Gallaudet University
Sorenson Language and Communication Center

THESIS PROPOSAL

Prepared by Patrick B. Murphy
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The Pennsylvania State University
Department of Architectural Engineering
Senior Thesis

Faculty Advisor:
Dr. James D. Freihaut

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EXECUTIVE SUMMARY

The Sorenson Language and Communication Center (SLCC) on the Gallaudet University campus in Washington, DC is a one-of-a-kind facility designed for the deaf. Its visu-centric design appeals to the visual communication and way of being within the deaf culture. The owners want the building to be an example not only for other deaf building projects, but also for its energy efficiency and sustainability. The mechanical system in particular is charged with meeting these criteria.

The 87,000 SF facility is served by six (6) Trane M-Series Climate Changer Air Handing Units. Each unit serves a distinct zone within the facility that is unique in use and occupation schedule. The spaces served include classrooms, offices, conference rooms, computer labs, media studios, therapy rooms, audiology labs, and typical support spaces. VAV terminal units with hot water reheat control airflow and supply air temperature to each zone. Chilled water from the Central Utilities Building directly serves the cooling coils in the system. High pressure steam service also comes from the Central Utilities Building and heats the heating hot water and domestic hot water through heat exchangers.

Previous reports found that the overall the design of the SLCC mechanical system is efficient and practical. Energy saving equipment such as variable speed drives for fan and pump motors and energy saving techniques such as zoning help reduce total energy consumption. Also, the building envelope, glazing, and roofing decisions reduce energy lost/gained from the environment. However, there is room for improvement in the energy efficiency, acoustics, and system access of the SLCC. The goal for this thesis will be to improve the energy efficiency of the building and to address these acoustic issues.

This thesis proposal addresses the energy efficiency and acoustics of the SLCC through the application of active and passive chilled beams with a dedicated outdoor air system. The total airflow conditioned and distributed throughout the building will be decreased, and equipment and ductwork can be downsized. Energy recovery would reduce energy waste from exhausted room air by heating the outdoor air. In addition, a green roof would be applied for potential energy savings, storm water management, acoustic insulation, and aesthetics. Breadth topics will include an acoustic analysis of the mechanical system and green roof, structural analysis for the green roof, and life cycle cost analysis. Several preliminary research resources have been noted as a starting point for the information described in this proposal. Finally, a schedule for the next semester is provided as an outline of steps that need to be taken for sufficient completion of this thesis.

ORIGINAL DESIGN OBJECTIVES

The design of the Gallaudet University Sorenson Language and Communication Center (SLCC) was based on a balance of energy efficiency, cost, and acoustics while meeting ventilation, energy, refrigeration, and fire protection codes and standards. The mechanical system is tagged with the responsibility to effectively heat and cool the 87,000 SF facility while meeting these requirements. The entire design of the facility is intended to garner a LEED v.2.0 Certified Rating.

SmithGroup performed the primary architectural and MEP engineering services for the SLCC. The design only needed to meet DC Codes, which referred to ASHRAE Standards 15-1994, 55-1992, 62.1-1989, 90.1-1989. However, LEED v.2.0 requires compliance with ASHRAE Standards written in 1999 and therefore the SLCC is designed to these criteria instead of DC Codes. Please note that this thesis evaluates the building design against 2004 editions of the ASHRAE Standards and LEED NC v.2.1.

Some of the specific mechanical design criteria include:

- Efficiently condition the spaces within the SLCC. This includes air-side economizer, AHU zoning, occupancy sensors, etc.
- Provide adequate acoustics for sensitive spaces such as classrooms, Audiology and Hearing Science Labs, Speech and Language Sciences Lab, and therapy rooms. These spaces are intended to be at or below NC-25.
- Provide adequate indoor air quality by complying with the IMC-2000 and ASHRAE Std. 62.1-1999; exhausting toilet rooms, rooms with large-format copiers and kitchens; effectively filtering outdoor air and mixed air; and maintaining positive pressurization inside the building.
- Utilize central utilities from the campus Central Utilities Building including chilled water (43°F) and steam (100 psig) to eliminate the need for redundant systems.
- Reduce power use by the equipment by employing variable frequency drives on fan motors.
- Minimize rooftop equipment for aesthetic and service-life purposes. This equipment is limited to exhaust fans on the third floor roof or near exhaust louvers on the side of the building. All equipment is particularly restricted from installation on the second floor roof because of sightlines from the third floor balcony of the atrium to this area.
- Distinct zones for scheduling control of the system. The SLCC includes classroom space, offices, a clinic, an atrium, and computer labs. The goal is to isolate high density spaces to reduce overall building ventilation instead of zoning both high and low density spaces. This avoids a penalty required to properly ventilate the low density spaces due to the primary outdoor air fraction (Z_p).

Other design criteria for synergy with other disciplines include:

- Minimize heat loss through exterior walls by meeting ASHRAE Standards for wall construction overall u-values, and including language in the specs for proper construction to minimize exfiltration. Also the design should strategically place glazing to minimize solar heat gain and heat transfer from the interior.
- Reduce solar radiation heat gain to the building by using highly reflective roofing materials.
- Locate the outdoor air intake away from pollutant sources such as cars in parking lots.

MECHANICAL SYSTEM OVERVIEW

Gallaudet University's future Soreson Language and Communication Center will be served by six AHUs that serve distinct zones within the building (see Figure 1) based on occupancy schedules and space types. These AHUs are served by hot water heating coils and chilled water cooling coils. Chilled water service is to be provided from the campus chiller plant while hot water is produced by a plate and frame heat exchanger served by campus steam. With the exception of AHU-2, the air handlers serve VAV terminal units with and without hot water reheat. AHU-2 serves the atrium, however, and provides a constant volume air supply to the large, open space. All return air is directed back to the air handlers via transfer ducts and plenum returns. Several support spaces above grade are served by fan coil units (FCUs) and the computer server room (3224) is served by a computer room air conditioning unit (CRAC). Below grade, unit heaters and a FCUs condition mechanical spaces. Secondary direct digital controls (DDCs) direct operation of VAVs, FCUs, and other equipment.

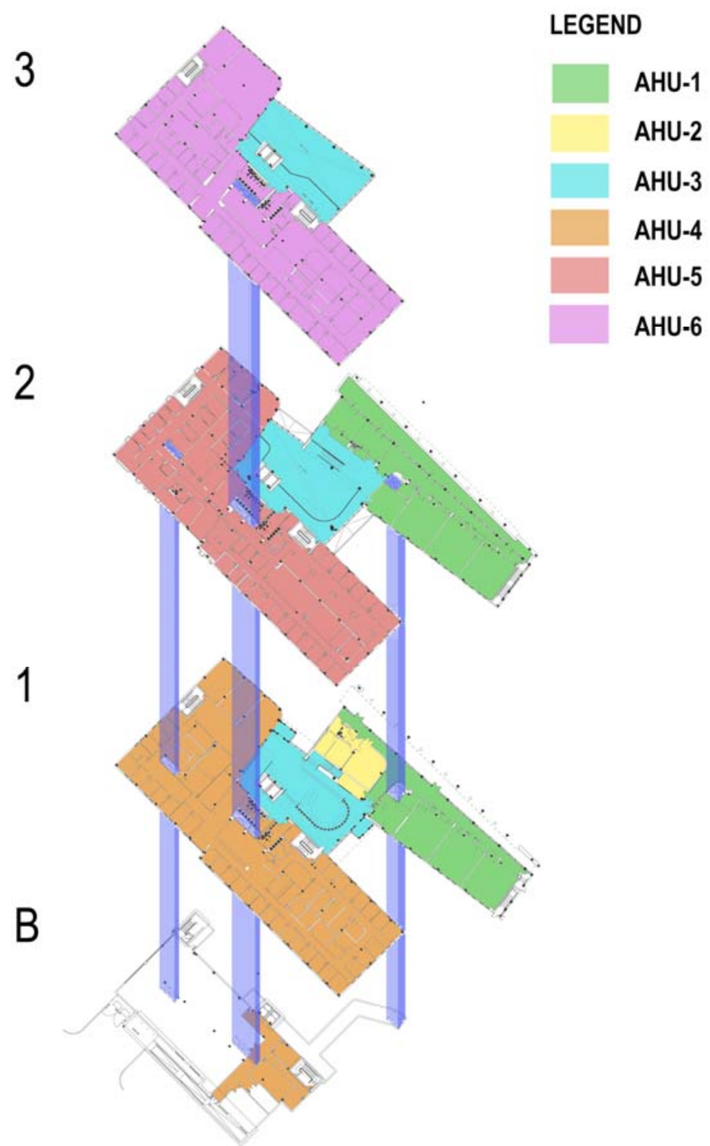

FIGURE 1: SLCC air handling unit service zones and shaft space.

DESIGN CRITIQUE

The mechanical system design for the SLCC is straightforward and effectively tailored to the conditions of the site. With chilled water and steam service from the campus utilities no plant was needed in the building itself. Instead this chilled water is directly delivered to the cooling coils that use it, and thermal energy in the steam is transferred to heating hot water and domestic hot water with heat exchangers. The division of the air side mechanical system for the facility into six (6) distinct zones allows flexibility and independence based on occupancy schedules. VAV boxes allow controllability of the system for each zone. FCUs, unit heaters, and a CRAC unit account for the unoccupied spaces and reduce the amount of energy used to heat and cool these spaces.

The building construction and layout generally works to the advantage of the mechanical system. The envelope meets ASHRAE Std. 90.1 criteria for construction and glazing area. Beyond that, the majority of the glazing is on the north, east and west facades thus reducing solar heat gain. Also, the roof is covered with a highly reflective roofing membrane to reduce the absorption of solar radiation. Within the building the MER and other support spaces are generously sized and there is reasonable access to all equipment for maintenance. Three shafts allow for air distribution to and from the MER and to exhaust fans on the roof. These shafts are adequately sized, though they take floor space away from the program of the building. Corridors are packed with ducts and VAV boxes and coordination in these spaces with other disciplines is particularly difficult, especially for maintenance access. Also, several VAV boxes could not fit in the corridors and are located in occupied spaces, thus compromising the specified noise criteria for these spaces. Also, the use of VAV fan boxes increases noise levels in the acoustically sensitive spaces such as the audiology labs and therapy rooms. While sound attenuators are used, they act as a band-aid rather than a solution to this problem. The actual source of mechanical noise is not minimized or eliminated.

The evaluation of ventilation requirements in the first technical report found conflicting results. The SLCC was designed to ASHRAE Std. 62.1-1999 requirements rather than the 2004 criteria. The earlier standard provided an occupant density calculation where the entire outdoor air requirement was based on space population for each occupancy type. The 2004 version calls for separate population and floor area components to the overall outdoor air requirement. Based on this 2004 standard, the calculations find that five of the six AHUs serving the SLCC do not meet the minimum requirements from ASHRAE Std. 62.1. AHU – 1 provides approximately 24% excess outdoor air to the spaces it serves. Overall, however, the designed HVAC system provides more than 30% less outdoor air than is necessary per Std. 62.1. Other discrepancies resulted from assumptions made in the calculations and which spaces controlled the design based on the primary outdoor air fraction.

The calculations in the building system energy report found that the SLCC meets the minimum requirements from ASHRAE Std. 90.1-2004 for building envelope and lighting efficiency. This is considering that the building is only designed to 1999 criteria. Also the overall SLCC design would earn enough points to gain a LEED Certified Rating. However, the building energy use is only potentially 23% less than the energy cost budget building which may earn two (2) of the ten (10) possible EA Credit 1 points.

The cost of the system is approximately $3.6M, or 17.5% of the total project cost. This may be slightly lower than for a typical building because no chilled water or steam plant was necessary for the building. As far as the operation costs, the Carrier HAP model made for the building system energy report shows some illogical discrepancies compared to the models performed by the primary MEP engineers. Based on the assumption that the Trane Trace model developed by the MEP engineers is correct, the SLCC consumes just under 4M MBH annually for an operation cost of $97,644/yr where as the budget building consumes over 5.3M MBH for an annual operation cost of $127,693/yr. Considering that the building does not include the steam and chilled water production, this is a sizeable reduction in energy consumption.

Overall the design of the SLCC mechanical system is efficient and practical. Energy saving equipment such as variable speed drives for fan and pump motors and energy saving techniques such as zoning help reduce total energy consumption. Also, the building envelope, glazing, and roofing decisions reduce energy lost/gained from the environment. However, the designers do not guarantee that the two (2) EA Credit 1 points will be earned. Another problem is that coordination with the larger size of ducts and confined plenums in corridors has led to some access and acoustical issues. The goal for this thesis will be to improve the energy efficiency of the building and to address these acoustic issues.

Gallaudet University SLCC 60% Construction Document Cost Estimate Comparison

Division	Description	ICI[†] Cost/SF *88,432*	ICI[†] Amount	Heery[‡] Cost/SF *87,704*	Heery[‡] Amount	Average Cost/SF	Average Cost	Average Portion of Total Cost
1	GENERAL REQUIREMENTS	37.15	3,284,919	35.70	3,130,654	38.64	3,207,787	15.3%
2	SITE WORK/DEMO	21.02	1,858,674	20.76	1,820,980	22.16	1,839,827	8.8%
3	CONCRETE	16.86	1,490,948	16.30	1,429,608	17.59	1,460,278	7.0%
4	MASONRY	7.52	665,232	6.45	565,746	7.41	615,489	2.9%
5	METALS	29.98	2,651,078	26.41	2,316,251	29.91	2,483,665	11.8%
6	WOODS & PLASTICS	3.20	282,609	3.00	263,121	3.29	272,865	1.3%
7	MOISTURE PROTECTION	15.39	1,361,003	13.84	1,213,656	15.50	1,287,330	6.1%
8	DOORS & WINDOWS	16.20	1,432,475	14.24	1,249,024	16.15	1,340,750	6.4%
9	FINISHES	21.95	1,941,193	26.76	2,347,035	25.82	2,144,114	10.2%
10	SPECIALTIES	1.81	159,935	1.83	160,236	1.93	160,086	0.8%
11	EQUIPMENT	0.08	7,450	0.27	23,500	0.19	15,475	0.1%
12	FURNISHINGS		0	0.51	44,648	0.27	22,324	0.1%
13	SPECIAL CONSTRUCTION		0		0	0.00	0	0.0%
14	CONVEYING SYSTEMS	3.05	270,000	3.08	270,000	3.25	270,000	1.3%
15	MECHANICAL	43.81	3,874,102	39.71	3,483,011	44.31	3,678,557	17.5%
16	ELECTRICAL	25.50	2,254,854	24.10	2,113,331	26.31	2,184,093	10.4%

Subtotal		21,534,472		20,430,801		20,982,637
Contingency	5%	1,076,724	5%	1,021,540	5%	1,049,132
Subtotal		22,611,196		21,452,341		22,031,768
Escalation	6.7%	1,442,810	7%	1,501,664	7%	1,542,224
Total	**272.01**	**24,054,006**	**261.72**	**22,954,005**	**267.6794**	**23,573,992**

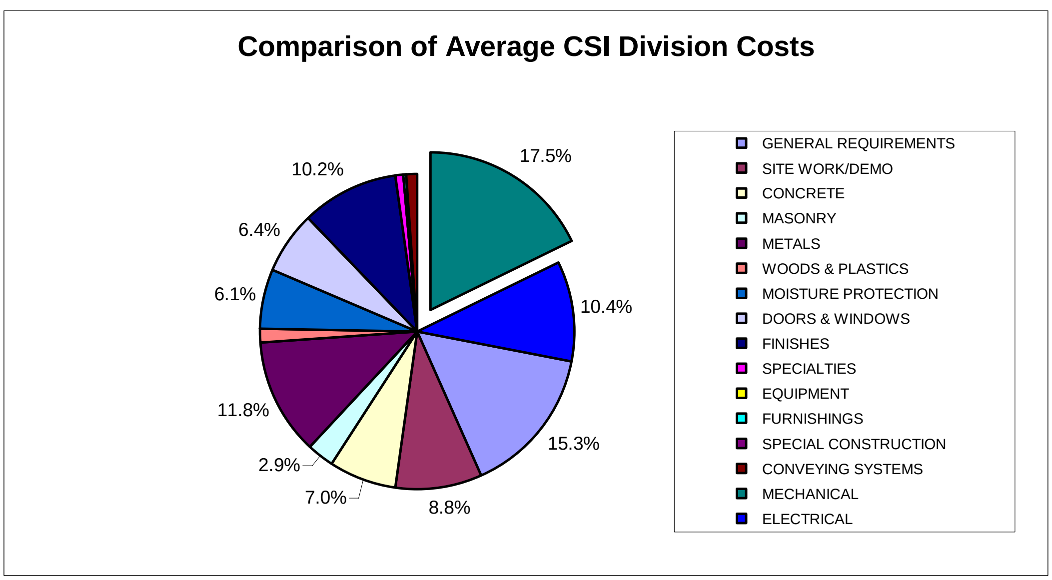

FIGURE 2: First Costs by CSI Division for original design.

PROPOSAL ALTERNATIVES CONSIDERED

The primary goals for this thesis are to improve the energy efficiency of the Sorenson Language and Communication Center, and to improve the acoustics in sensitive spaces. In order to achieve these goals, the initial instinct was to eliminate the VAV fan boxes in the acoustically sensitive spaces. This equipment is a major source of noise in the audiology labs, therapy rooms, etc. A consideration in typical office and laboratory design is providing enough background noise – also known as white noise – for occupant comfort. However, the SLCC is confronted with unique design considerations including a mostly deaf population and the need for NC-25 spaces. Here, mechanical noise should be limited as much as possible. Also, the design of the SLCC embraces sustainability and energy efficiency as goals. Therefore, any proposed changes to the mechanical system should provide the same interior conditions with the same or better efficiency and energy. With these criteria in mind, the option of a green roof also arises. The green roof has the potential to insulate the building both thermally and acoustically.

PRIMARY TOPIC 1: CHILLED BEAMS

Exploration of possibly more efficient air delivery and conditioning methods led to research into dedicated outdoor air systems (DOAS). Fundamentally, this means that the mechanical system only conditions enough outdoor air to meet ventilation requirements and latent loads on the air side, and utilizes a decoupled sensible cooling strategy in the occupied spaces on the water side. Active and passive chilling systems presented different energy consumption, acoustics, air quality maintenance, and air distribution. Also, these strategies are applicable in different types of spaces.

First, active chilled beam systems tie into the room's primary air supply ducts, mixing supply air with room air that is cooled by chilled water coils (see Figures 3, 4). Air is then introduced to the space through high-induction diffusers. The task of the AHU is to condition the amount of ventilation air per ASHRAE Standard 62.1. If this airflow can not counteract the space latent loads at the given supply temperature, the AHU will be required to condition more air than the minimum amount of outdoor air. Chilled water supplied to the cooling coils is maintained just above the dew point temperature to avoid condensation.

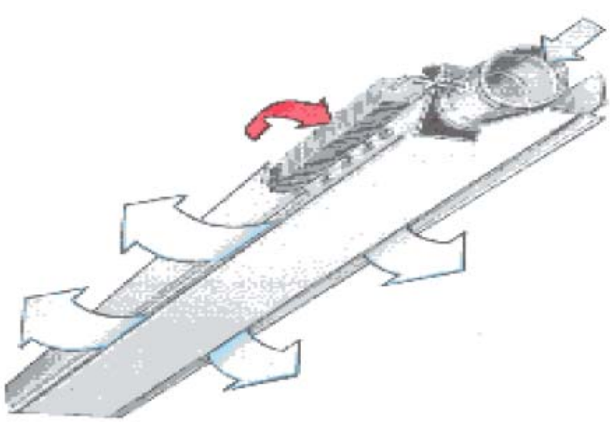

FIGURE 3: Configuration of an active chilled beam.

FIGURE 4: Chilled beams can be integrated with lighting.

Next, passive chilled beams were explored. The greatest difference between this passive system and active chilled beams is that the supply air delivery and sensible cooling are not tied together. Rather, natural convection forces warm room air into the ceiling plenum via perforated ceiling panels, and this air is cooled by the chilled beam as it descends back into the occupied space. Chilled water runs through the passive beams and fins absorb thermal energy from the air. Because the heavier cool air drops it continuously draws warm air from the plenum through the chilled beam (see Figure 5). It should be noted that the cooling capacity of passive chilled beams is not as great as for active chilled beams.

FIGURE 5: A passive chilled beam has openings for the cooled air to descend through it.

Since all air removed from the spaces is exhausted, the thermal energy associated with it is lost. Heat recovery from this exhaust air stream is thus a logical energy saving method in DOAS. Equipment such as an enthalpy or sensible wheel transfers the heat in the exhaust air stream to the incoming outdoor air and reduces the load on heating coils.

Greg Mella, the Project Architect on the SLCC at SmithGroup, was quoted in *Building Design and Construction Magazine* on the use of chilled beams. He said "it's a great concept, and I think it has tremendous potential in the U.S."

PRIMARY TOPIC 2: GREEN ROOF

The application of a green roof was also proposed in the schematic design phase of the project (see Figure 6). The occupied rooftop garden was intended for the roof of the two story classroom wing, with access from the third floor. Since the project is designed for LEED Certification, the green roof provided points for reducing the heat island effect, more effectively insulating the building, and reducing stormwater runoff. An analysis of the heat transfer through the roof and constructability would be performed. In addition, the specifications would be reviewed to ensure that the building envelope is properly sealed. Infiltration must be minimized so humidity does not enter the building and cause condensation on the chilled water pipes. The costs of both an occupied and unoccupied green roof would be determined. The occupied green roof would need access through both the classroom wing stair well and from the atrium, thus adding structure and significant first costs. This is why the idea was not pursued by the owner. An unoccupied green roof provides the thermal benefits of a green roof without this additional structure and could be more cost effective. An unoccupied green roof could also be installed on the third floor roof.

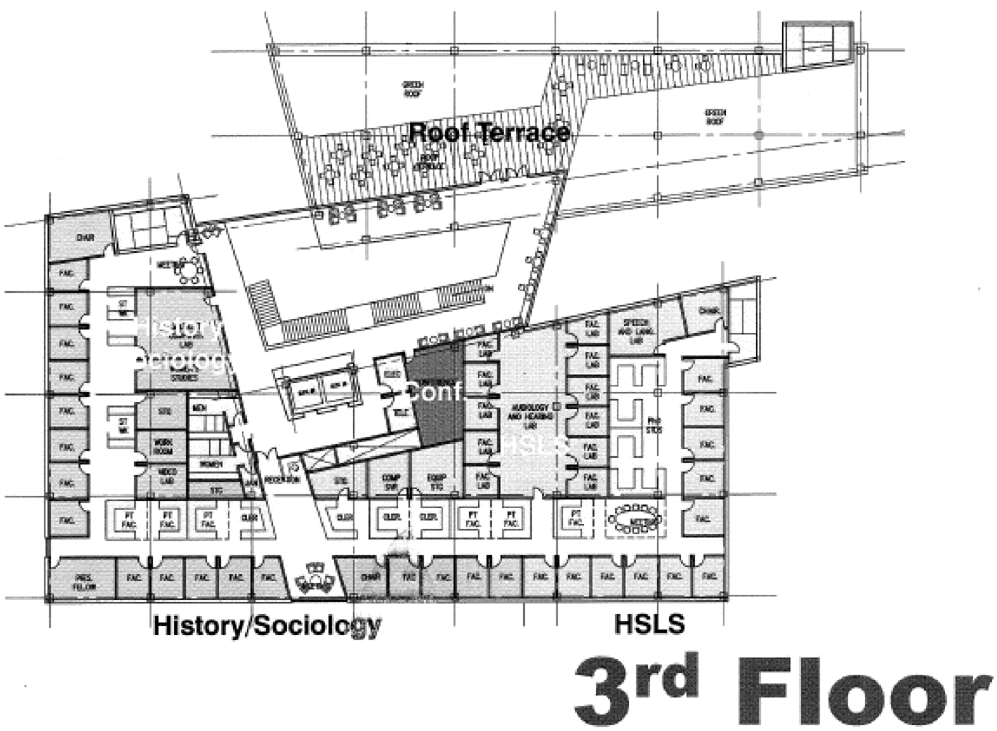

FIGURE 6: Schematic design proposal for a green roof.

BREADTH TOPICS

Further investigations into the redesign of the SLCC are based on the implications of the primary proposals. Since the acoustics of the spaces is a particular concern an acoustic analysis becomes an analysis. Also, the green roof adds a significant dead load upon the structure thus warranting a structural load analysis. A smaller, supplementary topic would be to resize the outdoor air filters for the facility. Finally, a life cycle cost evaluation will help quantify the benefits and drawbacks of all proposals.

First, with highly sensitive acoustic spaces the impact of any mechanical system redesign on the space noise should be investigated. The application of DOAS reduces the amount of air running through ducts and being introduced to these spaces. It also eliminates the need for VAV fan boxes which produce much of the noise in the spaces. However, the introduction of chilled water flow in the rooms and airflow through high induction diffusers creates new noise. An analysis of the original and proposed designs will be conducted using the Trane Acoustical Program (TAP). Also, the impact of the green roof on the acoustic insulation of the building will be investigated. This will be accomplished by measuring ambient outdoor noise at the site and estimating or simulating the sound transmission loss through the original and green roofs.

The addition of several inches of saturated soil and plant matter upon the roof increases the dead load the structure must carry. Therefore a structural analysis of the total loads for each roof type, roof deck, joists, girders, and columns must be conducted. Both hand calculations spot checking each structural member's capacity to carry the additional load and a simulation in RAM Structural Steel will be performed.

Filtration of outdoor air with DOAS is slightly different than filtration in traditional VAV systems. In particular, there is no dilution of outdoor air with recirculated air. As a result, an outdoor contaminant can be delivered to interior spaces at higher concentrations. This is a concern because the SLCC is located in an urban area where outdoor air quality is less than ideal, and because the facility is in close proximity to The Capitol Building where there is a potential for a CBR attack. A more efficient DOAS filter would be required to reduce contaminant concentration in the spaces to equal concentrations with the current VAV system. The smaller airflow would allow for a smaller filter, thus negating the increased cost for the filters. An optimization would determine the size, cost, and increased fan energy required for these new filters to compare with the current design (see Figure 7).

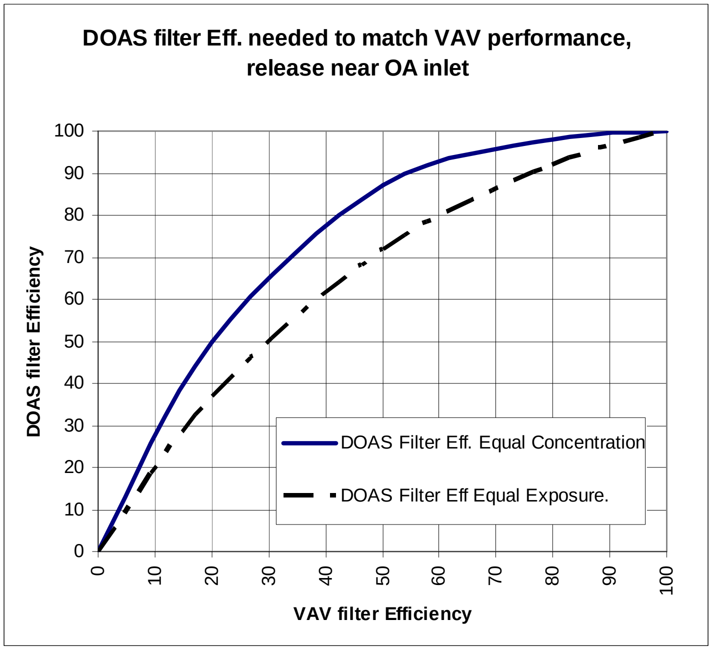

FIGURE 7: Equivalent filter efficiencies for DOAS and VAV systems for equal room contaminant concentration and exposure.

Finally, all proposals should be evaluated based on their cost. The first cost, energy savings, maintenance costs, and replacement costs must be considered over the life of the building. The total life cycle cost, first cost, and payback period will be the primary criteria for the evaluation. In addition, intangible costs and benefits will be weighed such as sustainability, LEED rating, constructability, etc.

THESIS PROPOSAL

Several of the proposal alternatives will be employed for the redesign of the SLCC this spring. This thesis must reflect the experience of graduate level courses and meet both Architectural Engineering Department and Schreyer Honors College Requirements. Therefore more than two breadth topics will be utilized and deeper investigation and analysis will be conducted. Of the proposal alternatives suggested, the DOAS system with both passive and active cooling will be employed where appropriate. Also the green roof will be added to the facility. For breadth, an acoustic analysis, structural analysis, and life cycle cost analysis would be performed.

The specific scope of this thesis will vary from topic to topic (see Figures 8-10). The DOAS system will be employed throughout the building except for the atrium, student media center, and support spaces. Active chilled beams will be used in perimeter spaces and those on the top floors because these spaces have the greatest thermal load. Passive systems will be employed in interior spaces where applicable. The most acoustically sensitive spaces will be checked for both passive and active chilled beam applications to decide on the optimal system. Factors for this decision will include acoustics and thermal comfort. The atrium and student media center are relatively unique spaces and are not ideal candidates for DOAS. Also, the second floor hearing clinic will need to remain on its own AHU because these spaces run on a separate schedule from the rest of the building. Otherwise AHU zones will be merged and/or AHUs will be resized wherever possible to minimize the number and cost of the AHUs. Energy waste will be minimized through investigation of heat recovery options. Shaft sizes will be reevaluated based on the new duct sizes and additional floor space will be returned to the building program where possible. Finally a new energy model using Carrier's HAP Program will be created to compare the old and new systems and to size equipment.

The green roof design proposed in the schematic phase of the SLCC design process will be evaluated. The costs, thermal insulation, and constructability issues will be addressed. If possible, the building envelope design program WUFI will be used to create a model of the original and new roof designs. Changes in roof insulation will be included in the new energy model. Sound transmission losses will also be approximated for the roof for its acoustic insulation properties.

An acoustic analysis will determine whether the audiology labs and hearing clinic spaces meet the originally specified noise criteria. Manufacturer's data and green roof sound transmission loss approximations will be used to determine the NC-level from mechanical noise for both the VAV and DOAS systems, and TAP model will be simulated to optimize the system. Consultation with Dr. Courtney Burroughs will also guide the design. Besides the elimination of VAV boxes and introduction of high induction diffusers and chilled water piping, other noise within the space from pumps, equipment, etc. will be investigated. Sound attenuators and more sound absorbing materials will also be suggested for these spaces. Individual analyses of the original design, each independent proposal, and the combined chilled beam and green roof proposal will be used to evaluate each design.

A structural breadth analysis using RAM Steel and hand calculations will evaluate the original structural design for its capacity to carry the additional green roof load. If the current structural design is not sufficient, members will be resized.

Finally, a life cycle cost analysis will be conducted to determine the appropriateness of these proposals. The first costs of the current design as provided by the construction manager will be compared with the cost data collected for the redesign. New equipment, maintenance costs, operational costs, and service life will be considered. Each proposal will be separately evaluated in an Excel spreadsheet to determine that proposal's unique benefits and costs. Combined evaluations will also be conducted. For instance, if the green roof isn't used, there is an impact on the energy model and thus potentially requiring larger equipment. If the green roof is recommended the cost of it may be offset by the energy savings and first cost savings for the mechanical equipment. Final recommendations for this thesis will depend greatly on this life cycle cost analysis as well as intangible costs and benefits such as sustainability, LEED rating, constructability, etc.

FIGURE 8: DOAS redesign scope.

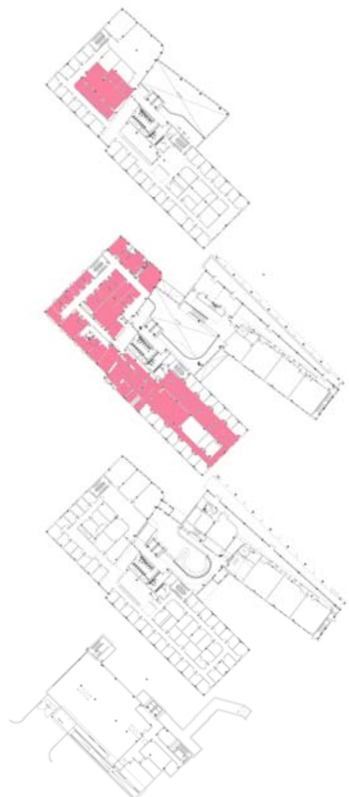

FIGURE 9: Acoustic analysis scope.

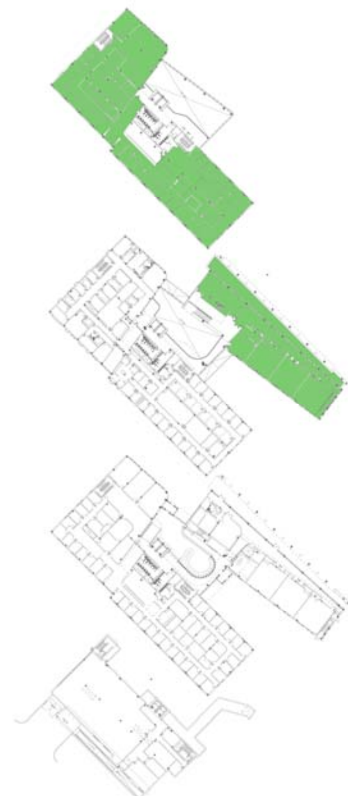

FIGURE 10: Green roof redesign scope.

PROPOSED SPRING SEMESTER SCHEDULE

Below is a calendar (see Figures 11-15) of the proposed redesign schedule. Each week will be dedicated to the topic described on Monday. Research will include reading technical papers, finding manufacturers' data, and possible analyses and optimizations. Since travel dominates the schedule, work that can be done while traveling will be done then. For example, reading technical papers and even doing work for other classes will free time while in State College to do work. The ASHRAE Winter Meeting will also help in the collection of research material through technical seminars and the product expo. Spring break will be used to complete the bulk of the report. On April 11th, a week before thesis presentations, the Central Pennsylvania Chapter of AHRAE will host its student night. In the past several students would give their full thesis presentation to the members. This year, since the meeting is before the presentations, students will make posters of their thesis work for feedback during a social hour. Finally, after the presentation, adjustments will be made and the thesis will be submitted to the Honors College for approval.

JANUARY 2007

MON	TUE	WED	THU	FRI	SAT	SUN
1 New Year's Day	2 Travel Discuss thesis proposal topics with primary MEP engineers, architects	3 Travel	4 Travel	5 Travel	6 Travel	7 Travel
8 Return to S.C. Continue research into DOAS application	9	10	11	12	13	14
15 File Intent to Graduate Research energy recovery methods	16 Classes Start	17 Travel	18 Travel	19 Travel	20 Travel	21 Travel
22 Research Green Roofs	23	24	25	26	27	28 Travel
29 Travel ASHRAE Winter Mtg. Attend Seminars on research topics.	30 Travel ASHRAE Winter Mtg. Attend Seminars on research topics.	31 Travel ASHRAE Winter Mtg. Attend Expo to research products.				

FIGURE 11: January schedule for thesis work.

FEBRUARY 2007

MON	TUE	WED	THU	FRI	SAT	SUN
			1	2 Travel	3 Travel	4
5 Research Acoustics of DOAS, schedule meeting with Dr. Buroughs	6	7	8	9	10	11
12 Begin analysis of integration of systems, Perform thermal analysis on green roof	13	14	15	16	17	18
19 Develop new energy model	20	21	22	23	24 Travel	25 Travel
26 Perform acoustic analysis, meet with Dr. Buroughs	27	28				

FIGURE 12: February schedule for thesis work.

MARCH 2007

MON	TUE	WED	THU	FRI	SAT	SUN
			1	2	3	4
5 Size equipment and find cost data	6	7	8	9	10 Spring Break	11 Spring Break
12 Spring Break Perform Life Cycle Cost analysis	13 Spring Break	14 Spring Break Begin compiling report	15 Spring Break	16 Spring Break	17 Spring Break	18 Spring Break
19 Continue work on report	20	21	22	23	24	25
26 Complete report, resolve potential issues	27	28	29	30 Travel	31 Travel	

FIGURE 13: March schedule for thesis work.

APRIL 2007

MON	TUE	WED	THU	FRI	SAT	SUN
30						1
2 Prepare presentation, resolve potential issues	3	4	5	6 Travel	7 Travel	8 Travel
9 Prepare poster	10	11 Central PA ASHRAE Student Night (Poster Presentation)	12 Travel Resolve any new potential issues resulting from ASHRAE feedback, print report	13 Travel	14 Travel	15 Travel Complete presentation
16 Thesis Presentations	17 Thesis Presentations	18 Thesis Presentations	19 Reformat report per Honors College requirements	20	21	22
23 Receive signatures for honors thesis submission, print honors thesis	24 Submit honors thesis	25 Travel	26 Travel	27 Travel	28 Travel	29 Travel

FIGURE 14: April schedule for thesis work.

MAY 2007

MON	TUE	WED	THU	FRI	SAT	SUN
	1	2	3 Second round of thesis presentations	4 Second round of thesis presentations, AE Banquet	5 Last Day of Classes	6
7 Finals	8 Finals	9 Finals	10 Finals	11 Finals	12	13
14	15	16	17	18 Honors College, College of Engineering Graduation	19	20 Graduate School Graduation
21	22	23	24	25	26	27
28	29	30	31			

FIGURE 15: May schedule for thesis work.

RESOURCES

Barista, Dave. *Chill the ceilings for cool energy savings. Building Design and Construction Magazine.* Nov. 2005. <http://www.labdesignnews.com/LaboratoryDesign/LD0512FEAT_3.asp>

Butt, Edwards. *The Sound of Silence. Building Services Journal*. 4 Feb. 2004. <http://www.hoarelea.com/news/article.cfm?content_id=271&e=1>

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