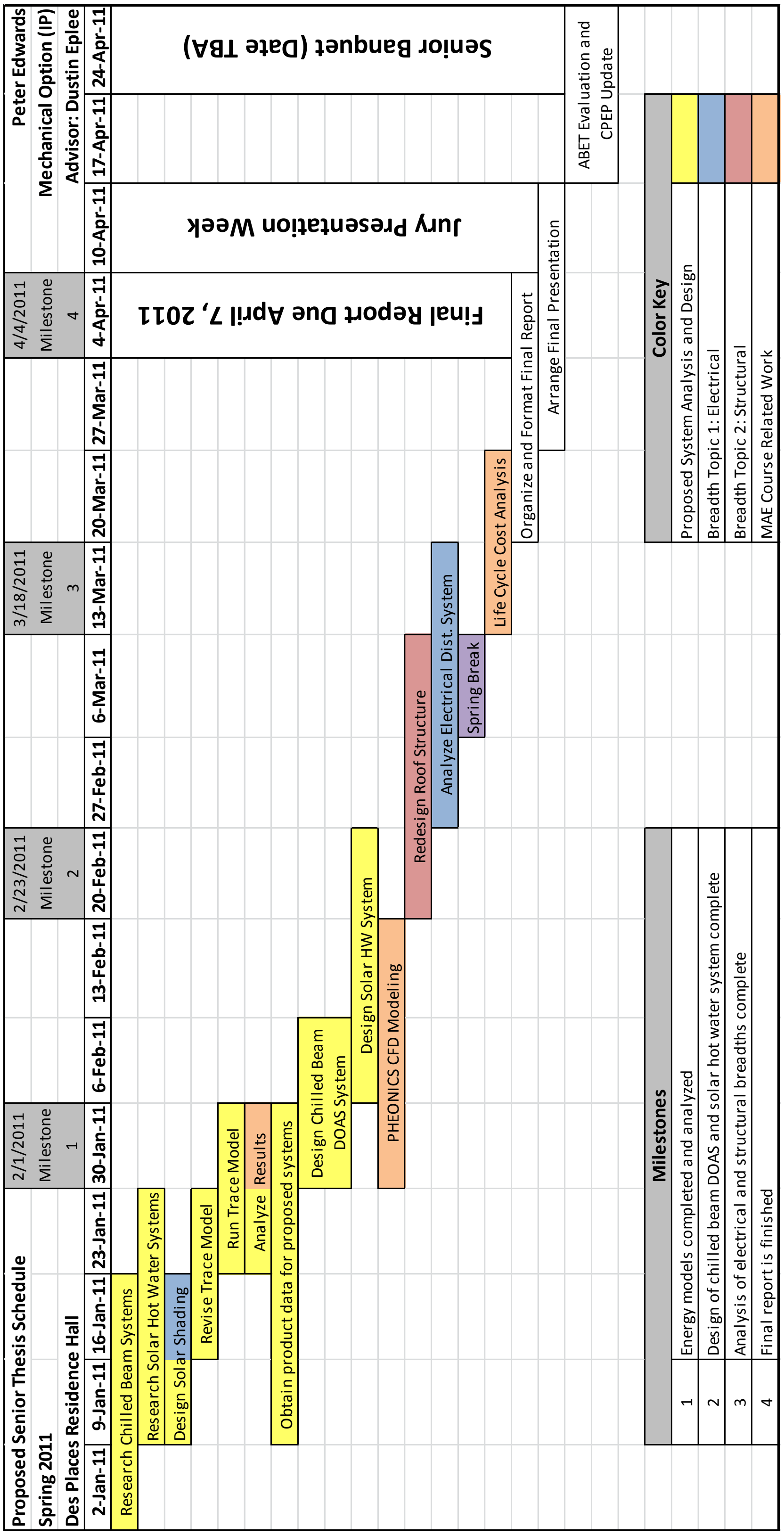
Figures

Tables

Appendix B

Work Schedule

A schedule of work is given below that outlines the various tasks that need to be completed in order to finish the thesis project outlined in the proposal above. This is only a tentative schedule that is meant to be flexible and adapt to unforeseen delays or unexpected lengths of various tasks. The only date that cannot be adjusted is the final presentation date on April 7th, 2010.


Proposed Senior Thesis Schedule
Spring 2011
Des Places Residence Hall
Peter Edwards
Mechanical Option (IP)
Advisor: Dustin Eplee
2/1/2011 Milestone 1
2/23/2011 Milestone 2
3/18/2011 Milestone 3
4/4/2011 Milestone 4
2-Jan-11
9-Jan-11
16-Jan-11
23-Jan-11
30-Jan-11
6-Feb-11
13-Feb-11
20-Feb-11
27-Feb-11
6-Mar-11
13-Mar-11
20-Mar-11
27-Mar-11
4-Apr-11
10-Apr-11
17-Apr-11
24-Apr-11
Research Chilled Beam Systems
Research Solar Hot Water Systems
Design Solar Shading
Revise Trace Model
Run Trace Model
Analyze Results
Obtain product data for proposed systems
Design Chilled Beam DOAS System
Design Solar HW System
PHEONICS CFD Modeling
Redesign Roof Structure
Analyze Electrical Dist. System
Spring Break
Life Cycle Cost Analysis
Organize and Format Final Report
Arrange Final Presentation
Final Report Due April 7, 2011
Jury Presentation Week
ABET Evaluation and CPEP Update
Senior Banquet (Date TBA)
Milestones
1 Energy models completed and analyzed
2 Design of chilled beam DOAS and solar hot water system complete
3 Analysis of electrical and structural breadths complete
4 Final report is finished
Color Key
Proposed System Analysis and Design
Breadth Topic 1: Electrical
Breadth Topic 2: Structural
MAE Course Related Work

Appendix C
Preliminary Research

Mumma, Stanley. "Overview of Integrating Dedicated Outdoor Air Systems with Parallel Terminal Systems." *ASHRAE Transactions*. 107.AT-01-7-1 (2001): 545-552. Print.

- This article discusses the various benefits of using a 100% outdoor air system in comparison to a more conventional variable air volume system. It also explains the different applications of a DOAS system in a building and provides an overview of the different parallel terminal units that can be used to meet the sensible loads in the building.

Jeong, Jae-Weon, Stanley Mumma, and William Bahnfleth. "Energy Conservation Benefits of a Dedicated Outdoor Air System with Parallel Sensible Cooling by Ceiling Radiant Panels." *ASHRAE Transactions*. 109.KC-03-7-1 (2003): 627-636. Print.

- This article explains why ceiling radiant cooling panels are the best choice for parallel sensible cooling in a dedicated outdoor air system. It does this by comparing the energy modeling results and actual energy consumption figures of a radiant cooling system to the other alternatives.

Mumma, Stanley and Yizai Xia. "Ceiling Radiant Cooling Panels Employing Heat Conducting Rails: Deriving the Governing Heat Transfer Equations". *ASHRAE Transactions 2006, Vol. 112 Pt. 1*: 34-41. Print.

- This article provides an overview of the different types of overhead hydronic radiant cooling systems and derives governing heat transfer equations that can be used to determine the cooling capacity of a given radiant cooling panel.

Beckman, Duffie. "Solar Engineering of the Thermal Processes". 2006. John Wiley and Sons, Inc.

- This textbook covers the newest developments in solar energy technology by providing a current overview of the governing principles, functioning, design and economics of solar thermal processes.

Apricus Solar Co., Ltd. 2010. Apricus Solar Hot Water. "What is Solar?". Retrieved from http://www.apricus.com.

- This website provides technical information on the different types of solar hot water systems and the priniciples behind solar energy. It also has information on the various products that the company makes and some background information on all of the products.

2008 ASHRAE Handbook, HVAC Systems and Equipment. American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc. Atlanta, GA.

2007 ASHRAE Handbook, HVAC Applications. American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc. Atlanta, GA.

MacKenna, Ella. 2010. "Natural Daylighting for Health and Energy Efficiency". Retrieved from http://hubpages.com.

Brown, Jerry. 2010. "Controlled Natural Daylight the Biggest Benefit of Green Buildings?". Retrieved from http://www.brownongreen.net.

- The two articles listed above discuss the many benefits that controlled natural daylighting has for the occupants of a building. It also talks about the health and psychological benefits that increased daylighting can have and why daylighting has been incorporated into the LEED certification guidelines.