7. MECHANICAL SYSTEM DESIGN

The second primary topic of this thesis is to investigate the application of a dedicated outdoor air system (DOAS) to the SLCC. The stated goals for this thesis of improved energy efficiency and acoustic performance are directly related to the design and performance of the mechanical system. A DOAS system is investigated for its ability to save energy and deliver less supply air to the occupied spaces, thus possibly dampening system noise. This section analyzes the energy performance of the DOAS system and compares it to the original VAV design.

7.1. PROPOSED SYSTEM DESIGN

The proposed DOAS design of the system is based on the idea of decoupling how the mechanical system addresses sensible and latent loads. Also, the DOAS system delivers an appropriate amount of outdoor air to each space for ventilation, but does not condition and as much more air as a standard VAV system does.

The outdoor air stream is conditioned to supply enough outdoor air to meet the greater of two requirements: compliance with ASHRAE Standard 62.1 for ventilation, or to compensate for the latent load in the space. The remaining sensible load of the space is cooled using a Halton CPT passive chilled beam parallel system (Halton)(Figure 7.1). The beams will be inserted into the ceiling grid and draw warm air from the plenum down across chilled water coils within the unit and into the space with natural buoyancy forces. Warm air is supplied to the plenum through return grilles. Figure 7.2 shows a potential layout of the beam system in a classroom space.

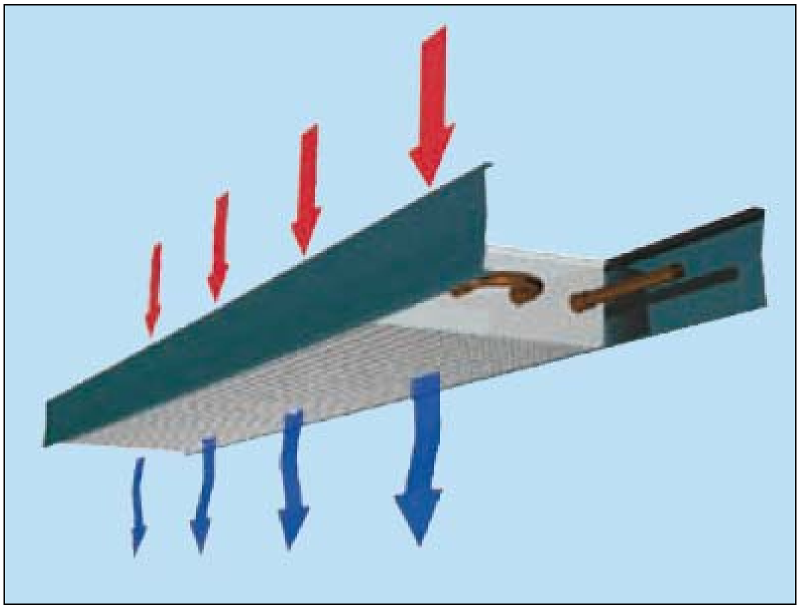

Figure 7.1: Passive chilled beam.

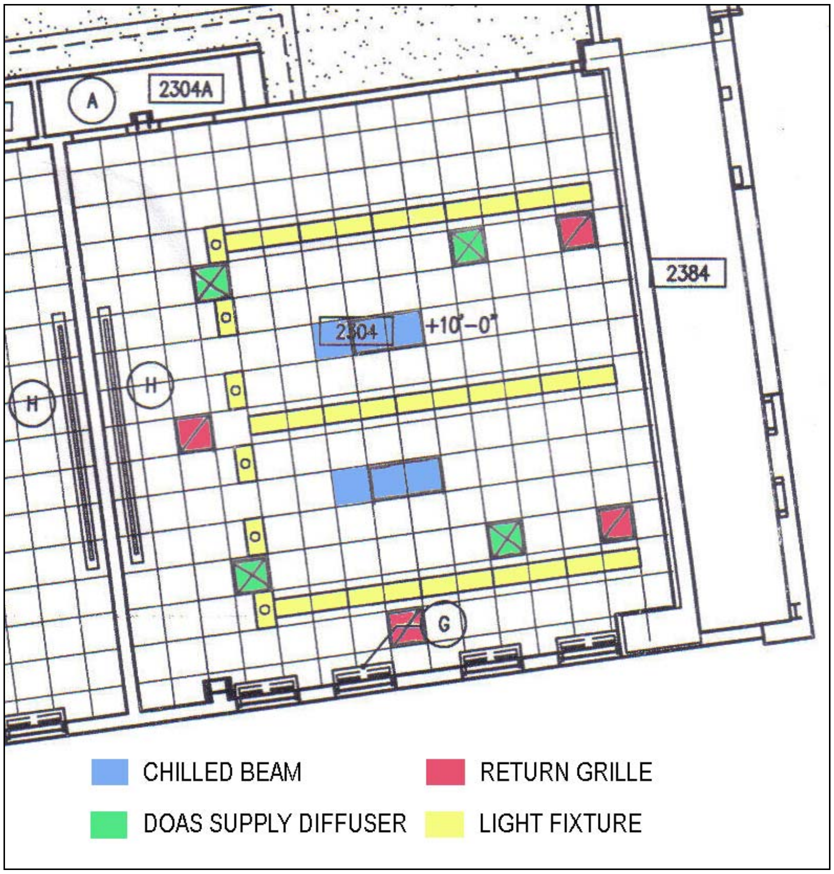

Figure 7.2: Proposed reflected ceiling plan for chilled beam system.

Radiant chilled water ceiling panels do not have the capacity to meet the cooling load within the ceiling area constraints of many spaces. According to the Aero Tech Radiant Panel Engineering Manual, radiant panels only cool about 21 BTU/hr-ft^2 for a 10°F ΔT. In a typical office about 28 2'x2' panels are required to properly cool the room, but only 20 2'x2' ceiling panels are available. Also, the metal panels would reflect sound differently than the acoustic ceiling tiles they replace.

Chilled water is used to exchange thermal energy in each space rather than air because of water's greater specific heat and density. As a result, air ducts may be significantly downsized as more chilled water is pumped throughout the building. The sizes of the pipes for this chilled water supply and return are much smaller than the air ducts. While fan energy decreases pumping energy increases.

The schematic in Figure 7.3 shows that 43°F chilled water from the Central Utilities Building is directed to the AHU cooling coils which experience a ΔT of 10°F. Because the chilled water temperature is below the dew point of the air in each space (57.9°F in summer, 52.4°F in winter), a secondary closed loop of chilled water supplies 60°F chilled water in the summer and 55°F chilled water in the winter to each parallel unit with a ΔT of 16°F. This prevents condensation on the unit and "raining" within the space. A plate heat exchanger transfers thermal energy between each loop. Three parallel CHWS pumps serve the system because of the large pressure drop and volume of flow. A standby pump is included to be turned on when another pump is out of order or receiving maintenance.

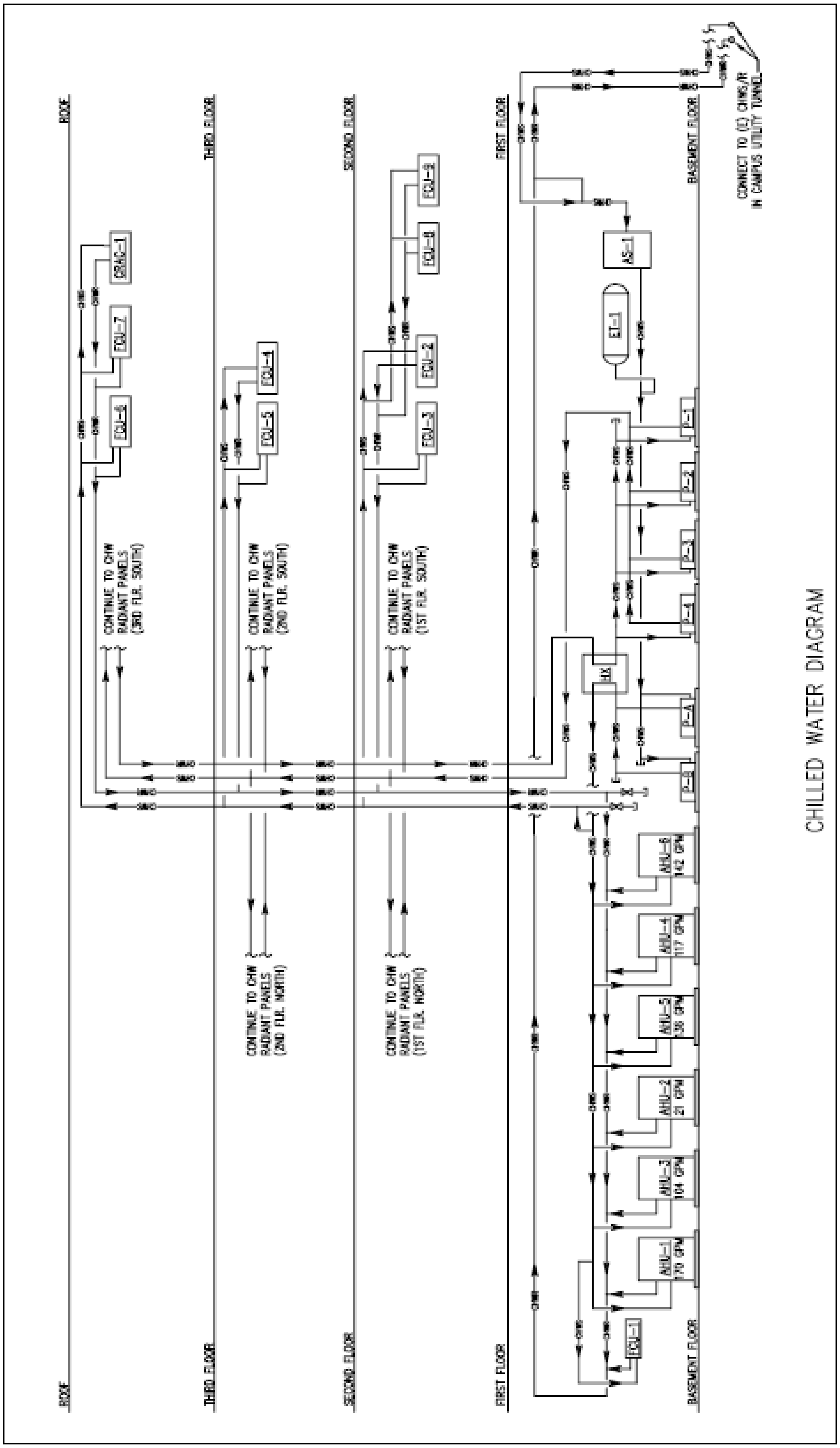

Figure 7.3: Proposed chilled water system schematic with two (2) CHW loops.

Perimeter spaces and those with roof loads would need some sort of parallel heating system. The proposed mechanical system uses baseboard heating because the radiant panels and air supply only cool the spaces. The baseboard heating warms the curtain of air against exterior walls where the heating load is located. Electricity is more expensive per unit of energy than the hot water supply from the Central Utilities Building so the baseboard heating would use hot water. The spark gap is approximately $0.295/MBH. Also, direct thermal energy extracted from a boiler is an approximately 80% efficient use of fossil fuels whereas electricity generation and transmission is an approximately 28% efficient use of fossil fuels (Pletchers).

The original zoning of the airside system generally remains intact because scheduled occupancies for each zone are slightly different from one another. The only exception to this is the merger of AHUs 4 and 6. All units except AHU 3 are dramatically downsized since they are only tasked with conditioning about 35% of the amount of air the original AHUs did. The supply air would continue to be supplied at 55°F. Instead of returning air to recycle it within the building, a DOAS system by definition generally exhausts as much air as it supplies. Rather than wasting the thermal energy in the exhaust air stream a Heat and Energy Recovery Ventilator (HRV/ERV) Enthalpy Exchanger would be used (Figure 7.4). This would exchange sensible and latent loads between the outdoor air intake and exhaust air streams for each AHU. In effect, this pre-heats and humidifies the outdoor air in the winter and pre-cools and dehumidifies it in the summer. Cross contamination of the air streams is not likely to be as much of a problem (Renewaire).

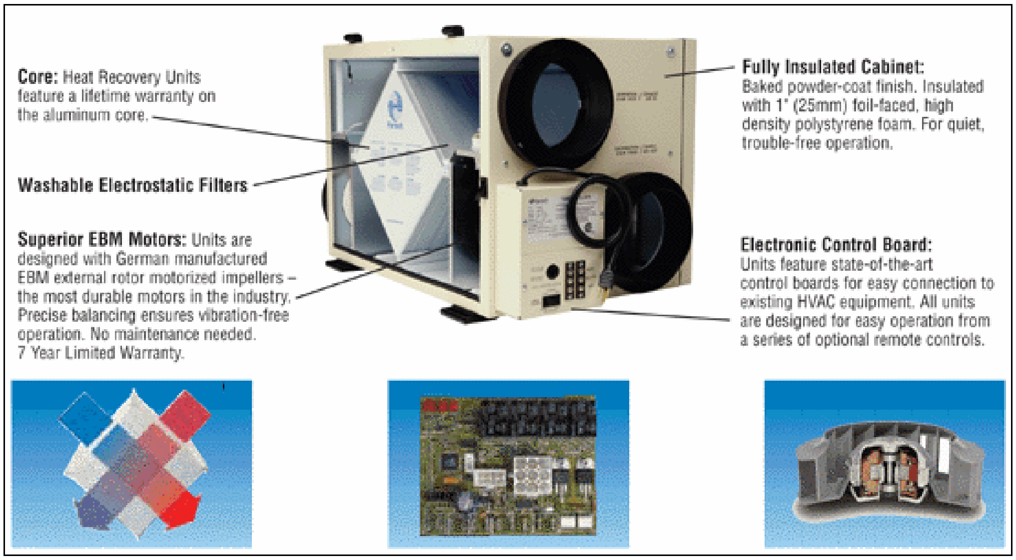

Figure 7.4: Typical Heat and Energy Recovery Ventilator (HRV/ERV) (Fantech).

Energy Recovery Ventilator Schedule

AHU	CFM	Unit*	Effectiveness		
			Sensible	Winter	Summer
1	2650	HE4XINH	74%	64%	50%
2	515	HE1XINH	76%	68%	54%
3	2890	HE4XINH	72%	62%	48%
4	3875	HE6XINH	73%	64%	50%
5	3725	HE6XINH	74%	65%	51%
6	4180	HE6XINH	70%	61%	47%

*Renewaire ERV Model

Figure 7.5: Schedule of selected ERVs

7.2. VENTILATION STRATEGY

The DOAS system only supplies enough conditioned outdoor air to each space to meet either the ASHRAE Standard 62.1 minimum ventilation requirement or the latent load in the space, whichever governs. Instead of meeting the minimum ventilation standards the calculations included an extra 30% outdoor air supply volume. This is to improve the indoor air quality and in keeping with LEED-NC v2.2 which offers a point for exceeding ventilation requirements by at least 30%. While this point can not be earned because the SLCC is designed to LEED-NC v2.1, the principle behind it is still assumed to be good practice for indoor air quality.

The proposed mechanical system delivers about 65% less air than the original VAV system at its peak (Table 7.1). As a result, AHUs, fans, and ducts are significantly downsized. There is actually a 13.5% reduction in the amount of outdoor air flow to the spaces even when the DOAS system supplies 30% extra outdoor air. This is due to the system efficiency (E_z) factor for critical spaces in Standard 62.1.

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]	Original Unit Capacity [CFM]
1	19	13185	2000	2650	4130	35.8%	2650	17400	84.8%	17700
2	3	1311	390	515	360	-43.1%	515	2230	76.9%	2500
3	0	7990	1240	2890	2890	0.0%	2890	13070	77.9%	13800
4	44	15285	2875	3875	4650	16.7%	3875	14080	72.5%	13300
5	37	15061	2405	3725	4550	18.1%	3725	11965	68.9%	11200
6	39	15146	2990	4180	4050	-3.2%	4180	14130	70.4%	13400
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%**	

Table 7.1: Comparison of outdoor and supply air flows for each system.

7.3. ENERGY ANALYSIS METHODOLOGY

The technical reports for this thesis conducted in the Fall 2006 Semester required building an energy model of the SLCC. This model was built in Carrier's Hourly Analysis Program (HAP). While HAP has code written to analyze variable-air volume systems there is no simple way to analyze a DOAS system. Instead, the program must be "tricked" to analyze the system properly. As a result, three versions of each space need to be created.

The first space created is used to model the space sensible load. All inputs remain the same as if the space were being analyzed as a VAV system except for the latent load of the occupants and the amount of outdoor air supply. These values are set to zero because the air supply carries these loads. Occupancy and load scheduling remain the same. The sensible cooling capacity of the supply outdoor air is included in "miscellaneous loads" by the equation ($Q_{sen} = -1.08 \text{ CFM } \Delta T$). The purpose is to model the cooling load on the parallel cooling system.

The second space to be modeled is the daytime latent and outdoor air load. A duplicate of the first space is made and outdoor air flows are reinstated for both occupancy and floor area. Also, all electrical equipment, lighting, walls, windows, and occupant sensible loads are set to zero. The latent load of the occupants is re-input into the program and occupancy is scheduled as normal. This space represents the cooling load of the outdoor air and latent load of the occupants during the occupied hours.

The final space created is the unoccupied outdoor air load. A duplicate of the previous space is made and the occupancy schedule is set to zero. Therefore the only load is the ventilation air per floor area.

The systems created address the unique aspects of each space. All “sensible load” spaces are conditioned with their own fan coil unit to recognize that these spaces are cooled using chilled water. The “daytime outdoor air and latent load” spaces are input into a special AHU whose schedule is to run only during occupied hours. The AHU is duplicated, the spaces are switched to “nighttime outdoor air load,” and the schedule of operation is set to the opposite of the previous AHU. The plants remain the same except for which systems they serve, and the building remains the same. The output is an approximation of the heating and cooling loads and lighting, electrical equipment, fan, and pump energy use.

7.4. CASE 1: EXISTING SYSTEM ENERGY ANALYSIS

An energy model of the SLCC was created in Fall 2006 for Technical Report 2. The results below show the annual energy use and cost (Table 7.2).

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

Table 7.2: Existing system annual energy cost and use.

7.5. CASE 2: DOAS SYSTEM ENERGY ANALYSIS

The HAP model created by the methodology described in Section 7.3 above produced the following outputs (Table 7.3):

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

Table 7.3: Annual energy cost and use for the DOAS system.

7.6. CASE 3: OVERALL IMPACT OF DOAS, GREEN ROOF LOADS

By combining the results of Sections 7.4 and 7.5 the annual energy uses and costs are as follows (Table 7.4):

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		2529430	2529430	$67,017
Fans	Electricity	101593		346635	$9,184
Pumps	Electricity	19580		66806	$1,770
Receptacles	Electricity	256925		876627	$23,226
TOTAL		601150	2565098	4616223	$121,855

Table 7.4: Annual energy cost and use for the DOAS system with a green roof.

7.7. ENERGY COST SAVINGS

A comparison of the results of Section 7.6 shows a total energy use and cost reduction of approximately 1.2MMBH and $31,147, respectively, with the proposed DOAS and green roof designs.