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Senior Thesis Design Proposal

Final Report [Fall 2010]

Analysis

SALK HALL ADDITION

The University of Pittsburgh, Pittsburgh

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Fall 2010, Senior Thesis Design Project

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Executive Summary

The University of Pittsburgh designed the Salk Hall Addition in order to accommodate increased learning in the Schools of Dental Medicine, Pharmacy, and the Graduate School of Public Health. Many factors influenced the design of the building, namely the constraints imposed by its laboratories and their support spaces. The mechanical system designed by Ballinger has been evaluated and has been determined to meet the criteria set forth by ASHRAE design standards as well as the University of Pittsburgh's lab standard.

The objective of this proposal is to minimize energy consumption of the building while achieving a decreased cost in the buildings annual operation. By reducing energy consumption, the re-design also hopes to reduce the carbon footprint of the building and achieve a higher LEED rating. In order to optimize the building's energy use, two systems have been proposed as alternatives. The two systems that were considered were: An active chilled beam system with dual wheel energy recovery and a typical VAV system using condensing boilers, heat recovery chillers, and an aircuity system.

Implementing either of the alternatives will require high integration within the building systems. Each system will be evaluated with its positives and negatives considered. The best option will be selected according to the design objectives set by the University of Pittsburgh.

Existing Mechanical System

The information found in this section is data previously published in Technical Reports One, Two, and Three.

Introduction

The scope for the Salk Hall Addition includes the construction of a new research tower, of approximately 81,100 gross square feet, connected to the existing Salk Hall. The project will create the much needed additional research laboratories and related ancillary spaces for the Schools of Dental Medicine, Pharmacy, and the Graduate School of Public Health.

Design Objectives and Requirements

The project scope includes renovations, upgrades, extensions, expansions and/or replacement of the following systems: HVAC, electrical, fire protection, water, waste, telecommunications, data, security, controls, and laboratory specialty systems in Salk Hall and the Salk Hall Annex. The underlining goals are to improve system function and increase energy efficiency, meet applicable Codes, and accommodate upgrades and the expansion of the buildings' research, teaching, administrative, and auxiliary facilities.

Site and Budget

The site for the proposed Salk Hall Addition is located on the University of Pittsburgh's main campus and is situated within the 4th Ward of the City of Pittsburgh, Pennsylvania. The proposed site is located within a square city block bounded to the north by Allequippa Street, to the east by Sutherland Drive, to the south by Terrace Street, and to the west by Darragh Street. The city block is approximately 6.5 acres in size and consists of two properties owned by the University of Pittsburgh. The proposed project area is currently under conditions of an existing bituminous asphalt pavement parking lot with a heavily wooded hillside. Total building construction is estimated to cost around $42 million.

The estimated cost for the HVAC system in the Salk Hall Addition is about $3.5 million. This value would yield a unit cost of $43.15 per square foot. The estimated cost of the plumbing system is around $1 million. The estimated first costs of the HVAC and plumbing systems are $225,000 and $44,000, respectively. The total cost of the combined HVAC and plumbing systems is around 10.7% of the estimated total building cost.

System Design Summary

Three identical 29,000 [CFM], 100%-outdoor-air, air handling units on the penthouse level will serve all air-conditioned spaces throughout the building. The three AHUs will have mainfolded supply ducts. The exhaust air will pass through the AHUs' energy recovery wheels, exchange energy with the supply air, and discharge through roof-mounted exhaust fans. Outdoor air will be drawn through wall louvers on the north side of the building into a double-wall, accessible plenum. There are 280 terminal units that support both the supply and exhaust airflow distributions. This sum of units includes the commercial VAV boxes, fan powered boxes, and venturi style Phoenix Laboratory Valves.

The building's chilled water will be supplied by the Peterson Event Center chiller plant. 6" supply and return pipes will connect to the campus system adjacent to the Peterson Event Center plant. The P.E.C. Chiller Plant will be expanded as part of this project. The plant expansion will include a primary pump, 1200 ton chiller, and an 1100 ton cooling tower. The designed chilled water will be at a supply temperature of 42°F and a return temperature of 58°F. An increase in the chilled water supply temperature above 42 degrees may cause a room temperature excursion above the room temperature set-point. The designed condenser water supply temperature will be at 85°F while the return temperature is designed to be 95°F.

The Salk Hall Addition's hot water demand is supplied by the University of Pittsburgh's campus steam loop. The hot water heating system will consist of two shell-and-tube LPS-to-hot water heat exchangers. Each heat exchanger will be sized for 100% of the load. Two primary system pumps will be provided, each with a variable-frequency drive and each sized for 100% of load. VFDs will maintain the differential pressure set point in the system. One or both pumps may operate to meet capacity for optimum energy use. Multiple secondary loops will be provided for the perimeter radiation. Each loop will consist of a 3 way mixing valve and hot water circulator pumps. This system will be constant volume. Reheat coils and other heating equipment will be provided with modulating two-way control valves located on the return side of each coil. Terminal reheat valves will modulate to maintain the room temperature set-point.

Evaluation

Ballinger's basis of design for the Salk Hall Addition has been evaluated and has been determined to meet the criteria set forth by ASHRAE design standards as well as the University of Pittsburgh's lab standard. The current system is sized appropriately but has the potential to be undersized if peak thermal and exhaust loads exist simultaneously. Keep in mind that the current design has been simulated and operates within an acceptable range of the per unit operating cost of neighboring buildings on campus. A more detailed breakdown of the system design is available in Technical Report Three.

When evaluating the system from a "re-design" perspective, it is important to keep a few of the key variables that affect the mechanical system in mind. The most important load that the air handling system faces is that of the required ventilation load. The high air change rates in the laboratories and their support spaces demand a large amount of fan power. It is also important to recognize that the linear equipment corridors need chilled water a rate that is nearly constant all year round. The third design issue that will be under consideration in the re-design is the amount of hot water used in the terminal reheat units.

Proposed Mechanical Systems

Chilled Beams with Dual Wheel Energy Recovery

When used in laboratories, active chilled beams allow for the designer to decouple ventilation requirements from sensible heating and cooling functions. Laboratories require a fixed amount of ventilation air to maintain safety, but air distribution systems are often sized to meet the cooling load. When comparing the required airflows to meet an equivalent cooling capacity between a typical VAV system and an active chilled beam system, a 3:1 ratio should be considered. To achieve the same cooling capacity, active chilled beams require less airflow and therefore reduce the sizes of the required ductwork as well as the overall size of the air handling units. This design approach should be taken into consideration since laboratories often have high internal loads, ranging from 5 to 15 [W/ft^2]. When compared to traditional all-air systems, the use of chilled beams can reduce the need for high volume ductwork and allow for a decrease in the floor to floor height by 6 inches to 18 inches.

The use of active chilled beams in laboratories can drastically reduce the energy demand by the HVAC system. Reheating supply air at terminal units can easily account for up to 20% of the annual HVAC energy use in laboratories. Active chilled beams allow for ventilation air to be supplied at 65°F to 70°F. When supply air is at 70°F, cooling is accomplished in the chilled beam's cooling coil and reheat is completely eliminated. Another energy benefit of active chilled beams is that cooling is accomplished with pumped chilled water instead of blown cold air. Water has a volumetric heat capacity that is 3,500 times that of capacity of air. The use of chilled beams, when compared to a typical VAV system, can reduce fan power by a factor of 7.

While active chilled beams present significant savings, there are a number of drawbacks that limit their practicality. When ventilation rates are high, two scenarios exist. If high airflows are pushed through the chilled beams, the noise of the induction nozzles can be noticeable and become a problem. If this problem is to be avoided, it is likely that a large number of chilled beams would have to be purchased. Chilled beams are often at a premium price since they are typically imported from companies outside the United States. Chilled beams come in a variety of sizes and capacities, but lack the flexibility of traditional supply diffusers. If chilled beams were to be used in the Salk Hall Addition, the ceiling grid would most likely shift directly effecting exhaust ductwork as well as the lighting plan throughout the building. Chilled beams have a maximum cooling capacity and often cannot be used where equipment loads are equal to or greater than 20 [W/ft^2]. In the case of the Salk Hall Addition, fan coil units would still need to be used in the linear equipment corridors. Condensation is a legitimate concern and potential drawback of using chilled beams. In spaces where it is difficult to control the humidity, chilled beams are not recommended. With regards to the Salk Hall Addition, the most overwhelming factor against the use of chilled beams is the density of the fume hoods within the Salk Hall Addition's laboratories. When fume hoods are active, it is necessary for make-up ventilation air to be supplied to the space. If the Salk Hall Addition was to be redesigned with active chilled beams, a separate make-up ventilation VAV system would need to be installed to serve the appropriate laboratories and their support spaces.

Laboratory design conditions can be diagnosed in three ways: load drive, air-change driven, or exhaust driven. The Salk Hall Addition can be considered air change driven throughout much of the building. When make-up air is needed with the use of chilled beams, energy recovery using a dual wheel arrangement can produce neutral air. Neutral air refers to air that is slightly lower than room temperature and has been dehumidified to maintain the relative humidity level in the building. Cooling for each space is accomplished using the active chilled beams while the VAV bypass system provides the required ventilation air. Hot, humid air is cooled and dehumidified by the first air-to-air total energy wheel. A coiling coil is controlled during the summer to maintain the humidity level in the building. The second air-to-air energy recovery device, such as a sensible wheel, provides efficient reheat to the dehumidified supply air which can then be delivered to the active chilled beam terminal units.

VAV with a Heat Recovery Chiller and a Condensing Boiler

With the implementation of the screw chiller, which is capable of producing condenser water temperatures as high as 140°F, came an opportunity for recovering heat from a dedicated heat recover chiller's condenser water circuit. A dedicated heat recovery chilled can be piped and controlled to produce the desired evaporator or condenser temperature. The ability to recover heat from a chiller's condenser has been improved in recent years due to the development of small tonnage compressors that can operate at high discharge pressures and be controlled from either the condenser or evaporator water temperatures. Heat recovery chillers can efficiently meet simultaneous heating and cooling requirements.

Recovered heat can be used to supply domestic hot water systems, heating coils, or terminals reheat coils. The combination of a dedicated heat recovery chiller along with the University of Pittsburgh's campus chilled water loop, with the DHRC operating at the most efficient condenser water temperature allowed by ambient conditions, allows for the ideal loading of the DHRC to serve heating loads while the remainder of the cooling load is served by the campus loop.

The economical application of the DRHC is dependent on the simultaneous need for hot water, 130°F or less, and chilled water. While the application of a DRHC allows for recovered heat to be used in a variety of ways, the re-design of the Salk Hall Addition would use the recovered heat to achieve "free reheat" for the terminal VAV supply units. There is no need to heat 55°F supply air with 180°F water; a heat recovery chiller can be useful in producing warm water to distribute to the reheat coils at 110°F in the summer and 130°F in the winter. The application of a dedicated heat recovery chiller is best applied in coordination with boilers operating at low temperatures, such as condensing boilers. If excess heat is available after the terminal reheat hot water loop has been addressed, the Salk Hall Addition re-design could utilize the available heat for either the domestic hot water supply or the preheat coils in the air handling units.

A condensing boiler saves energy by reducing hot water system design temperatures. Non-condensing boilers typically have a minimum allowable temperature of 140°F in order to avoid condensation and corrosion in the boilers.

The condensing boiler is designed to use condensation as a means of achieving a higher thermal efficiency. Non-condensing boilers typically have a peak efficiency around 80% while a condensing boiler can yield a thermal efficiency of up to 87%. Condensing boilers are configured to accept the condensation without damage and supply water at temperatures as low as 120°F to 130°F. Return temperatures are often in the range of 80°F to 90°F. Condensing boilers are more expensive than non-condensing boilers but their piping is simpler since there is no need for warm-up procedures as there is with most non-condensing boilers. The warm-up procedure often mandates that extra primary pumps, a primary bypass, and a secondary three-way mixing valve are available to allow the loop to warm up to the minimum boiler return temperature.

The most significant benefit when using a condensing boiler results when it is used in coordination with a heat recovery chiller. Heat rejected from chillers is the largest source of heat recovery in the HVAC industry. When the condensing boiler is operated at 130°F, the condenser water from the heat recovery chiller can be used to inject heat upstream of the boilers and supplement of replace heat from the boilers. When used in conjunction, a heat recovery chiller and condensing boiler can also eliminate the need for preheat coils which would be a positive application for the Salk Hall Addition.

Laboratories and vivariums typically consume large amounts of energy and have high carbon emissions due to the large volumes of outside air that are supplied to these spaces. Demand based ventilation is a new trend in laboratory design. The University of Pittsburgh's laboratory design standard mandates that all laboratories and their associated support spaces receive a ventilation airflow equivalent to 6 air changes per hour. In 2009, ASHRAE sponsored a study that involved 1.6 million operating hours of recorded data that represented more than 20 million sensor values from over 300 lab spaces on 18 sites. The study determined that, on average, laboratories were only under unsuitable indoor environmental conditions for 1.5 hours a week. An aircuity system measures the amount of contaminants in a space and relays the information to the mechanical BAS system. This addition allows for minimum air change rates to be reset and ramped accordingly in the case of an emergency. High air change rates are set in laboratories in order to ensure occupant's safety and to dilute harmful contaminants that may be released into the air. A typical VAV system, with the incorporation of aircuity sensors, can therefore lower its minimum ventilation requirements as long as it has the capacity to provide the maximum dilution rate. In the case of the Salk Hall Addition, the minimum air change rates of the laboratories can most likely be reduced to 2 or 4 air changes per hour. This would drastically reduce the amount of outdoor air introduced into the building and would yield very large savings with respect to the original fan power requirement. The aircuity system must be tied in with the fume hood exhaust system in order to ensure that make-up ventilation air is introduced when fume hoods or biological safety cabinets are active.

Breadth Topics

Electrical Breadth

The addition of a condensing boiler and heat recovery chiller will result in necessary changes to the electrical service of the Salk Hall Addition. Both units will increase the building electrical demand and therefore the emergency power plan will need to be revised. This may include the purchase of a new emergency generator for the Salk Hall Addition. The cooling and heating capacities that the re-design system will provide may also result in significant changes in HVAC equipment, specifically on the hydronic side. While the installation of an aircuity system will not change the size of the fans, the fan power demand on the electrical system will decrease significantly. All of these additional system components and changes to the existing electrical design will be investigated. New service panels will be incorporated to operate the pumping systems efficiently. All of the changes to the building's electrical demand will be evaluated and taken into consideration during the re-design process.

Architectural Breadth

The roof of the Salk Hall Addition includes a variety of mechanical equipment, with a large portion of the components being exhaust fans which are elevated on structural curbs. Due to the cold, wet ambient conditions in Pittsburgh, PA, a rain-water collection/snow melting system will be investigated in order to provide "free" chilled water. The linear equipment corridors found in the Salk Hall Addition require yearly cooling and a harvesting system creates the potential for free cooling during winter months. A recovery system would need to include primary as well as secondary pumps and a filtration unit. The recovery system would also aid in the University of Pittsburgh's ambition to achieve LEED certification.

Tools for Analysis

Energy Modeling

Commercial energy modeling software will be the primary medium for evaluating the re-design's energy performance. Energy models will be created by either Trane TRACE 700 or eQuest. All energy modeling software has its limitations and it is important to select the package that most accurately can simulate the appropriate building systems. A TRACE 700 model will be used regardless in order to establish an equivalent model that can be compared to Ballinger's original design. eQuest has the potential capability to model the fume hood exhaust system and advanced hydronic system in much greater detail than that of TRACE 700.

Engineering Equation Solver

Engineering Equation Solver will be used for a component evaluation of the different proposed systems. It has the capability to accurately model and provide results for the analysis of the condensing boiler and heat recovery chiller operations. It will most likely be used in combination with Microsoft Excel to evaluate different manufacture's equipment in order to select the most efficient designs. VBA macros will also be utilized within Microsoft Excel to compute energy consumption and differential economic parameters between the campus loops and on-site utility generation equipment.

Standards

ASHRAE Standards, as well as ANSI-ASA Standards, will be used in the evaluation of the proposed alternatives. It is important to meet the thermal and ventilation requirements when redesigning a mechanical system. These standards will be referenced when evaluating the DOAS. NERC standards will also be applied when evaluating and re-designing the electrical system within the Salk Hall Addition.

Appendix A: Primary Research

Chilled Beams

Barnet, Barry M. "Chilled Beams For Labs." *ASHRAE Journal* (2008): 28-37. Print.

Rumsey, Peter. "Chilled Beams in Labs." *ASHRAE Journal* 49 (2006): 18-25. Print.

Heat Recovery Chillers & Condensing Boilers

Durkin, Thomas H. "Dedicated Heat Recovery." *ASHRAE Journal* (2003): 18-23. Print.

Rishel, James B. "Reducing Energy Costs With Condensing Boilers and Heat Recovery Chillers." *ASHRAE Journal* (2007): 46-55. Print.

Demand Controlled Ventilation

Sharp, Gordon P. "Demand-Based Control of Lab Air Change Rates." *ASHRAE Journal* (2010): 30-41. Print.

Appendix B: Spring 2011 Proposed Re-design Schedule

Task Name	Duration	Start Date	Finish Date
Begin learning eQuest	14 days	1/10/2011	1/24/2011
Classes Begin	1 day	1/10/2011	1/11/2011
Research capabilities of TRACE in modeling proposed designs	2 days	1/12/2011	1/14/2011
General Research on Chilled Beams	5 days	1/17/2011	1/21/2011
General Research on Dual Wheel Energy Recovery Strategies	5 days	1/17/2011	1/21/2011
General Research on Demand Control Ventilation Systems	5 days	1/24/2011	1/28/2011
General Research on Heat Recovery Chillers	5 days	1/24/2011	1/28/2011
General Research on Condensing Boilers	5 days	1/24/2011	1/38/2011
Research on Hydronic Control of Boilers and Chillers	5 days	1/31/2011	2/4/2011
Research on control of Dual Energy Wheels and Chilled Beams	5 days	1/31/2011	2/4/2011
Analysis of ASHRAE Standards regarding redesign	5 days	2/7/2011	2/11/2011
Sizing and Selection of Chilled Beam & Dual Wheel System	5 days	2/14/2011	2/18/2011
Sizing and Selection of VAV & CB & DHRC components	5 days	2/21/2011	2/25/2011

Implementation of TRACE 700 model for baseline comparison	5 days	2/28/2011	3/4/2011
Begin eQuest simulation of VAV system	2 weeks	2/28/2011	3/11/2011
Begin eQuest simulation of Chilled Beam system	2 weeks	2/28/2011	3/11/2011
Electrical Breadth Research & Analysis	5 days	3/14/2011	3/18/2011
Architectural Breadth Research & Analysis	5 days	3/14/2011	3/18/2011
CB system summary	2 days	3/14/2011	3/16/2011
VAV system summary	2 days	3/14/2011	3/16/2011
Compare Economics of alternatives	5 days	3/21/2011	3/25/2011
Breadth summaries due	5 days	3/28/2011	4/1/2011
Review Summaries	2 days	4/4/2011	4/6/2011
Final Summary Report	ON-GOING	1/10/2011	4/7/2011
Final Presentation			TBA

January 2011

Search Calendar (C

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	
6	27	28	29	30	31	Jan 1, 11
	3	4	5	6	7	8
	10 Learning & Understanding eQuest Classes Begin	11	12 Research Capabilities of TRACE in modeling proposed designs	13	14	15
Learning & Understanding eQuest	17 General Research on Chilled Beams General Research on Dual Energy Wheel Recovery Strategies	18	19	20	21	22
Learning & Understanding eQuest	24 General Research on Condensing Boilers General Research on Demand Control Ventilation Systems General Research on Heat Recovery Chillers	25	26	27	28	29

February 2011

Search Calendar (Ctrl+E)

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	31	Feb 1	2	3	4	5
	Research on Hydronic Control of Boilers and Chillers					
	7	8	9	10	11	12
	Analysis of ASHRAE Standards regarding redesign					
	14	15	16	17	18	19
	Sizing and selection of chilled beam and dual wheel system					
	21	22	23	24	25	26
	Sizing and selection of VAV, CB, and DHRC components					
	28	Mar 1	2	3	4	5
	Implementation of TRACE 700 model for baseline comparison					

March 2011

Search Calendar (Ctrl+E)

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
7	28	Mar 1	2	3	4	5
	Begin eQuest simulation for CB system					
	Begin eQuest simulation of VAV system					
	Implementation of TRACE 700 model for baseline comparison					
	7	8	9	10	11	12
Begin eQuest simulation for CB system						
Begin eQuest simulation of VAV system						
	14	15	16	17	18	19
	Architectural Breadth research and analysis					
	Electrical breadth research and analysis					
	CB system summary					
	VAV system summary					
	21	22	23	24	25	26
	Economic Comparisons of alternatives and BOD					
	28	29	30	31	Apr 1	2
	Breadth summaries					

April 2011

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Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Sa
7	28	29	30	31	Apr 1	2
	Breadth summaries					
	4	5	6	7	8	9
	Review Summaries			**FINAL REPORT DUE**		