Sustainable Solutions for

Energy Efficiency and Acoustic Performance

Gallaudet University

Sorenson Language and Communication Center

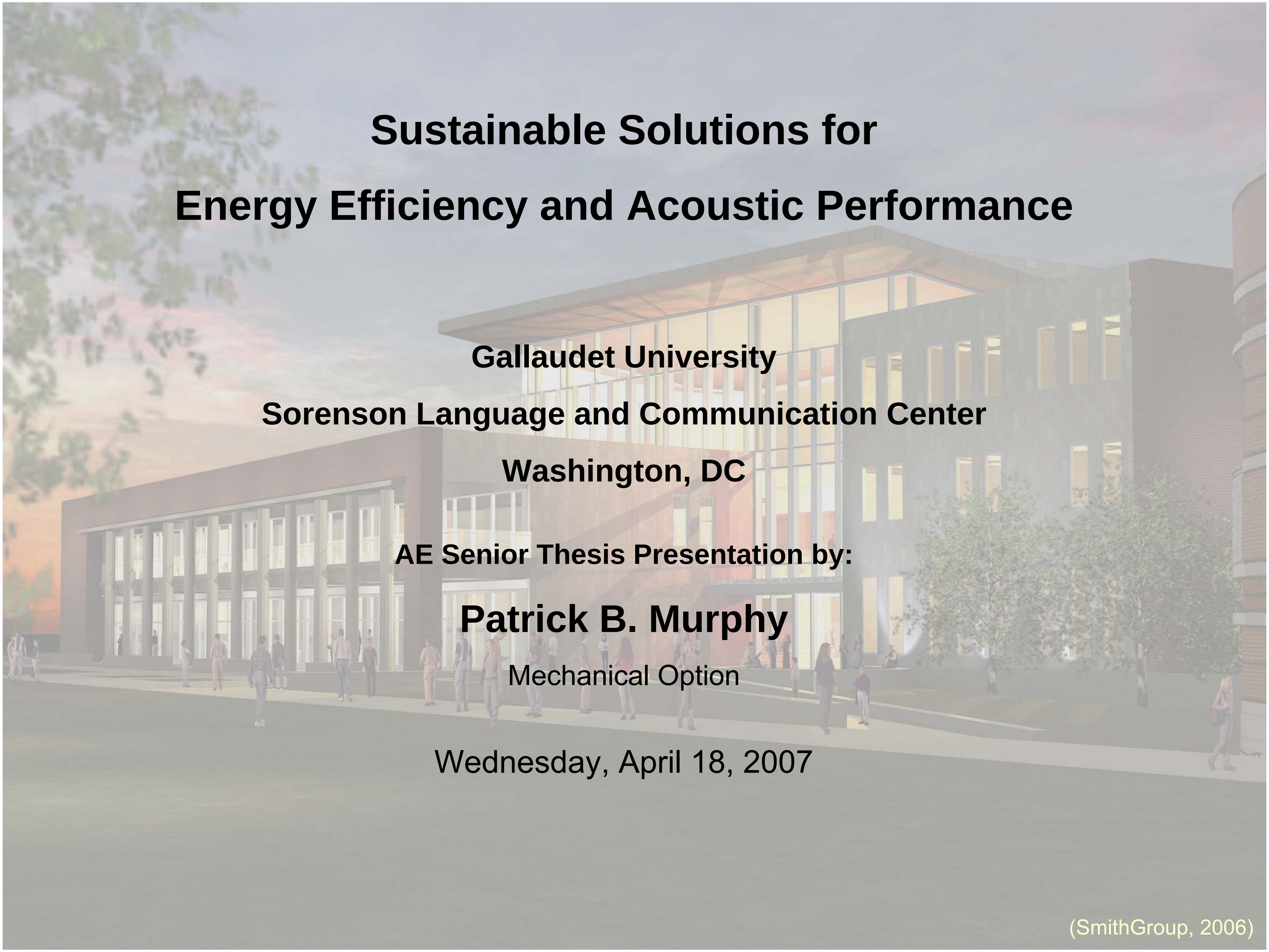
Washington, DC

AE Senior Thesis Presentation by:

Patrick B. Murphy

Mechanical Option

Wednesday, April 18, 2007



(SmithGroup, 2006)

(Gallaudet University, 2006)

(Gallaudet University, 2006)

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Wednesday, March 18, 2007

vis·u·cen·tric (vĭzh'ōō–sĕn'trĭk) *adj.*: the design of a distinctive structure that clearly and unmistakably says: "This is a space for deaf people."

(Gallaudet University, 2006)

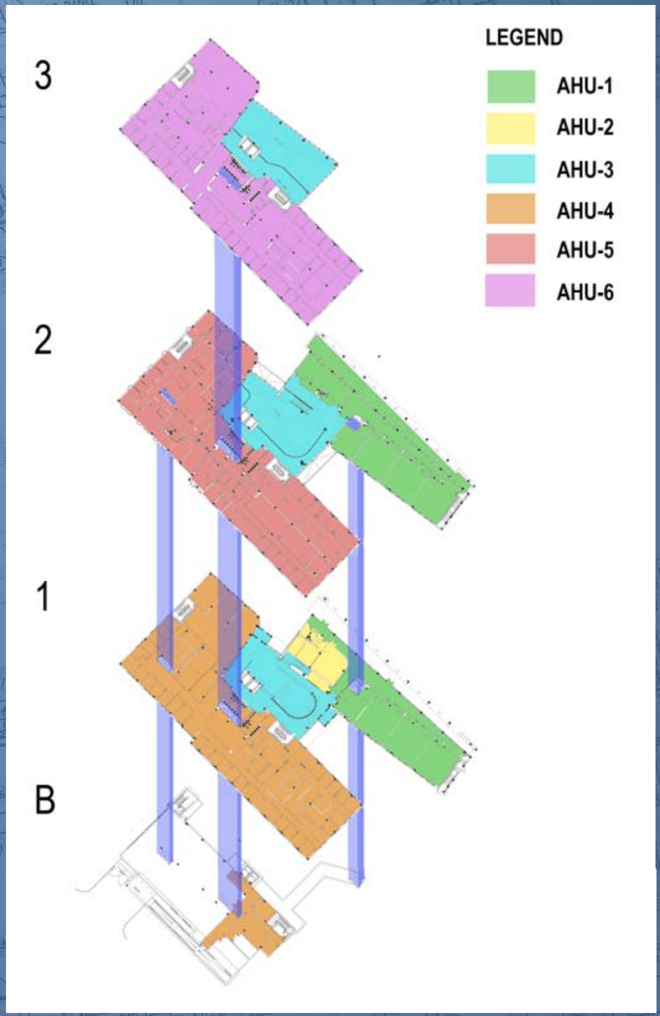
(SmithGroup, 2006)

Existing Mechanical System

Conditioned Air

Chilled Water

Steam



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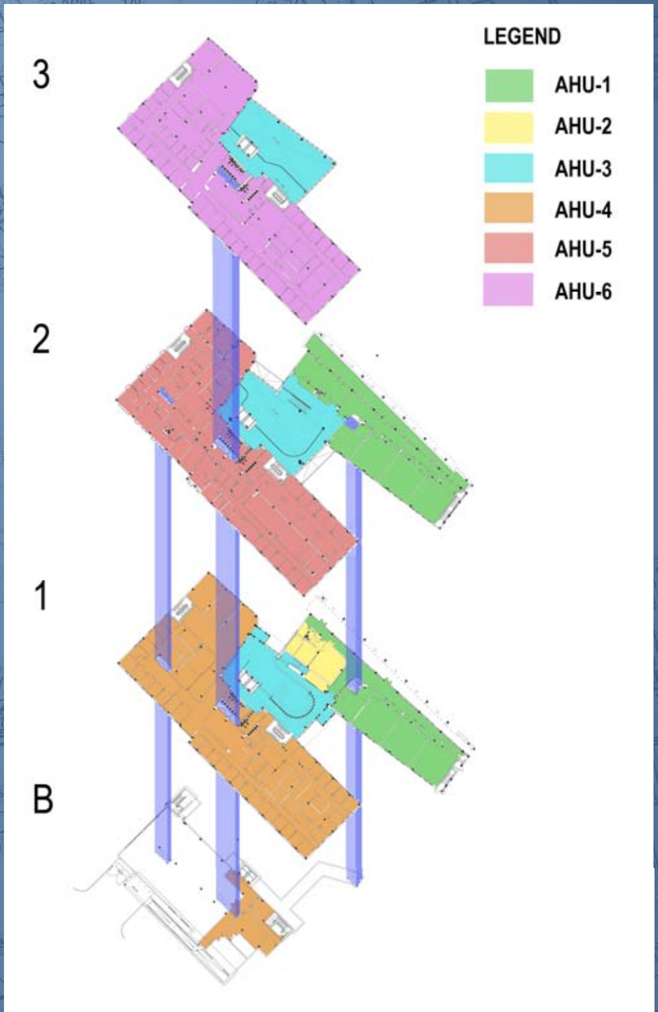
Existing Mechanical System

Conditioned Air

- Facility served by six (6) AHUs
- AHUs located in basement
- Appx. 30% Outdoor Air
- 53°F Supply Air
- VAV Terminal Units (142)

Chilled Water

Steam

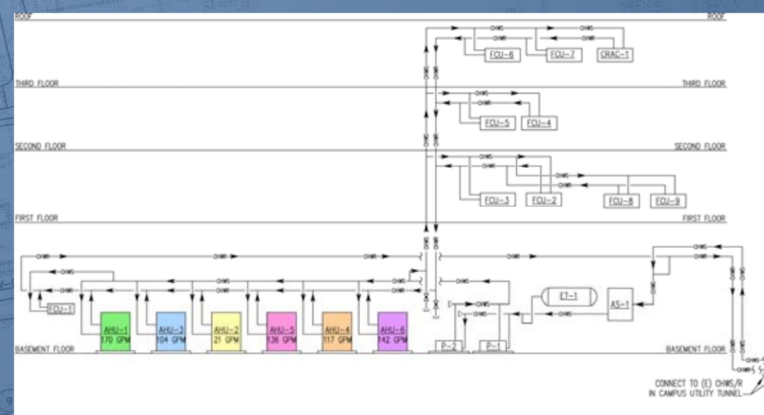


Existing Mechanical System

Conditioned Air

Chilled Water

- Service from Central Utilities Building
- 43°F Chilled Water Supply
- Serves AHU Cooling Coils



CHILLED WATER DIAGRAM

Steam

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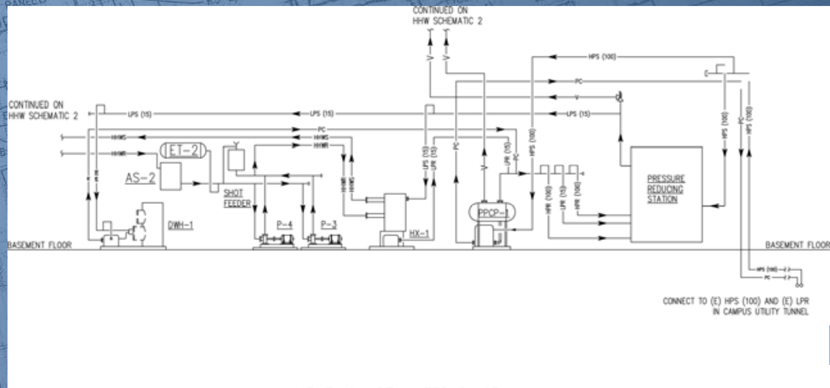
Existing Mechanical System



HEATING HOT WATER DIAGRAM 1

Conditioned Air

Chilled Water

Steam

- Service from Central Utilities Building
- HPS (100 psig) reduced to LPS (15 psig)
- Plate-Frame HX uses LPS to produce 108°F HHW at 280 gpm
- HHW serves AHU Heating, VAV Reheat Coils

THESIS DESIGN GOALS

1. Reduce facility energy use
2. Improve acoustic conditions in sensitive spaces

Thesis Investigations

- DOAS w/ Parallel Cooling
- Green Roof Application
- Energy Analysis
- Acoustics Analysis
- Structural Analysis
- LEED Analysis
- Cost Analysis

A Dedicated Outdoor Air System (DOAS) supplies a constant volume of outdoor air per ventilation requirements.

A Parallel Cooling System compensates for space sensible loads.

The DOAS System will supply 30% greater outdoor air than required by ASHRAE Std. 62.1.

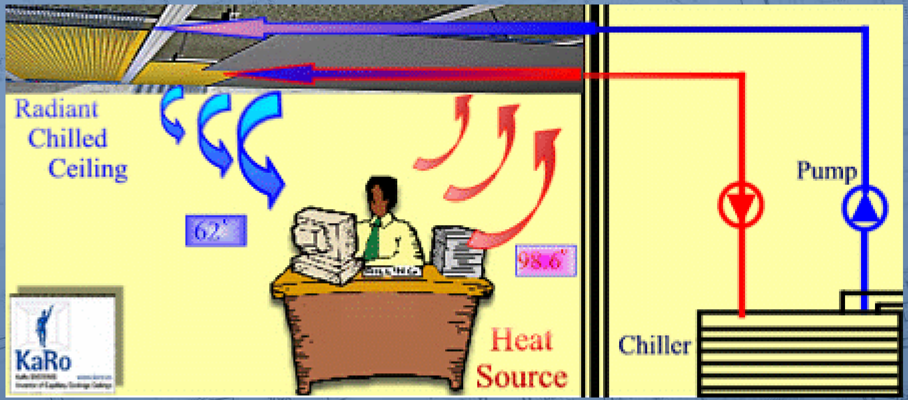
- System only delivers about 35% of original VAV supply air at T_{SA} of 55°F.
- VAV boxes may be eliminated.
- AHUs and ductwork may be significantly downsized.
- Reduced fan energy required.

SUMMARY

AHU	# Zones / VAVs	Area Served [SF]	ASHRAE Minimum OA [CFM]	DOAS Design OA [CFM]	Original Design OA [CFM]	Reduction in OA Flow [CFM]	DOAS Design SA [CFM]	Original Design SA [CFM]	Reduction in SA Flow [CFM]
1	19	13185	2000	2650	4130	35.8%	2650	17400	84.8%
2	3	1311	390	515	360	-43.1%	515	2230	76.9%
3	0	7990	1240	2890	2890	0.0%	2890	13070	77.9%
4	44	15285	2875	3875	4650	16.7%	3875	14080	72.5%
5	37	15061	2405	3725	4550	18.1%	3725	11965	68.9%
6	39	15146	2990	4180	4050	-3.2%	4180	14130	70.4%
4/ 6	83	30431	5865	8055	8700	7.4%	8055	28210	71.4%
TOTALS	**142**	**67978**	**11900**	**17835**	**20630**	**13.5%**	**25890**	**72875**	**64.5%**

One parallel cooling strategy is radiant panels.

- Chilled water (60°F) runs through piping thermally coupled to metal panel in ceiling.
- Sensible cooling capacity of about 21 BTU/SF.



(www.naturalcooling.com, 2007)

One parallel cooling strategy is radiant panels.

- Chilled water (60°F) runs through piping thermally coupled to metal panel in ceiling.
- Sensible cooling capacity of about 21 BTU/SF.

NOT SELECTED BECAUSE:

- Too many panels are necessary to fit in available ceiling space of some rooms.
- Metal panels replace acoustic ceiling panels, alter space acoustics.

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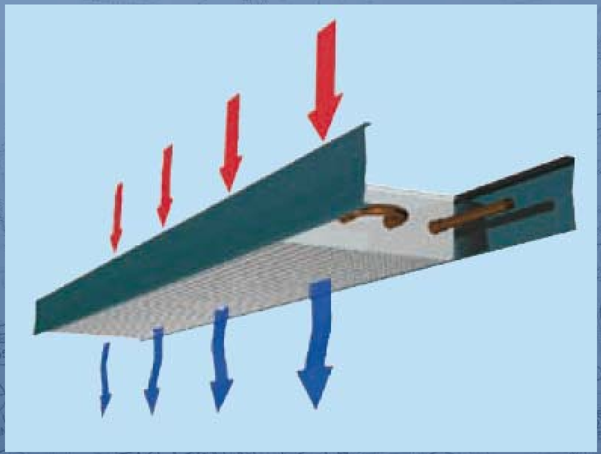
Another parallel cooling strategy is passive chilled beams.

- Chilled water (60°F) runs through piping thermally coupled to metal fins in ceiling beam unit.
- Warm air from plenum is drawn through unit and into space by natural buoyancy forces.
- Sensible cooling capacity of about 250 BTU/hr-SF.



(www.halton.com, 2007)

Another parallel cooling strategy is passive chilled beams.

- Chilled water (60°F) runs through piping thermally coupled to metal fins in ceiling beam unit.
- Warm air from plenum is drawn through unit and into space by natural buoyancy forces.
- Sensible cooling capacity of about 250 BTU/hr-SF.

SELECTED BECAUSE:

- Higher cooling capacity than radiant panels means fewer units.
- Relatively quiet distribution of cool air.

A separate chilled water loop is necessary to supply 60°F water to the chilled beams.

- Chilled water supplied to beams must be warmer than the room air dew point to prevent condensation.

  $T_S = 60°F < T_{dp} = 57.8°F$

- This loop is maintained at a 16°F ΔT, must be adequately controlled to prevent condensation on unit piping.
- Chilled water is supplied to facility at 43°F with a 10°F ΔT.
- Three (3) parallel pumps and one backup.

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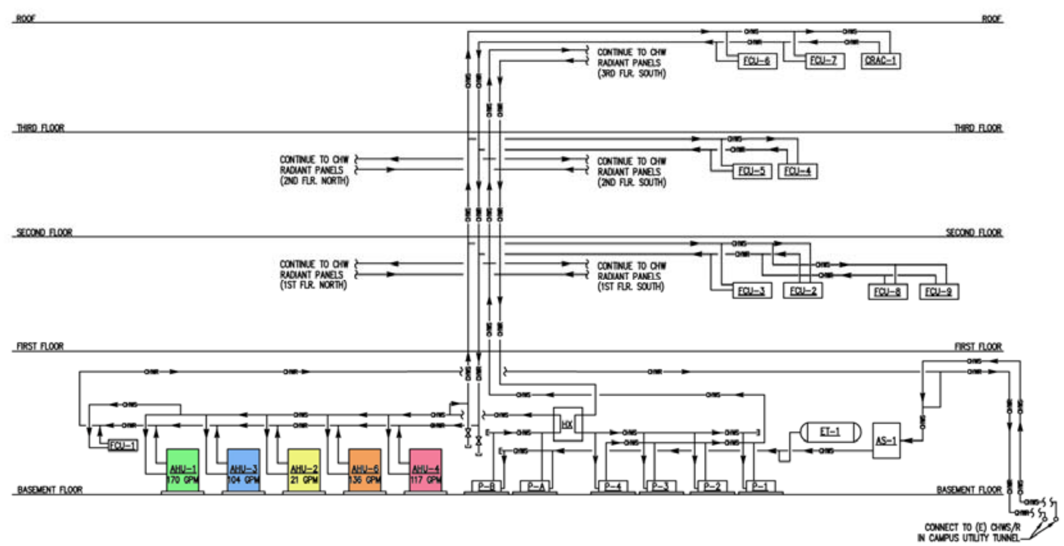
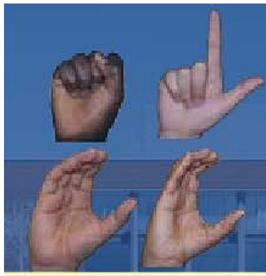
A separate chilled water loop is necessary to supply 60°F water to the chilled beams.



CHILLED WATER DIAGRAM



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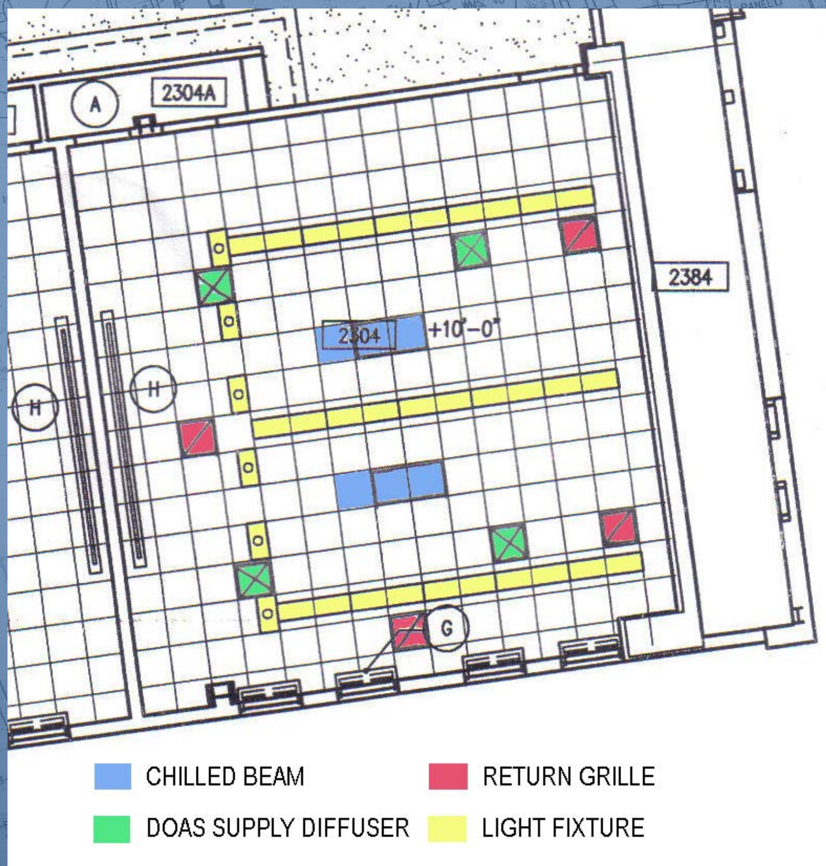
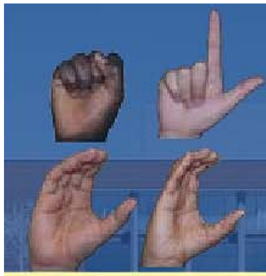


Thesis Investigations

- **DOAS w/ Parallel Cooling**
  - **Ventilation Strategy**
  - **Radiant Panels**
  - **Chilled Beams**
  - **System Schematic**
  - **Suggested Layout**
  - **Design Implications**
- Green Roof Application
- Energy Analysis
- Acoustics Analysis
- Structural Analysis
- LEED Analysis
- Cost Analysis

A DOAS system with chilled beams conditions spaces effectively and quietly.

- Air distribution is significantly reduced.
- AHUs, fans, ductwork, etc. are downsized.
- Chilled beams fit within the ceiling area of rooms while radiant panels do not.



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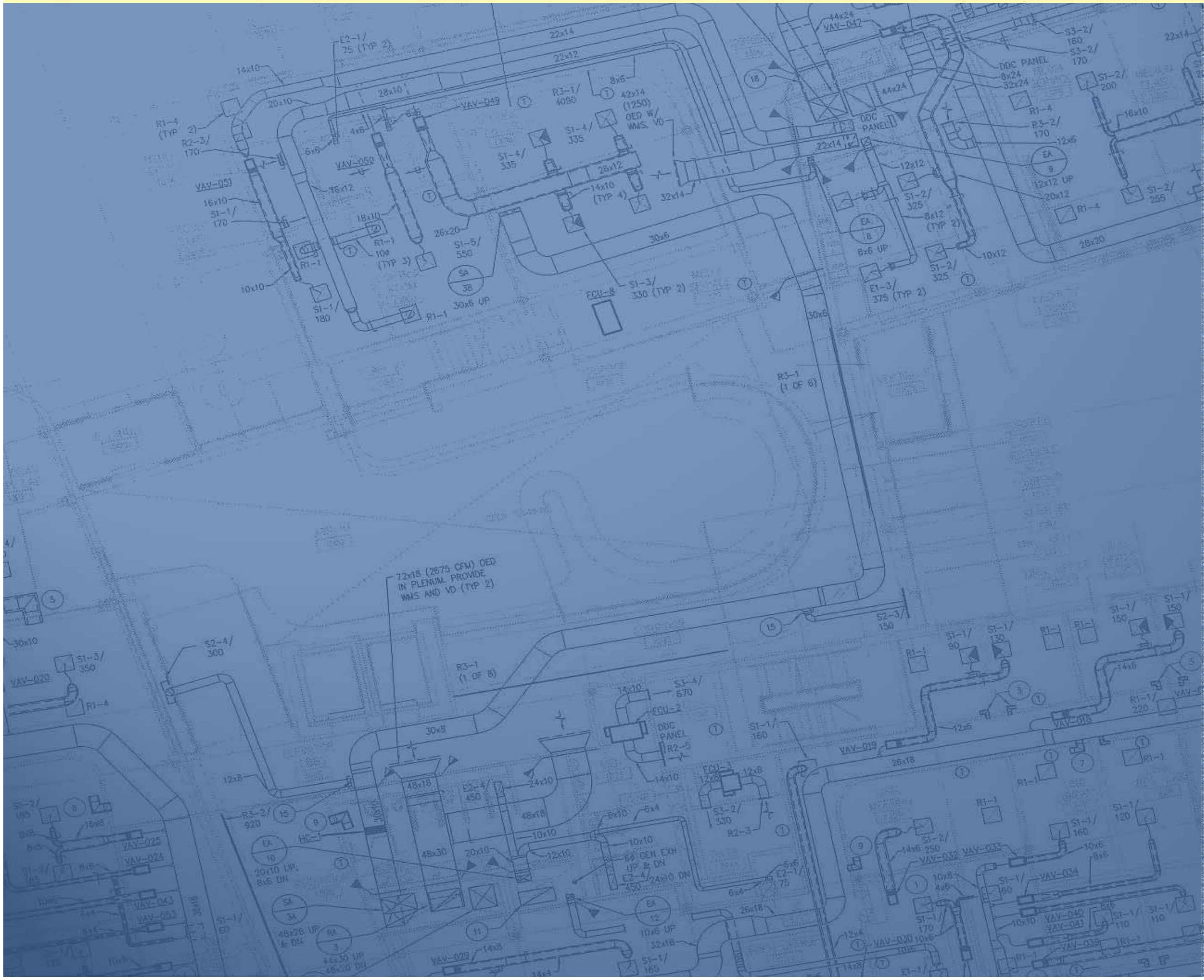


Thesis Investigations

- DOAS w/ Parallel Cooling
- **Green Roof Application**
  - **Design Goals**
  - **Intensive vs. Extensive**
  - **Selection and Layout**
  - **Design Implications**
- Energy Analysis
- Acoustics Analysis
- Structural Analysis
- LEED Analysis
- Cost Analysis

Green Roof Design Goals:

1. Reduce building cooling loads.
2. Improve acoustic insulation from outside noise.
3. Significantly reduce site stormwater runoff.
4. Create a more aesthetically pleasing roof.

There are two typical types of green roofs:

Intensive		Extensive
Larger grasses, shrubs, small trees.	**Plants**	Small seedum, grasses, mosses.
6"+	**Soil Depth**	2"-4"
Deep	**Root Structures**	Shallow
50 lbs/SF +	**Structural Loads**	Appx. 25 lbs/SF


(greenroofplants.com)


(greenroofplants.com)

An extensive green roof is selected for the SLCC.

The extensive green roof has the benefits of:

- Reduced building cooling loads.
- Acoustic insulation.
- Stormwater retention.
- Reduced Urban Heat Island Effect.
- Improved aesthetics.

…without as negative an impact on:

- Increased structural loads.
- Increased first cost.

Proposed scope of green roof application:

Plant Selection: *sedum kamtschaticum*

- Highly drought resistant.
- Mid-summer bloom of white flowers.
- Up to 6" tall.

(greenroofplants.com)

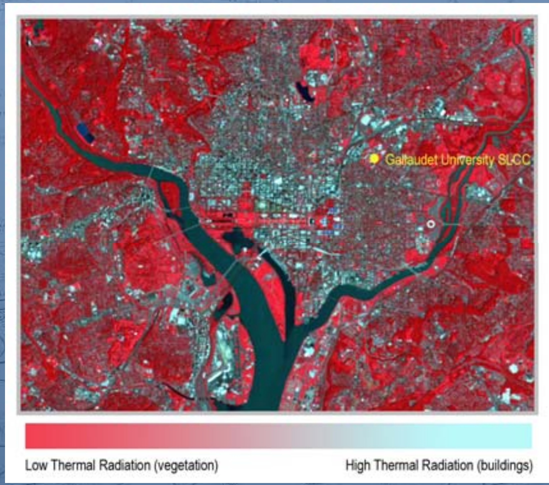
A Green Roof will improve stormwater management.

- Green Roofs withhold about 70% of rainfall.
- Non-green roofs shed about 95% of rainfall.
- Rain leaders may be downsized.
- Less pollution is swept into the Anacostia River and Chesapeake Bay.

(Anacostia Watershed Society)

A Green Roof will help reduce the urban heat island effect.

- Cities can experience up to 10F warmer temperatures than surrounding rural areas.
- Pavement, sidewalks, buildings absorb and radiate radiation.
- Plants, however, provide shade and use energy for evapotranspiration.
- The original high-albedo "cool roof" also achieves this goal.



(Baumann)

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Thesis Investigations

- DOAS w/ Parallel Cooling
- Green Roof Application
- **Energy Analysis**
  - **Original Design**
  - **DOAS System**
  - **Green Roof**
- Acoustics Analysis
- Structural Analysis
- LEED Analysis
- Cost Analysis

The total building energy required with the original VAV system is expected to be about $153,000.

Annual Energy Use and Cost by End Use

End Use	Energy Type	Electric [kWh]	Oil [MBH]	Energy Use [MBH]	Energy Cost
Lighting	Electricity	223695		763246	$20,222
Space Heating	Remote HW		89314	89314	$1,237
Space Cooling	Remote CW		3403435	3403435	$90,174
Fans	Electricity	83838		286057	$7,579
Pumps	Electricity	115144		392871	$10,409
Receptacles	Electricity	258639		882478	$23,381
TOTAL		681316	3492749	5817400	$153,002

(Carrier's HAP)

The total building energy required with the DOAS system is expected to be about $128,600.

This is a savings of about $25,000 over the VAV system.

Annual Energy Use and Cost by End Use

End Use	Energy Type	Electric [kWh]	Oil [MBH]	Energy Use [MBH]	Energy Cost
Lighting	Electricity	223053		761057	$20,164
Space Heating	Remote HW		35668	35668	$494
Space Cooling	Remote CW		2786186	2786186	$73,820
Fans	Electricity	101593		346635	$9,184
Pumps	Electricity	19580		66806	$1,770
Receptacles	Electricity	256925		876627	$23,226
TOTAL		601150	2821854	4872979	$128,658

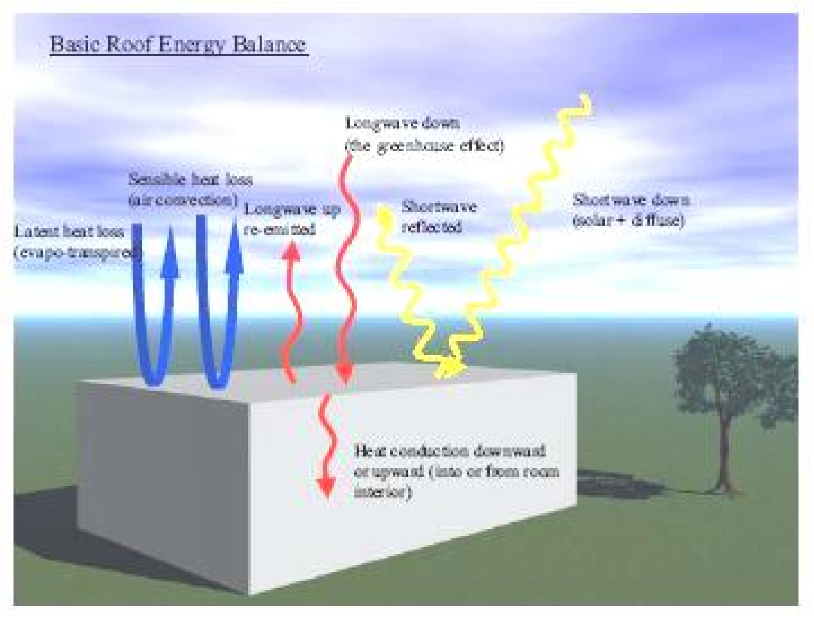
(Carrier's HAP)

Thesis Investigations

- DOAS w/ Parallel Cooling
- Green Roof Application
- **Energy Analysis**
  - Original Design
  - **DOAS System**
  - Green Roof
- Acoustics Analysis
- Structural Analysis
- LEED Analysis
- Cost Analysis

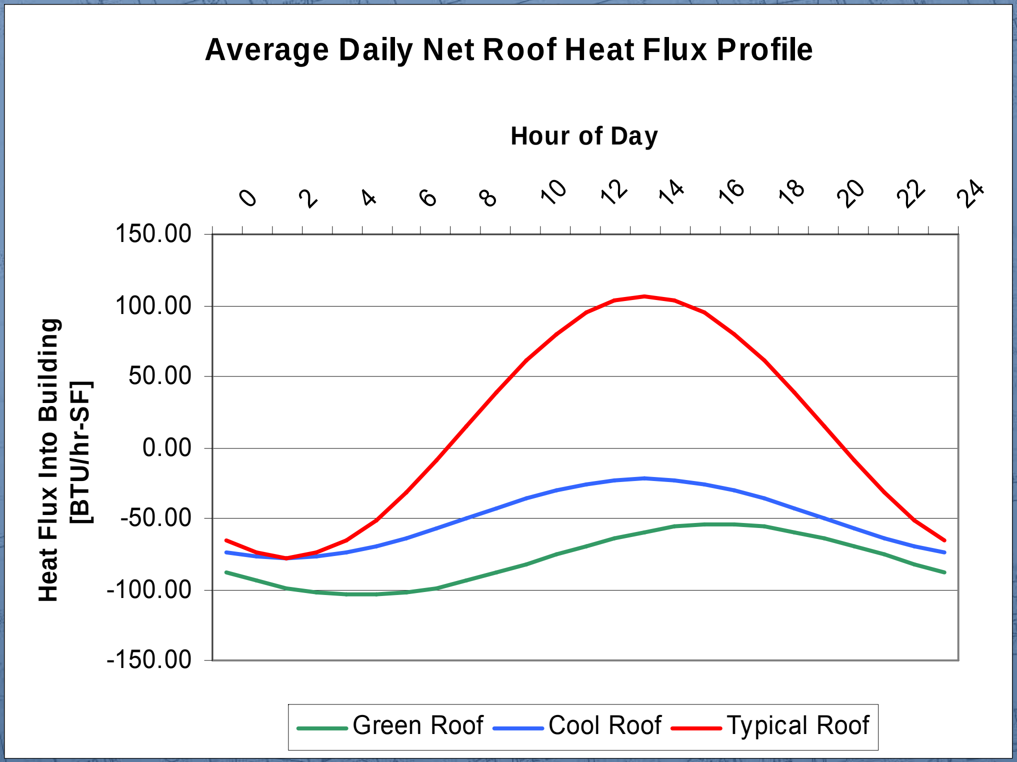
A Green Roof experiences several modes of heat transfer:

- Incident and Reflected Solar (Shortwave) Radiation
- Incident and Emitted Infrared (Longwave) Radiation
- Convection
- Conduction
- Evapotranspiration



(Gaffin, et al.)

An energy balance of the Green Roof for one month bins produces the following conductive heat gain:



The proposed Green Roof could reduce building cooling loads by an average of 20 BTU/hr-SF and save almost $7,000 annually.

- This is not a significant energy cost savings over the original "cool roof."
- The green roof could provide significant energy savings over a traditional roof.

Total Energy Savings for Green Roof Design

	Green Roof			Cool Roof	Typical Roof
	Cooling Load [BTU/hr-ft^2]	Savings [MBH/hr]	Savings [$]	Cooling Load [BTU/hr]	Cooling Load [BTU/hr]
Average 24hr	79.09	723	$0.02	49.83	
		4,236	$0.11		92.35
Annual	28,887	264,110	**$6,997.60**	18,199	
		1,547,283	**$40,995.27**		33,730

Green Roof Area: 24710ft^2

The SLCC has several acoustically sensitive spaces:

- **Audiology Labs (NC 25)**
- **Classrooms (NC 25)**
- **Hearing Aid Clinic (NC 20)**

Thesis Investigations

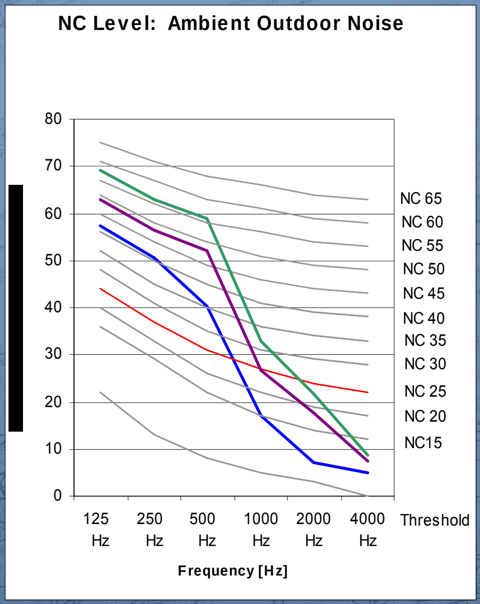
- DOAS w/ Parallel Cooling
- Green Roof Application
- Energy Analysis
- **Acoustics Analysis**
  - **Ambient Outdoor Noise**
  - **Green Roof Effect**
  - **Mechanical Noise**
  - **Design Comparison**
- Structural Analysis
- LEED Analysis
- Cost Analysis

Three cases of outdoor ambient noise are considered:

Case 1: Average ambient conditions (NC 47, Blue).

Case 2: A car driving by the site (NC 58, Purple).

Case 3: A large diesel truck driving by the site (NC 62, Green).



(Measured on site during morning rush hour)

The Green Roof mass dampens sound waves under 1000hz and soil/plants dampen sound waves over 2000hz.

$$TL_{1000} = 20 \log (M_{green\ roof} / M_{original\ roof})$$

$$TL_{2000} = freq * thickness * (0.5\ dB\ cm\text{-}1\ khz\text{-}1)$$

There is an additional 10dB TL through the Green Roof at each octave band.

Calculated Roof Transmission Losses

	Transmission Loss (TL) [dB]					
Frequency [Hz] →	125	250	500	1000	2000	4000
Original Roof	17	22	26	30	35	41
Green Roof	27	32	36	40	45	61

Mass of Original Roof [psf]:	10.0
Mass of Green Roof [psf]:	30.0
Green Roof Thickness [cm]:	10.0
Soil Attenuation Coefficient [dB cm^{-1} khz^{-1}]:	0.5

The proposed DOAS system is quieter than the original VAV system.

- Sound attenuators may be eliminated.
- Air flow and fan noise is reduced.

The Green Roof allows mechanical noise to dominate in all cases.

The quieter mechanical system allows spaces to meet design noise criteria.

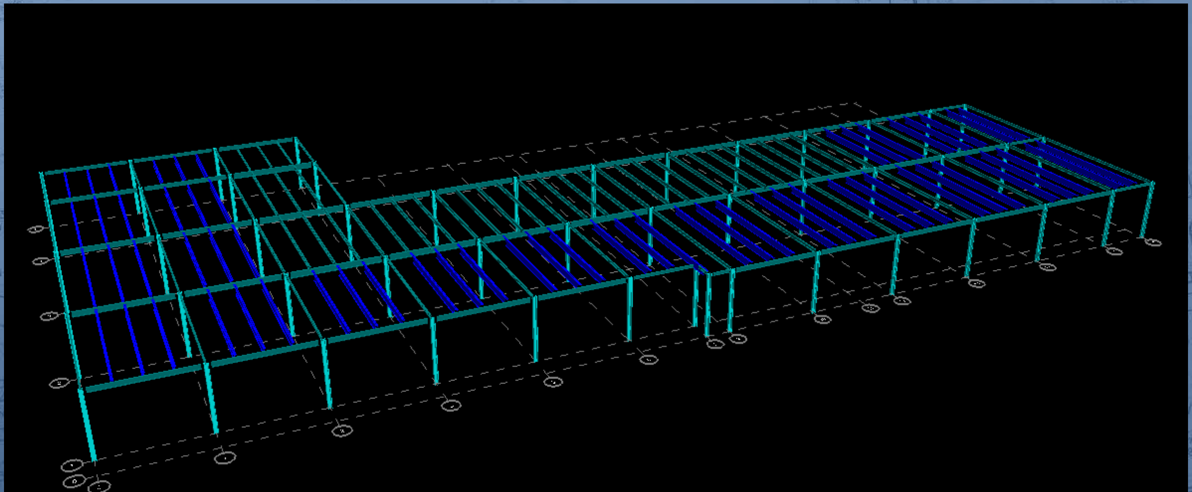
NC Levels for Various Scenarios and System Designs

Scenario			NC Level [dB] within SLCC			
			HSLS Audiology Lab (3122)	HSLS Fac. Lab (3122B-C, H-L)	Classroom (2302)	Hearing-Aid Fitting (2207)
Design Goal (per Project Narrative) →			<25	<25	25	20
Original Mechanical System	Original Roof	Case 1: Average Outdoor Noise	25	20	20	16
		Case 2: Car driving by site	32	32	33	20
		Case 3: Large truck driving by site	32	32	33	19
Original Mechanical System	Green Roof	Case 1: Average Outdoor Noise	25	17	20	
		Case 2: Car driving by site	25	20	21	
		Case 3: Large truck driving by site	25	21	23	
Proposed DOAS System	Original Roof	Case 1: Average Outdoor Noise	20	23	20	<15
		Case 2: Car driving by site	31	33	33	18
		Case 3: Large truck driving by site	30	31	32	<15
Proposed DOAS System	Green Roof	Case 1: Average Outdoor Noise	20	20	20	
		Case 2: Car driving by site	20	23	20	
		Case 3: Large truck driving by site	20	23	20	

(Red values indicate scenarios that do NOT meet design noise criteria)

The original structural design has the capacity to carry the additional green roof gravity load.

- Extensive roof gravity load only 25 psf.
- All roof joists, girders, and columns are capable of supporting this additional load.



(RAM Steel Model)

The SLCC is designed to LEED-NC v2.1 criteria.

(USGBC)

Thesis Investigations

- DOAS w/ Parallel Cooling
- Green Roof Application
- Energy Analysis
- Acoustics Analysis
- Structural Analysis
- **LEED Analysis**
  - **Original Design**
  - **Proposed Design**
- Cost Analysis

The original SLCC is expected to garner a LEED Certified Rating.

LEED™ Scorecard - Gallaudet University - SLCC

Y	?	N			Possible Points
28	4	37	**Total Project Score**		69

Certified 26 to 32 points **Silver** 33 to 38 points **Gold** 39 to 51 points **Platinum** 52 or more points

Y	?	N		Sustainable Sites	Possible Points 14
6	1	7			
Y			Prereq 1	**Erosion & Sedimentation Control**	
1			Credit 1	**Site Selection**	1
		1	Credit 2	**Urban Redevelopment**	1
		1	Credit 3	**Brownfield Redevelopment**	1
1			Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
		1	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
		1	Credit 4.3	**Alternative Transportation**, Alternative Fuel Refueling Stations	1
	1		Credit 4.4	**Alternative Transportation**, Parking Capacity	1
		1	Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
1			Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
		1	Credit 6.1	**Stormwater Management**, Rate and Quantity	1
1			Credit 6.2	**Stormwater Management**, Treatment	1
1			Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	1
1			Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	1
		1	Credit 8	**Light Pollution Reduction**	1

Y	?	N		Water Efficiency	Possible Points 5
4		1			
1			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
1			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
		1	Credit 2	**Innovative Wastewater Technologies**	1
1			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
1			Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Y	?	N		Energy & Atmosphere	Possible Points 17
3	2	12			
Y			Prereq 1	**Fundamental Building Systems Commissioning**	
Y			Prereq 2	**Minimum Energy Performance**	
Y			Prereq 3	**CFC Reduction in HVAC&R Equipment**	
1	1		Credit 1.1	**Optimize Energy Performance**, 20% New / 10% Existing	2
		2	Credit 1.2	**Optimize Energy Performance**, 30% New / 20% Existing	2
		2	Credit 1.3	**Optimize Energy Performance**, 40% New / 30% Existing	2
		2	Credit 1.4	**Optimize Energy Performance**, 50% New / 40% Existing	2
		2	Credit 1.5	**Optimize Energy Performance**, 60% New / 50% Existing	2
		1	Credit 2.1	**Renewable Energy**, 5%	1
		1	Credit 2.2	**Renewable Energy**, 10%	1
		1	Credit 2.3	**Renewable Energy**, 20%	1
1			Credit 3	**Additional Commissioning**	1
1			Credit 4	**Ozone Depletion**	1
		1	Credit 5	**Measurement & Verification**	1
	1		Credit 6	**Green Power**	1

Y	?	N		Materials & Resources	Possible Points 13
6		7			
Y			Prereq 1	**Storage & Collection of Recyclables**	
		1	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
		1	Credit 1.2	**Building Reuse**, Maintain 100% of Existing Shell	1
		1	Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
1			Credit 2.1	**Construction Waste Management**, Divert 50%	1
1			Credit 2.2	**Construction Waste Management**, Divert 75%	1
		1	Credit 3.1	**Resource Reuse**, Specify 5%	1
		1	Credit 3.2	**Resource Reuse**, Specify 10%	1
1			Credit 4.1	**Recycled Content**, Specify 25%	1
1			Credit 4.2	**Recycled Content**, Specify 50%	1
1			Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
1			Credit 5.2	**Local/Regional Materials**, of 20% Above, 50% Harvested Locally	1
		1	Credit 6	**Rapidly Renewable Materials**	1
		1	Credit 7	**Certified Wood**	1

Y	?	N		Indoor Environmental Quality	Possible Points 15
6	1	8			
Y			Prereq 1	**Minimum IAQ Performance**	
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	
		1	Credit 1	**Carbon Dioxide** (CO_2) **Monitoring**	1
		1	Credit 2	**Increase Ventilation Effectiveness**	1
1			Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
	1		Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
1			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
1			Credit 4.2	**Low-Emitting Materials**, Paints	1
1			Credit 4.3	**Low-Emitting Materials**, Carpet	1
1			Credit 4.4	**Low-Emitting Materials**, Composite Wood	1
1			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
		1	Credit 6.1	**Controllability of Systems**, Perimeter	1
		1	Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
		1	Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
		1	Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
		1	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
		1	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Y	?	N		Innovation & Design Process	Possible Points 5
3		2			
1			Credit 1.1	**Innovation**: Educational Case Study	1
		1	Credit 1.2	**Innovation**: Exceed Water Use Reduction by an additional 10%	1
1			Credit 1.3	**Innovation in Design**: Exceed Recycled content by an additional 25%	1
		1	Credit 1.4	**Innovation in Design**: Process Load Reduction	1
1			Credit 2	**LEED™ Accredited Professional**	1

James Lee Sorenson Language and Communication Center

Patrick B. Murphy
Mechanical Option
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The proposed SLCC design could gain a LEED SILVER Rating.

LEED™ Scorecard - Gallaudet University - SLCC Proposed Design

34	3	32	Total Project Score	Possible Points 69

Certified 26 to 32 points **Silver** 33 to 38 points **Gold** 39 to 51 points **Platinum** 52 or more points

Y	?	N	Sustainable Sites		Possible Points 14
7	1	6			
Y			Prereq 1	**Erosion & Sedimentation Control**	
1			Credit 1	**Site Selection**	1
		1	Credit 2	**Urban Redevelopment**	1
		1	Credit 3	**Brownfield Redevelopment**	1
1			Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
		1	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
		1	Credit 4.3	**Alternative Transportation**, Alternative Fuel Refueling Stations	1
	1		Credit 4.4	**Alternative Transportation**, Parking Capacity	1
		1	Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
1			Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
1			Credit 6.1	**Stormwater Management**, Rate and Quantity	1
1			Credit 6.2	**Stormwater Management**, Treatment	1
1			Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	1
1			Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	1
		1	Credit 8	**Light Pollution Reduction**	1

Y	?	N	Water Efficiency		Possible Points 5
4		1			
1			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
1			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
		1	Credit 2	**Innovative Wastewater Technologies**	1
1			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
1			Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Y	?	N	Energy & Atmosphere		Possible Points 17
8	1	8			
Y			Prereq 1	**Fundamental Building Systems Commissioning**	
Y			Prereq 2	**Minimum Energy Performance**	
Y			Prereq 3	**CFC Reduction in HVAC&R Equipment**	
2			Credit 1.1	**Optimize Energy Performance**, 20% New / 10% Existing	2
2			Credit 1.2	**Optimize Energy Performance**, 30% New / 20% Existing	2
2			Credit 1.3	**Optimize Energy Performance**, 40% New / 30% Existing	2
		2	Credit 1.4	**Optimize Energy Performance**, 50% New / 40% Existing	2
		2	Credit 1.5	**Optimize Energy Performance**, 60% New / 50% Existing	2
		1	Credit 2.1	**Renewable Energy**, 5%	1
		1	Credit 2.2	**Renewable Energy**, 10%	1
		1	Credit 2.3	**Renewable Energy**, 20%	1
1			Credit 3	**Additional Commissioning**	1
1			Credit 4	**Ozone Depletion**	1
		1	Credit 5	**Measurement & Verification**	1
	1		Credit 6	**Green Power**	1

Y	?	N	Materials & Resources		Possible Points 13
6		7			
Y			Prereq 1	**Storage & Collection of Recyclables**	
		1	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
		1	Credit 1.2	**Building Reuse**, Maintain 100% of Existing Shell	1
		1	Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
1			Credit 2.1	**Construction Waste Management**, Divert 50%	1
1			Credit 2.2	**Construction Waste Management**, Divert 75%	1
		1	Credit 3.1	**Resource Reuse**, Specify 5%	1
		1	Credit 3.2	**Resource Reuse**, Specify 10%	1
1			Credit 4.1	**Recycled Content**, Specify 25%	1
1			Credit 4.2	**Recycled Content**, Specify 50%	1
1			Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
1			Credit 5.2	**Local/Regional Materials**, of 20% Above, 50% Harvested Locally	1
		1	Credit 6	**Rapidly Renewable Materials**	1
		1	Credit 7	**Certified Wood**	1

Y	?	N	Indoor Environmental Quality		Possible Points 15
6	1	8			
Y			Prereq 1	**Minimum IAQ Performance**	
Y			Prereq 2	**Environmental Tobacco Smoke (ETS) Control**	
		1	Credit 1	**Carbon Dioxide (CO_2) Monitoring**	1
		1	Credit 2	**Increase Ventilation Effectiveness**	1
1			Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
	1		Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
1			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
1			Credit 4.2	**Low-Emitting Materials**, Paints	1
1			Credit 4.3	**Low-Emitting Materials**, Carpet	1
1			Credit 4.4	**Low-Emitting Materials**, Composite Wood	1
1			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
		1	Credit 6.1	**Controllability of Systems**, Perimeter	1
		1	Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
		1	Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
		1	Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
		1	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
		1	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Y	?	N	Innovation & Design Process		Possible Points 5
3		2			
1			Credit 1.1	**Innovation**: Educational Case Study	1
		1	Credit 1.2	**Innovation**: Exceed Water Use Reduction by an additional 10%	1
1			Credit 1.3	**Innovation in Design**: Exceed Recycled content by an additional 25%	1
		1	Credit 1.4	**Innovation in Design**: Process Load Reduction	1
1			Credit 2	**LEED™ Accredited Professional**	1

Thesis Investigations

- DOAS w/ Parallel Cooling
- Green Roof Application
- Energy Analysis
- Acoustics Analysis
- Structural Analysis
- **LEED Analysis**
  - Original Design
  - **Proposed Design**
- Cost Analysis

The proposed SLCC design has a $1.83M increased first cost.

100% Cost Estimate

CSI Division	Description	Actual Design Estimate	Proposed Design Estimate	Per SF*	$ %
1	General Requirements, OH&P	$3,089,683	$3,089,683	$35.23	12.9%
2	Site Work	$1,892,332	$1,907,497	$21.75	8.0%
3	Concrete Work	$1,450,126	$1,450,126	$16.53	6.1%
4	Masonry Work	$672,143	$672,143	$7.66	2.8%
5	Metals	$2,457,684	$2,457,684	$28.02	10.3%
6	Wood and Plastics	$297,970	$297,970	$3.40	1.2%
7	Thermal and Moisture Protection	$1,331,078	$1,621,177	$18.48	6.8%
8	Doors and Windows	$1,351,056	$1,351,056	$15.40	5.7%
9	Finishes	$2,407,854	$2,389,132	$27.24	10.0%
10	Specialties	$145,529	$145,529	$1.66	0.6%
11	Equipment	$69,701	$69,701	$0.79	0.3%
12	Furnishings	$33,018	$33,018	$0.38	0.1%
13	Special Construction	$0	$0	$0.00	0.0%
14	Conveying Systems	$274,720	$274,720	$3.13	1.1%
15	Mechanical Systems	$3,835,441	$4,576,300	$52.18	19.2%
16	Electrical Systems	$2,364,277	$2,364,277	$26.96	9.9%
SUB-TOTAL		$21,672,612	$22,700,013	$258.83	
5.25% Escalation to Const.:		$22,810,424	$23,891,764	$272.41	

*Area [SF] = 87,704

The proposed SLCC design has an expected annual savings of $31,000.

- Higher mechanical system replacement costs.
- No need to replace green roof.
- Roof maintenance for possible leaks replaces regular cleaning of high-albedo membrane.

Operation and Maintenance Costs

Description	Unit	Original Total	Proposed Total	Savings
Electricity	$/yr	$61,591.00	$54,344.00	$7,247.00
Chilled Water	$/yr	$90,174.00	$67,024.00	$23,150.00
Hot Water	$/yr	$1,237.00	$494.00	$743.00
Mech. System Maintenance	$/yr	$115,063.23	$114,407.51	$655.72
Mech. System Repairs/Replacement	$/5yr	$383,544.10	$457,630.02	-$74,085.92
Mech. System Repairs/Replacement	$/20yr	$2,876,580.75	$3,432,225.17	-$555,644.42
Roof Maintenance	$/yr	$9,935.05	$9,776.00	$159.05
Roof Replacement	$/20yr	$198,701.00	$0.00	$198,701.00

The proposed SLCC design has an expected 34 year simple payback period.

- An ideal payback period is less than 3 years.
- Since the owner is an institution they may be more willing to absorb the first cost.

Simple Payback Period

	First Cost	Change in First Cost	O&M Cost per year	Payback (yrs.)
Original Design	$22,810,424	$0	$278,000	0.00
Proposed Design	$23,891,764	$1,081,340	$246,046	33.84

Therefore the proposed DOAS system AND Green Roof should be applied to the current SLCC design.

- Energy savings of about $31,000/yr.
- All spaces meet acoustic criteria.
- Improved LEED Rating of Silver.
- These benefits and the institutional nature of the owner may outweigh the relatively long payback period.

I would like to thank these people for their help in completing this thesis:

Design Team: SmithGroup, Inc.

Greg Mella, Project Architect

Cindy Cogil, Lead Mechanical Engineer

Penn State Architectural Engineering Faculty

My family, especially my parents.

My friends and colleagues, especially Malory and Erin.

Questions?