1050 K St
Washington, D.C.
Mechanical Systems Analysis

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Senior Thesis 2007
Mechanical Option
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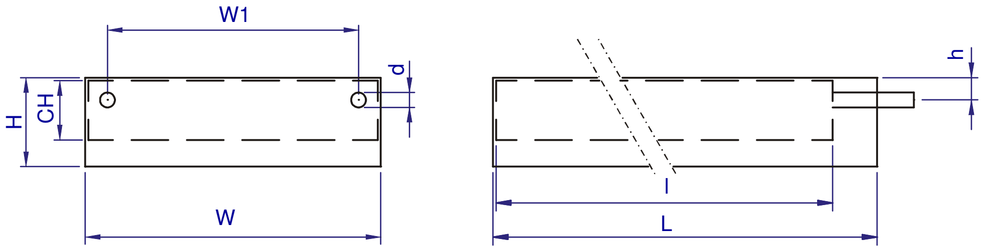
CPA
Passive Chilled Beam

- Modular convector for mounting flush or below ceiling plane
- Quiet operation
- No moving parts
- Long maintenance interval and low cost
- Individual/multiple beam control
- Suitable for offices, conference rooms, retail, hotels and healthcare environments
- Can be delivered with 2- or 3-port valve
- Standard height 130 mm with optional coil configuration output
- Customized perforation and multi-service solutions on request

DIMENSIONS



W	H	CH	h	d	W1	l	L
315	130	75	40	15	225	1000 4000	l + 200
465	130	75	40	15	375	1000 4000	l + 200
615	130	75	40	15	525	1000 4000	l + 200
315	130	100	30	15	225	1000 4000	l + 200
465	130	100	30	15	375	1000 4000	l + 200
615	130	100	30	15	525	1000 4000	l + 200

ACCESSORIES & PRODUCT OPTIONS

- Pipe connection in the end (WD=S)
- Pipe connection at the top (WD=U)
- Factory-fitted 2- or 3-port valve (Taylored)
- Flexible connection pipes

COOLING CAPACITY

Cooling capacities per unit length (P'W) [W/m] are presented for water flow rate qmw=0.08 kg/s.

Model	6 DT (°C)	7 DT (°C)	8 DT (°C)	8,5 DT (°C)	9 DT (°C)	9,5 DT (°C)	10 DT (°C)	11 DT (°C)
CPA-130/075-315	86	107	131	144	157	170	183	212
CPA-130/075-465	136	170	207	228	248	269	290	335
CPA-130/075-615	180	226	276	294	312	349	386	446
CPA-130/100-315	102	126	153	167	181	196	209	242
CPA-130/100-465	168	208	252	276	300	323	345	400
CPA-130/100-615	214	266	322	352	382	411	440	510

DT = ΔT = temperature difference Tr-(Tw1 + Tw2)/2, °C

Correction factor for water flow rate

qmv (kg/s)	kc
0.015	0.79
0.02	0.83
0.025	0.86
0.03	0.88
0.035	0.91
0.04	0.92
0.045	0.94
0.05	0.96
0.055	0.97
0.06	0.98
0.08	1.0

Cooling capacity is measured according to EN 14518.

Water loops - slings

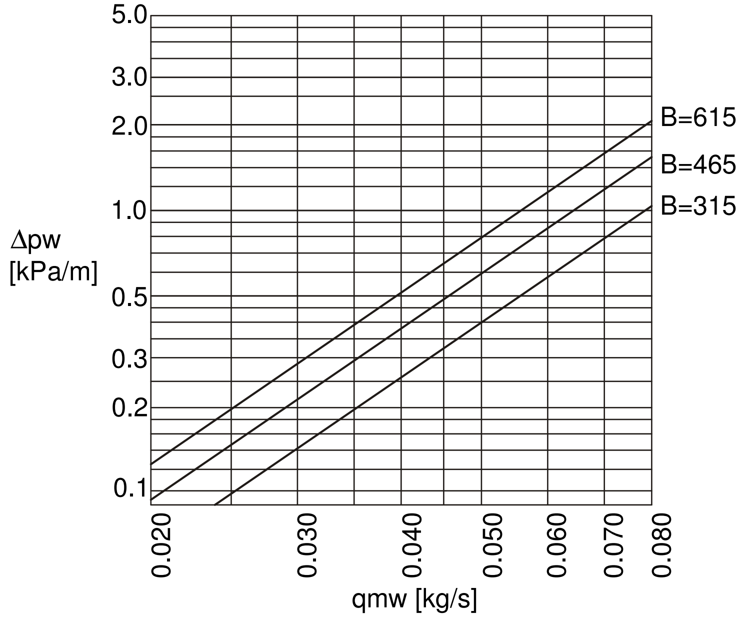
To avoid too high pressure drops **(>15 kPa)** it is recommended to use 2 parallel water loops in the coil. A coil with 2 loops has a connection pipe Ø 22 mm.

	L	Dt=7,5C°	Dt=8,0C°	Dt=8,5C°	Dt=9,0C°	Dt=9,5C°
CPA-130/075-315-L	1200	1	1	1	1	1
	1500	1	1	1	1	1
	1800	1	1	1	1	1
	2100	1	1	1	1	1
	2400	1	1	1	1	1
	2700	1	1	1	1	1
	3000	1	1	1	1	1
	3300	1	1	1	1	1
	3600	1	1	1	1	1
	3900	1	1	1	1	1
	4200	1	1	1	1	1
CPA-130/075-465-L	1200	1	1	1	1	1
	1500	1	1	1	1	1
	1800	1	1	1	1	1
	2100	1	1	1	1	1
	2400	1	1	1	1	1
	2700	1	1	1	1	1
	3000	1	1	1	1	1
	3300	1	1	1	1	1
	3600	1	1	1	1	1
	3900	1	1	1	1	1
	4200	1	1	1	1	1
CPA-130/075-615-L	1200	1	1	1	1	1
	1500	1	1	1	1	1
	1800	1	1	1	1	1
	2100	1	1	1	1	1
	2400	1	1	1	1	1
	2700	1	1	1	1	1
	3000	1	1	1	1	1
	3300	1	1	1	1	1
	3600	1	1	1	1	1
	3900	1	1	1	1	2
	4200	1	1	1	2	2

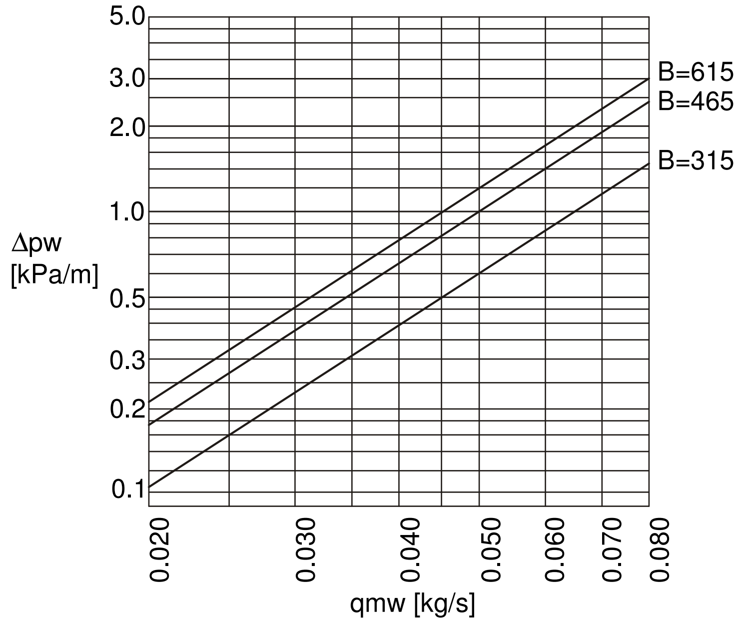
	L	Dt=7,5C°	Dt=8,0C°	Dt=8,5C°	Dt=9,0C°	Dt=9,5C°
CPA-130/100-315-L	1200	1	1	1	1	1
	1500	1	1	1	1	1
	1800	1	1	1	1	1
	2100	1	1	1	1	1
	2400	1	1	1	1	1
	2700	1	1	1	1	1
	3000	1	1	1	1	1
	3300	1	1	1	1	1
	3600	1	1	1	1	1
	3900	1	1	1	1	1
	4200	1	1	1	1	1
CPA-130/100-465-L	1200	1	1	1	1	1
	1500	1	1	1	1	1
	1800	1	1	1	1	1
	2100	1	1	1	1	1
	2400	1	1	1	1	1
	2700	1	1	1	1	1
	3000	1	1	1	1	1
	3300	1	1	1	1	1
	3600	1	1	1	1	1
	3900	1	1	1	2	2
	4200	1	1	1	2	2
CPA-130/100-615-L	1200	1	1	1	1	1
	1500	1	1	1	1	1
	1800	1	1	1	1	1
	2100	1	1	1	1	1
	2400	1	1	1	1	1
	2700	1	1	1	1	1
	3000	1	1	1	1	1
	3300	1	1	1	2	2
	3600	1	2	2	2	2
	3900	2	2	2	2	2
	4200	2	2	2	2	2

Pressure drop of water flow

CPA-130/75



CPA-130/100



Δt	temperature difference water (Tw1+Tw2) /2, °C
Tr	room temperature, °C
Tw1	water flow temperature, °C

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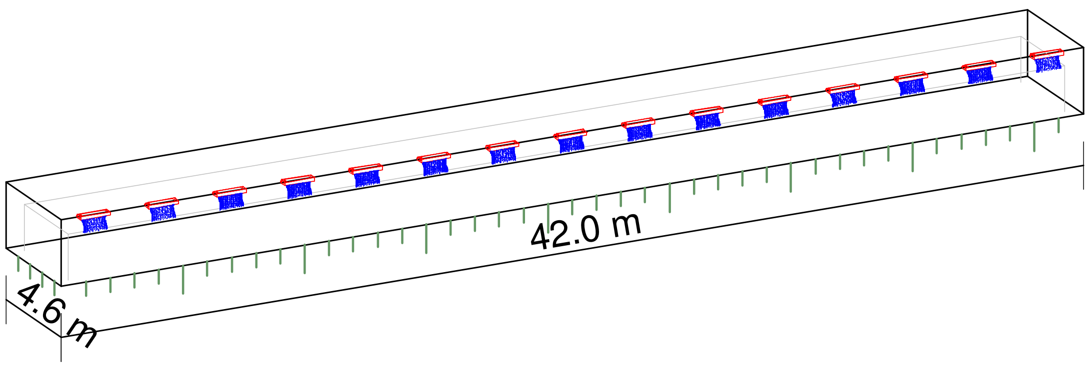
Tw2	return water temperature, °C
P'w	cooling capacity per unit length, W/m
L	unit length, m
cv	specific heat capacity water = 4200 J/kgxK
qmw	water mass flow rate, kg/s
kc	correction factor for water flow rate
Δpw	pressure drop of water flow per unit length, kPa

$$qmv = \frac{P'w \times L}{cv \times \Delta t} = kg/s$$

Cooling	CPA-75-1200-315-1		2006.10
Room:		Supply air flow rate:	400 l/s
Room size:	42.0 x 4.6 x 2.6 m		2.1 l/(sm^2)
Occupied zone:	h=1.8 m / dw=0.5 m	Supply air temperature:	18.0 °C
Room air:	22.0 °C / 50 %	Jet outlet temperature:	20.2 °C
Heat gain:	0 W	Primary air capacity:	1914 W
Perforated ceiling:	-	Total pressure drop:	-
Installation height:	2.44 m	Total cooling capacity:	3238 W
Inlet water temperature:	14.0 °C		17 W/m^2
Outlet water temperature:	15.4 °C	Dew point temperature:	11.1 °C
Water flow rate:	0.226 kg/s (15 x 0.015 kg/s)	Velocity control:	-
Coil capacity:	1324 W (15 x 88 W)		
	88 W/m		
Water pressure drop:	0.0 kPa		

vmax in occupied zone:				
v				
ΔT				
				vlim = 0.20 m/s



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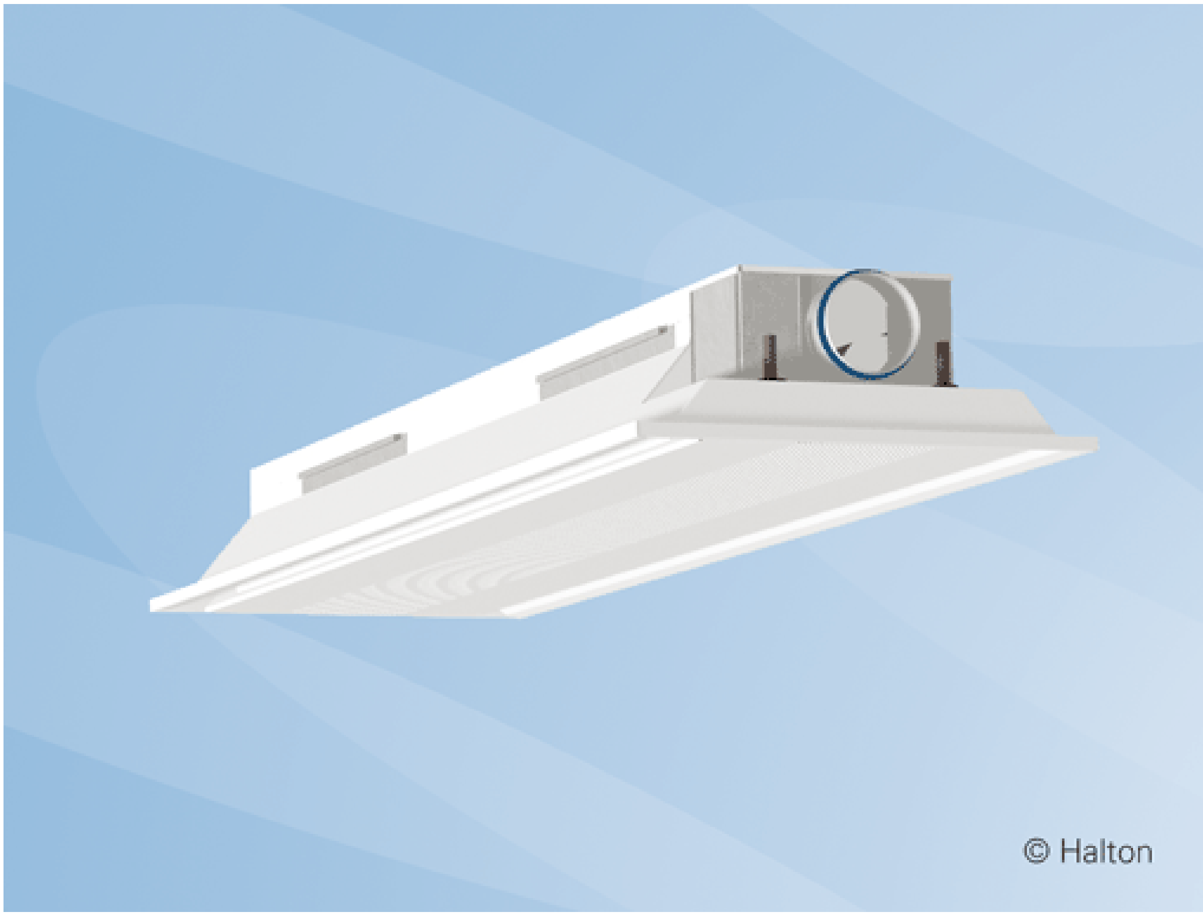
Halton
CARE FOR INDOOR AIR

CBC
Active Chilled Beam

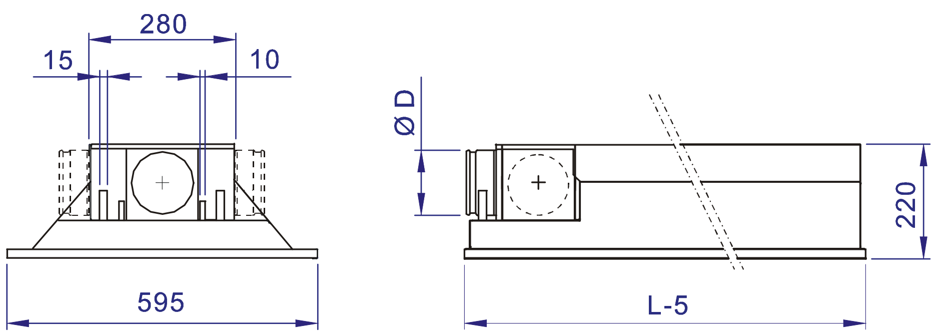


- Combined cooling, heating and supply air unit for flush installation within suspended ceiling
- Comprises an integral recirculation air path
- Well suited for spaces with high cooling loads, low humidity load and low ventilation requirements
- Ideal for a wide range of buildings, where high quality environmental conditions and individual room control are required
- Typical applications: office rooms, landscape offices, meeting rooms, hotel guest rooms and patient care rooms etc.
- Individually adjustable velocity conditions with Halton velocity control
- In-built flexibility in layout changes with Halton velocity control
- Enhanced life-cycle performance with low air and water flow rates

Product Models & Accessories

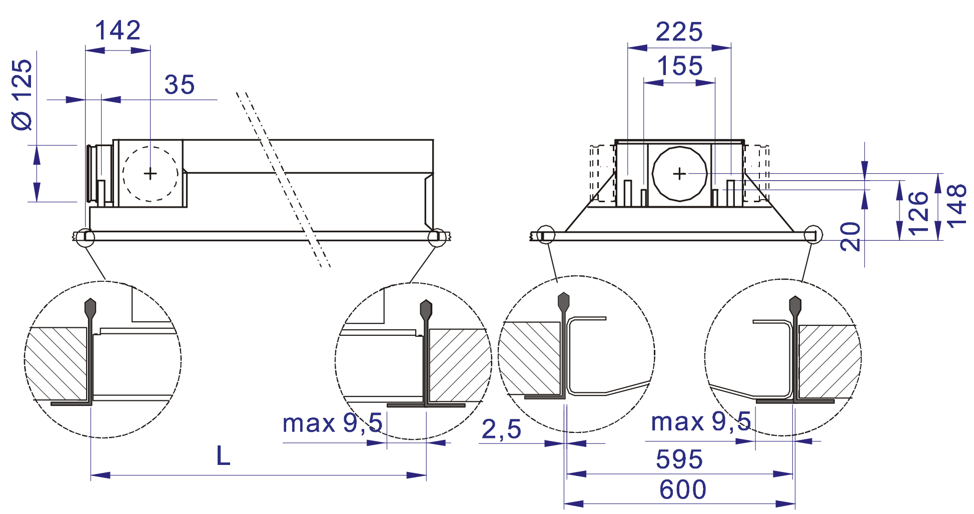
- Model with combined cooling and heating coil

DIMENSIONS AND WEIGHT



ØD	125
Coil length	900, +100, ..., 3300
L-5	1195, +100, ..., 3595
kg/m	14

Location of the pipe connections and integration to suspended ceiling



PRODUCT OPTIONS AND ACCESSORIES

ACCESSORY/MODEL	CODE	DESCRIPTION	NOTE
Combined cooling and heating coil	TC = H	Coil with hot water circulation	Cooling/heating copper water pipe connestions are Ø 15/10 mm
Airflow adjustment damper	FD = Y	Removable through access panel	

ADJUSTMENT

Cooling

The recommended cooling water mass flow rate is 0.02 - 0.10 kg/s resulting in a temperature rise of 1 - 4℃ in the heat exchanger. To avoid condensation the recommended inlet water temperature of the heat exchanger is 14 - 16℃.

Heating

The recommended heating water mass flow rate is 0.01 - 0.04 kg/s resulting in a temperature drop of 5 - 15℃ in the heat exchanger.
It is recommended that the temperature difference between the jet outlet and room air is max. 3℃. The temperature of the inlet water to the heat exchanger is 35℃.

Balancing and control of water flow rates

Balance the water flow rates of the chilled beam with adjustment valves installed on the outlet side of the cooling and heating water loops. Cooling capacity and heating capacity of the chilled beam are controlled by regulating water mass flow rate. The water mass flow rate can be controlled either using an ON/OFF valve or a 2- or 3-way valve with proportional operation.

Adjustment of supply airflow rate

Each chilled beam can be equipped with an airflow adjustment damper, which enables fast and accurate adjustment of the supply airflow rate. Connect a manometer in the measurement tap and measure the static pressure in the chilled beam. The airflow rate is calculated with the formula below.

$$q_v = k * l_{eff} * \sqrt{\Delta p_m}$$

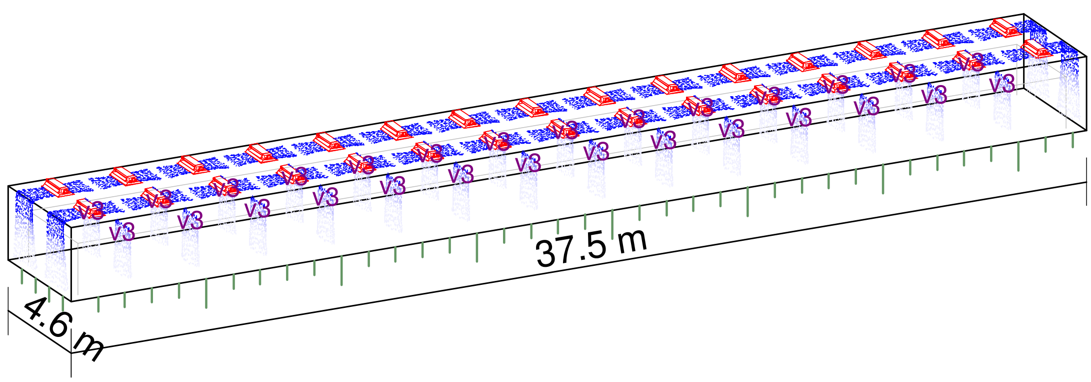
MODEL	k
A	0.63
B	0.99
C	1.37
D	1.90
E, J	0.50
F, K	0.68
G, M	0.95

Cooling	CBC/A-125-1200-900		2005.10
Room:		Supply air flow rate:	154 l/s (30 x 5 l/s)
Room size:	37.5 x 4.6 x 2.6 m		5.7 l/(sm), 0.9 l/(sm2)
Occupied zone:	h=1.8 m / dw=0.5 m	Supply air temperature:	18.0 ℃
Room air:	22.0 ℃ / 50 %	Primary air capacity:	741 W (30 x 25 W)
Heat gain:	0 W	Total pressure drop:	82 Pa
Installation height:	2.60 m	Total cooling capacity:	6673 W (30 x 222 W)
Inlet water temperature:	14.0 ℃		247 W/m, 39 W/m2
Outlet water temperature:	15.5 ℃	Dew point temperature:	11.1 ℃
Water flow rate:	0.945 kg/s (30 x 0.031 kg/s)	Velocity control:	side=3, middle=3
Coil capacity:	5932 W (30 x 198 W)	L_d:	-
	220 W/m		
Water pressure drop:	0.5 kPa		

vmax in occupied zone:	v3			
v	~0.20 m/s			
v(dt=0)	~0.15 m/s			
▲T	-0.8 ℃			

Heat sources and their location may influence the velocity and direction of the jet

vlim = 0.20 m/s



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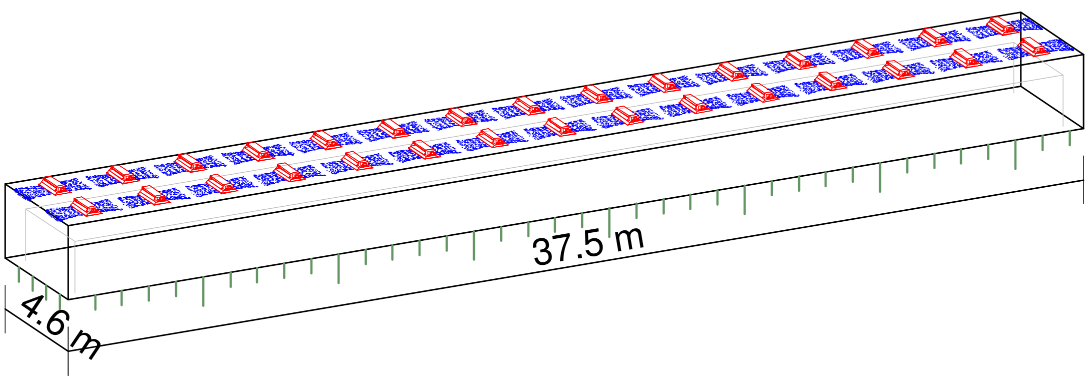
Heating	CBC/A-125-1200-900		2005.10
Room:		Supply air flow rate:	154 l/s (30 x 5 l/s)
Room size:	37.5 x 4.6 x 2.6 m		5.7 l/(sm), 0.9 l/(sm2)
Occupied zone:	h=1.8 m / dw=0.5 m	Supply air temperature:	25.0 ℃
Room air:	20.0 ℃ / 50 %	Primary air capacity:	932 W (30 x 31 W)
Heat loss:	0 W	Total pressure drop:	82 Pa
Installation height:	2.60 m	Total heating capacity:	7691 W (30 x 256 W)
Inlet water temperature:	40.0 ℃		285 W/m, 45 W/m2
Outlet water temperature:	35.0 ℃	Dew point temperature:	9.3 ℃
Water flow rate:	0.323 kg/s (30 x 0.011 kg/s)	Velocity control:	side=3, middle=3
Coil capacity:	6759 W (30 x 225 W)		
	250 W/m		
Water pressure drop:	0.2 kPa		

vmax in occupied zone:				
v				
▲T				
				vlim = 0.20 m/s



CBC - Active Chilled Beam

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EXECUTIVE SUMMARY

1050 K Street is an office building located in downtown Washington, D.C. The mechanical system currently provides energy efficient cooling and heating to the occupants through one central outdoor air unit and variable air volume units located on each floor. The outdoor air unit utilizes an energy recovery wheel to preheat and cool the incoming air. Cooling coils are provided in both the ERU and each AHU to provide further cooling. All of the coils are fed by three 115 ton rotary screw chillers and when whether permits, a water side economizer heat exchanger between the cooling towers and the chilled water loop. All space heating is provided by the energy recovery unit and electric reheat at the perimeter terminal units.

The DOE-2 software eQuest was used to perform energy simulations to determine the efficiency of the system. The VAV system described above was compared to a chilled beam system which will also use the energy recovery unit for its outdoor air. The most critical differences between the systems is that the VAV system requires an air handling unit on each floor to mix the return air and outdoor air while the chilled beams provide mixing directly in the space. The chilled beam system also provides the cooling coil in the space while the VAV system has one in each of the AHUs. Although the chilled beam system can provide the cooling more efficiently than the VAV system, the high initial costs make it less feasible to implement. In this case there is a 61 year payback period between the energy savings and the initial costs of the VAVs and AHUs and the chilled beams. Given such a long payback period it is not economical to implement the chilled beam system over the VAV system currently installed.

1. BUILDING SUMMARY

1.1. Site & Architectural Summary

1050 K Street will be a new 150,000 square foot 11 story office building in downtown Washington, D.C. Although the building provides primarily office space, retail space will also be provided on the first above grade level. Below grade 1050 K Street offers 4 levels for parking & bicycle storage as well as a mezzanine level boasting a fitness center, locker rooms, and storage areas. On the exterior of the building, the alley facing facades of the building are 8 inch pre-cast concrete panels. The exterior of the building is clad in a low emissivity glass curtain wall on the north and west exposures. Topping off the building are two types of green roof systems. Both the semi-intensive and extensive systems utilize a storm water and HVAC condensate collection system for landscape irrigation. Limiting the potable water used for irrigation is one of the methods the design team employed to achieve a USGBC LEED CS Gold Rating.

1.2. Mechanical Systems Summary

As seen in the upcoming sections, the LEED principles are at the forefront of the 1050 K Street design.

1.2.1. Design Conditions Summary

1.2.1.1. Outdoor Conditions

The mechanical system is designed for 0.4% and 99.6% design conditions in 2001 ASHRAE Handbook of Fundamentals. Each condition is used to perform load calculations or equipment selection. A summary of these design points as well as their purpose is provided in Table 3-1.

Outdoor Design Conditions					
Outdoor Condition	**Dry Bulb (F)**	**Wet Bulb (F)**	**Dew Point (F)**	**Humidity Ratio (gr/lb)**	**Calculations/ Equipment**
Summer	95	76	-	-	Peak Cooling
Summer Dehumidification	83	-	76	136	ERU
Summer Evaporation	89	76	-	-	Cooling Towers
Winter	15	-	-	-	Peak Heating

Table 1-1 - Summary of outdoor design conditions and data uses.

1.2.1.2. Indoor Conditions

The typical design conditions provided in **Error! Reference source not found.** were used in load and energy calculations to ensure the comfort of the building occupants. If these conditions are met, the space will be a thermally comfortable and productive environment.

Indoor Design Conditions		
Requirement		**Design**
Dry Bulb	Summer	75 F
	Winter	70 F
Rel Humidity	Summer	50 %
Population Density	Office	1 person/142 SF
	Conference	1 person/20 SF
Lighting Level	All Areas	Per ASHRAE 90.1 - 2004
Equipment	All Areas	2 W/SF
Ventilation	All Areas	20 CFM/Person

Table 1-2 - Summary of indoor design conditions

1.2.2. Cooling System Summary

Cooling is provided to room supply air in many stages. First, the warm incoming air passes through the enthalpy wheel and releases some of its heat to the exhaust stream. In addition to the enthalpy wheel, a cooling coils also provides cooling within the energy recovery unit. The third step in cooling the supply air is in the floor by floor air handling units, all of which are equipped with a cooling coil. Each coil is supplied with 42 F chilled water from the three

115 ton rotary screw chillers located in the penthouse. The chiller heat rejection is provided by a 2 cell induced draft open cell cooling tower on a 85 F to 95 F condenser water loop. When conditions permit, the cooling tower provides free cooling to the chilled water loop through the plate and frame heat exchanger.

1.2.3. Heating System Summary

Like the cooling system, the heating system is applied in multiple steps. The enthalpy wheel in the energy recovery unit extracts heat from the exhaust air and uses it to preheat the entering air stream. Where further heating is necessary, typically in the perimeter zones, the variable air volume boxes are equipped with an electric reheat. Since all of the heating is provided through the enthalpy wheel and electric reheat, there is no need for a central heating plant.

1.2.4. Air Systems Summary

Outdoor air is supplied to the building through only the penthouse energy recovery unit. The air is conditioned by the enthalpy wheel and cooling coil and is then passed down to an air handling unit in a mechanical room on each floor. In that room, the outdoor air is introduced to and mixed with return air. Then, through variable volume boxes, the air is passed into the space. The variable volume exhaust boxes control the amount of return air that is mixed with the outdoor air and the amount that is passed through the enthalpy wheel and exhausted.

1.3. Controls Summary

1050 K Street is controlled through an all electric direct digital control building automation system with electronic sensors and actuators. As a result the set points and system optimization can be controlled remotely and metering may be done. All measurements may be reported to comply with the LEED standard.

1.4. Electrical Systems Summary

Power is supplied to the building through a high voltage circuit by PEPCO. The power will be stepped down to 480Y/277 for distribution on site. Each floor will have an electrical room housing a secondary transform that will step the power down to 208Y/120 to accommodate building loads. The building will also be served by a 750 KW diesel generator which will power essential loads and equipment such as lighting and stair pressurization fans.

2. EXISTING DESIGN ASSESSMENT

2.1. ASHRAE Standard 62.1 Analysis Summary

ASHRAE standard 62 provides a guideline to provide the necessary amount of ventilation into a space. An analysis of the 1050 K Street has been performed to determine accordance with ASHRAE standard 62.1 – 2004. Since all of the building ventilation air passes through the energy recovery unit, this system was the focus of the analysis. The calculations were broken down by each secondary air handling unit to confirm that each floor is receiving the minimum ventilation air. The results of the analysis show that all units are supplied with enough ventilation air to meet the standard. Table 2-1 summarizes the calculations performed to determine compliance.

Outdoor Air Standard 62 Calculation

Project Name	1050 K Street
System Tag	ERU
Location	PH
Service	OA for all AHUs
Design Total CFM	30000 CFM
Design OA CFM	30000 CFM
System V_{OT}	19841
% OA	100%

A_z	Floor Area (SF)	V_{dz}	Supply airflow (incl. local recirculation)
P_z	Maximum # of Occupants	V_{dzm}	Minimum airflow
R_a	OA per ft^2 (CFM/SF)	Z_p	OA Fraction
R_p	OA per person (CFM/person)	E_v	Ventilation Efficiency
A_z*R_a	Uncorrected CFM/SF	E_z	Zone air dist effectiveness
P_z*R_p	Uncorrected CFM/Person	E_z	Zone air dist effectiveness
V_{oz}	Corrected OA = A_z*R_a + P_z*R_p/E_z	X_s	Average outdoor air fraction = $V_{oz}/\Sigma V_{pz}$
Vpz	Primary airflow (w/o local recirculation)	Z_d	Discharge outdoor air fraction = V_{oz}/V_{dz}

Tag/ Location	Zone Description	Zone Type	A_z	P_z	R_a	R_p	A_z*R_a	P_z*R_p	E_z	V_{oz}	V_{pz}	V_{dz}	Z_p
AHU-1/ Level 1	Locker Room	Corridors	550	0	0.06	0	33	0	1	33	135	400	0.244
	Lobby	Corridors	1635	0	0.06	0	98	0	1	98	456	1350	0.215
	Corridors	Corridors	1130	0	0.06	0	68	0	1	68	236	700	0.287
	Fitness Center	Health club/weight rooms	1515	16	0.06	20	91	320	1	411	810	2400	0.507
	Filing Rooms	Office space	1350	7	0.06	5	81	35	1	116	135	400	0.859
AHU-2/ Level 2	Office	Office space	7451	38	0.06	5	447	190	1	637	2336	10815	0.273
	Conference	Conference / meeting	754	16	0.06	5	45	80	1	125	237	1095	0.530
AHU-3/ Level 3	Office	Office space	9826	50	0.06	5	590	250	1	840	2402	11120	0.350
	Conference	Conference / meeting	812	17	0.06	5	49	85	1	134	199	920	0.673
AHU-4/ Level 4	Office	Office space	9826	50	0.06	5	590	250	1	840	2402	11120	0.350
	Conference	Conference / meeting	812	17	0.06	5	49	85	1	134	199	920	0.673
AHU-5/ Level 5	Office	Office space	9826	50	0.06	5	590	250	1	840	2402	11120	0.350
	Conference	Conference / meeting	812	17	0.06	5	49	85	1	134	199	920	0.673
AHU-6/ Level 6	Office	Office space	10782	54	0.06	5	647	270	1	917	2426	11230	0.378
	Conference	Conference / meeting	812	17	0.06	5	49	85	1	134	183	845	0.733
AHU-7/ Level 7	Office	Office space	10782	54	0.06	5	647	270	1	917	2426	11230	0.378
	Conference	Conference / meeting	812	17	0.06	5	49	85	1	134	183	845	0.733
AHU-8/ Level 8	Office	Office space	10782	54	0.06	5	647	270	1	917	2426	11230	0.378
	Conference	Conference / meeting	812	17	0.06	5	49	85	1	134	183	845	0.733
AHU-9/ Level 9	Office	Office space	10782	54	0.06	5	647	270	1	917	2426	11230	0.378
	Conference	Conference / meeting	812	17	0.06	5	49	85	1	134	183	845	0.733
AHU-10/ Level 10	Office	Office space	10782	54	0.06	5	647	270	1	917	2426	11230	0.378
	Conference	Conference / meeting	812	17	0.06	5	49	85	1	134	183	845	0.733
AHU-11/ Level 11	Office	Office space	10682	54	0.06	5	641	270	1	911	2510	12125	0.363
	Conference	Conference / meeting	805	17	0.06	5	48	85	1	133	189	915	0.704

Ps	System Population	600
D	Occupant Diversity Ratio	0.85
V_{ou}	Uncorrected OA intake	9679
$Z_{p,max}$	Max Z_p	0.859
E_v	Ventilation Efficiency	Appendix A
E_v (Appendix A)	Ventilation Efficiency	0.488
V_{OT}	System OA intake	19841
V_{PS}	System primary supply	27887
X_s	Average outdoor air fraction	0.347

Table 2-1 - Ventilation Air Calculation Summary

2.2. ASHRAE Standard 90.1 Analysis Summary

Compliance with ASHRAE Standard 90.1 requires efficient design in many different aspects of the building. Components such as the building envelope, lighting power density, and equipment efficiencies can all greatly impact the overall energy consumption of a building. ASHRAE 90.1 supplies minimum and maximum guidelines to follow during design. The following sections examine 1050 K Street to determine whether the design is in compliance with the standard.

2.2.1. Building Envelope

Separating the interior from the exterior, the building envelope provides a barrier to prevent heat transfer from a mechanically conditioned space. The exterior components of the 1050 K Street design were intended to prevent as much load transfer through the walls while still keeping the North and West facades as open as possible. By specifying glazing with low conductive properties, the building envelope meets the requirements of the standard and are summarized in **Error! Reference source not found.** below.

Building Envelope Compliance Summary						
Component	R-Value	U/C/F Factor	SHGC	Assembly Max	Assembly Min	Compliance
Vegetated Roof	32	0.031	-	0.063	15	YES
Ballasted Roof	23	0.044	-	0.063	15	YES
Above Grade Walls	26.85	0.037	-	0.151	5.7	YES
Vision Glazing	-	0.270	0.32	0.46	0.36	YES
Non-Vision Glazing	-	0.300	0.23	0.46	0.36	YES

Table 2-2 - Summary of building envelope compliance analysis.

2.2.2. Lighting Power Density

Since lighting is used throughout the day and year in most commercial buildings, the power consumed by inefficient lighting can be a large portion of the electrical consumption. The maximum power densities in ASHRAE help ensure that building designers use more efficient lighting that rejects less heat to the space. **Error! Reference source not found.** below summarizes the lighting densities in typical spaces and assesses the design compliance.

Lighting Power Density			
Room Description	**W/SF**	**90.1 Max**	**Compliance**
Office Space	1.1	1.1	YES
Conference Space	1.3	1.3	YES
Garages	0.196	0.2	YES
Stairs	0.58	0.6	YES
Restrooms	0.27	0.9	YES
Elevator Lobbies	0.56	1.1	YES
Main Lobby	3.1	3.3	YES
Locker Room	0.68	0.9	YES
Retail	1.7	1.7	YES
Storage	0.75	0.8	YES
Mech/Elec	1	1.5	YES

Table 2-3 - Summary of lighting power density calculations.

2.2.3. Equipment Efficiencies

Large pieces of equipment can contribute quite dramatically to the energy consumption. Since some equipment can operate at relatively low efficiencies, the consumption can be driven up rapidly. The following tables provide the efficiencies of the large pieces of equipment in comparison with the efficiency requirements in the standard.

Chiller Efficiency Compliance - ASHRAE 90.1 - 2004						
Tag	Type	Capacity	KW	Efficiency	Minimum Efficiency	Compliance
		Tons		COP	COP	
CH-1	Rotary	115	68	5.95	4.45	YES
CH-2	Rotary	115	68	5.95	4.45	YES
CH-3	Rotary	115	68	5.95	4.45	YES

Table 2-4 - Summary of chiller efficiency

Cooling Tower Efficiency Compliance								
Tag	Fan Type	Number Cells	Capacity/ Cell	GPM	HP	Efficiency	Min Eff	Compliance
						GPM/HP	GPM/HP	
CT-1	Axial	2	210	640	10	64.00	38.2	YES

Table 2-5 - Summary of cooling tower efficiency compliance

Fan Power Limitiation Compliance								
Tag	Location	Fan Type	Control Type	CFM	HP	Power HP/1000 CFM	Max Power HP/1000 CFM	Compliance
GF 1-8	Garage	Prop	CV	7,250	1	0.14	1.1	YES
GF 12	Garage	Prop	CV	14,500	2	0.14	1.1	YES
GF 13	Garage	In-Line	VAV	58,000	15	0.26	1.5	YES
EF-1	Pump Room	Prop	CV	660	1/8	0.19	1.1	YES
EF-2	Generator	In-Line	CV	300	1/4	0.83	1.1	YES
EF-3	Lockers	In-Line	CV	480	1/4	0.52	1.1	YES
EF-4-14	Elec/ Tele	Ceiling	CV	125	1/50	0.16	1.1	YES
EF-15	Chiller Plant	In-Line	CV	1,400	1/2	0.36	1.1	YES
EF-16-18	Storage	In-Line	CV	300	1/4	0.83	1.1	YES
SF-1-2	Stair 1&2	In-Line	VAV	10,000	7.5	0.75	1.7	YES
ERU Sup	ERU	In-Line	VAV	15,000	20	1.33	1.7	YES
ERU Exh	ERU	In-Line	VAV	14,840	12.5	0.84	1.7	YES
AHU-1	AHU's	In-Line	VAV	8,000	10	1.25	1.7	YES
AHU-2-10	AHU's	In-Line	VAV	12,500	20	1.60	1.7	YES
AHU-11	AHU's	In-Line	VAV	13,500	20	1.48	1.7	YES

Table 2-6 - Summary of fan power efficiency compliance

2.3. LEED Assessment

The US Green Building Council provides a series of standards for environmental design. The LEED certification standards encompass many different environmentally conscientious topics. This includes site selection, equipment efficiency, water management, and environmental quality. The existing design for 1050 K Street has been to compared to the core and shell standard provided by the USGBC. As seen in Table 2-7 below, the building has been designed to receive a gold rating. Additionally, a breakdown of points earned in each category as well as the rating requirements is provided in the appendix.

LEED Core & Shell 2.2 Summary	
Category	**Credits Obtained**
Sustainable Sites	6
Water Efficiency	4
Energy & Atmosphere	7
Materials & Resources	4
Indoor Environmental Quality	11
Innovative Design	3
Total:	**35**
Rating:	**Gold**

Table 2-7 - LEED Assessment Results Summary

Providing a well rounded design is essential in achieving a LEED rating, as illustrated in Table 2-7, the building will be awarded points in every category of the rating system. By building on a site that is located in a densely developed area, the building will not disrupt any natural habitats. Also for its location, 1050 K Street will also be awarded points for provided alternative transportation methods such as close proximity to the metro as well as bicycle storage and changing facilities. The design also implements a green roof design, the benefits of which are two fold. Not only with the green roof help insulate the building from external loads, decreasing the cost of the mechanical system, but the vegetation also provides storm water management. Since the roof is irrigated through a combination of the condensate collection system and storm water the effect of the roof on water management is minimal. These are just a few of the design aspects implemented to diminish the buildings impact on its environmental surroundings. As previously noted, the mechanical plant also utilizes efficient systems, free cooling components, and advanced controls, while the architectural design uses low emitting materials and fairly efficient glazing.

2.4. Lost Rentable Space

Although the system provided is fairly energy efficient, one of the drawbacks of the VAV system is the space required for the mechanical rooms on each level. Housed in each room is the air handling unit that receives the outdoor air from the energy recovery unit and distributes it to the variable volume boxes. In addition to the penthouse and mechanical rooms on each level, a pump room is located on the first below grade level. The total lost rentable space due to the mechanical system is provided in Table 2-8

Lost Rentable Space			
Level	**Mechanical**	**Total Area**	**Percentage**
P1	330	13000	2.5%
G	50	13000	0.4%
2	240	13000	1.8%
3	240	13000	1.8%
4	240	13000	1.8%
5	240	13000	1.8%
6	240	13000	1.8%
7	240	13000	1.8%
8	240	13000	1.8%
9	240	13000	1.8%
10	240	13000	1.8%
11	240	13000	1.8%
	2780	156000	1.8%

Table 2-8 - Lost Rentable Space Summary

2.5. Energy Consumption

By utilizing each of the energy saving strategies the existing mechanical system provides a comfortable space at a relatively low energy costs. The DOE-2 based eQuest software was utilized to determine the amount of energy consumed in a year.

2.5.1. Zoning

Each floor of the modeled building was broken down into five zones as seen below in Figure 2-1, a perimeter zone for each of the four facades and a core zone. Plenum zones were also included in the model, but were not conditioned.

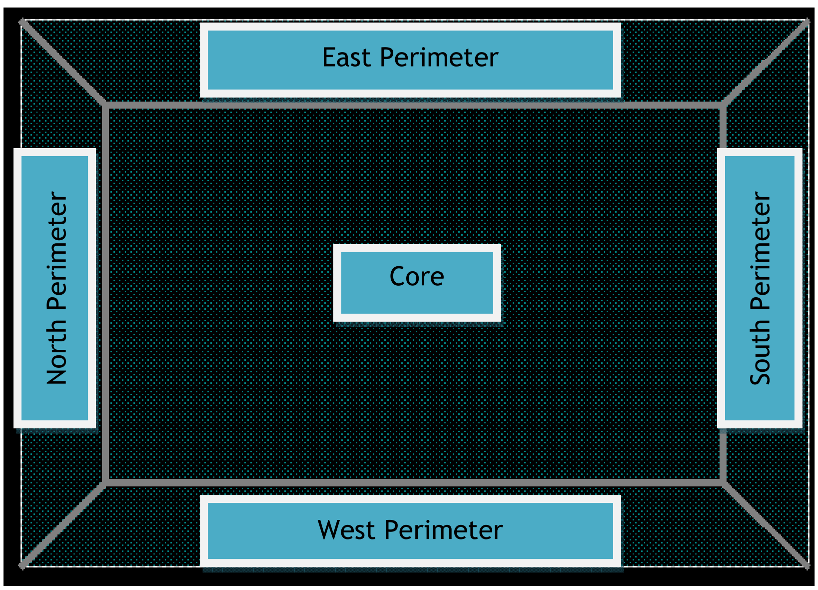

Figure 2-1 - Zone Assignment by Floor

2.5.2. AHU & ERU Modeling

Each AHU was modeled as a separate variable air volume system with electric reheat and a chilled water cooling coil. The AHU's received outdoor air from the central energy recovery unit which preheats and cools the outdoor summer 55 F in the winter and air to 65 F in the. This allows each AHU to reheat and cool the supply air as required by its respective zones.

2.5.3. Chiller & Chilled Water

The chilled water loop was set to 44 F for as specified in the design documents, with a 12 degree temperature increase through the system. The chilled water loop is attached to the chiller plant as well as the water side economizer.

2.5.4. Energy Simulation Results

The following figures provide a brief summary of the simulation results of the existing VAV design. These results will be used in future sections as a baseline case.

Energy Simulation Summaries	
Enduse	**KWh**
Space Cooling	124400
Heat Rejection	7000
Space Heating	154200
Hot Water	44500
Vent Fans	242700
Pumps & Auxillary	243200
Misc Equipment	277700
Lighting	482700
Total	1576400

Table 2-9 - VAV Energy Simulation Summary

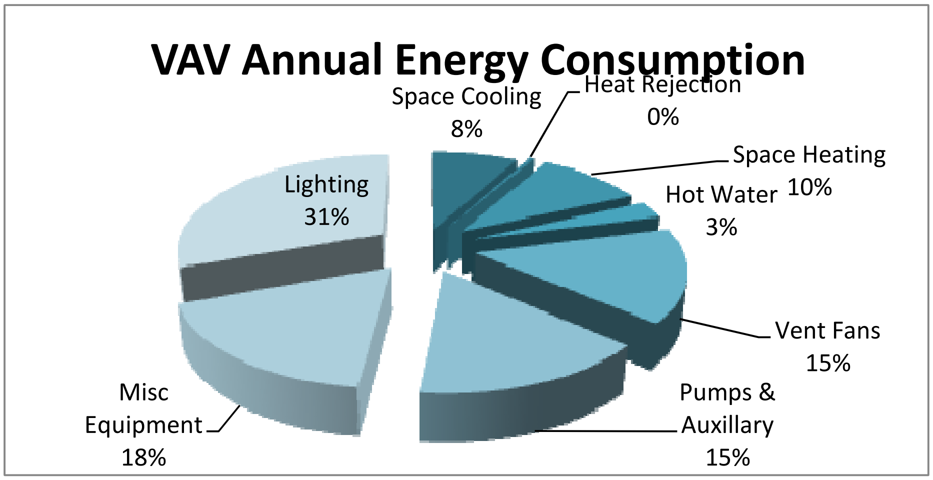

Figure 2-2 - VAV Enduse Breakdown

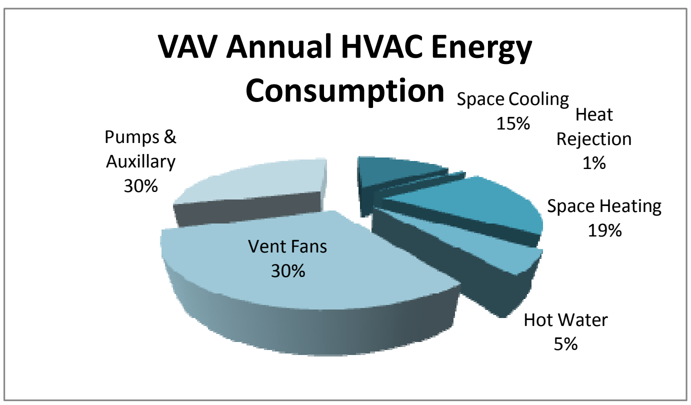

Figure 2-3 - VAV HVAC Enduse Breakdown

2.6. Initial Cost Estimate

The initial cost of the VAV system has been analyzed briefly to lend itself to comparisons in future sections. Any equipment that will not be altered or replaced has not been included.

VAV System Initial Cost Data				
Component Description	Materials Cost	Unit	Total Units	Cost
VAV Box 300-600 CFM W/RH	$ 358.00	Ea	80	$ 28,640.00
VAV Box 500-1000 CFM W/RH	$ 368.00	Ea	11	$ 4,048.00
VAV Box 800-1600 CFM W/RH	$ 383.00	Ea	1	$ 383.00
VAV Box 500-1000 CFM W/o RH	$ 345.00	Ea	22	$ 7,590.00
Air Handling Unit 8000 CFM	$ 13,353.00	Ea	1	$ 13,353.00
Air Handling Unit 12500 CFM	$ 18,470.00	Ea	1	$ 18,470.00
Air Handling Unit 13500	$ 19,850.00	Ea	9	$ 178,650.00
				$ 251,134.00

3. DEPTH WORK – ALTERNATIVE MECHANICAL SOLUTION

3.1. Objectives & Goals

The objective of this section is to examine the benefits of implementing a chilled beam system in place of the variable air volume system that is currently designed. The systems comparison will examine variations in the initial cost estimate, operations and maintenance, lost rentable space, and annual energy consumption. The analysis of the two systems is for purely educational purposes and in no way suggests that the existing design is inadequate.

3.2. Chilled Beam Overview

A chilled beam system is an energy efficient air conditioning system combine cooling, heating, ventilation, and even lighting into a single unit. There are two main types of chilled beams, active and passive. Passive chilled beams induce warm room air into the top of the beam by free convection and as the warm air passes through the beam it is cooled by the chilled water coil and is then released through a grille on the bottom of the beam. Figure 3-1 illustrates the air flow through the beam. Typically passive chilled beam systems are used as a parallel conditioning source in dedicated outdoor air systems.

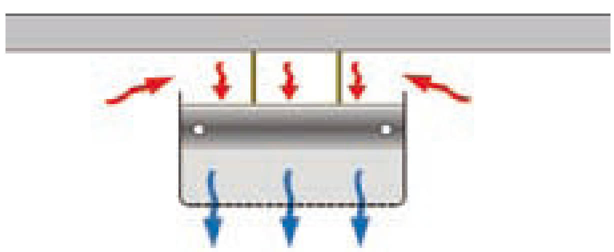

Figure 3-1 - Passive chilled Beam

An active chilled beam combines the ventilation air into the chilled beam design. Like the passive chilled beams, the warm air is induced into the chilled beam and after passing through the coils, it mixes with the ventilation air provided through nozzles. The velocity of the ventilation air entrains the conditioned room air and is pushed back into the space, as seen in Figure 3-2. As a result there is no need for additional diffusers in the space. Because the ventilation air induces the room air into the beam and are not reliant on free convection alone, active chilled beams can also provide heating. Since most beams have limited heating capacities, chilled beams with heating should only be used in applications where the cooling is prevalent.

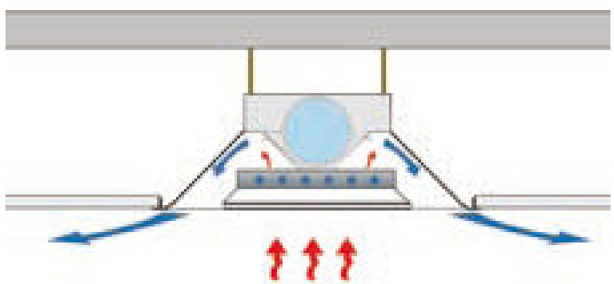

Figure 3-2 - Active Chilled Beam

With the active chilled beam, the amount of cooling that can be done is contingent upon the ventilation air brought in. When cooling loads are high compared to the ventilation requirements of a space, such as perimeter zones, passive beams can be used to supply additional cooling without increasing the amount of conditioned outdoor air.

When dampers are applied to active chilled beams, the response of the beams to varying loads can be very flexible. Thus, as the space function changes over time, so can the capacity of the beam. Additionally, the beams are typically hung from the structure and can either exposed or flush with a hung ceiling allowing for aesthetic flexibility as well.

3.3. Overview of Alternative System

The system to be supplemented in for the VAV system will still incorporate many of the energy efficient aspects of the existing design. The alternative system will keep the energy recovery unit to utilize as the dedicated outdoor air unit with the chilled beams. In addition, the water side economizer will also remain in the alternative design. The critical alterations in the design will include removal of the VAV boxes and air handling units and will replace them with both active and passive chilled beams. The passive beams will be used in perimeter zones with high cooling loads.

3.4. Calculation Methods & Procedures

Like the VAV analysis, the chilled beams analysis has been performed using eQuest. Although the zoning assignments have remained the same as in the previous section, each zone will have its own system. Since chilled beams are not provided as a system option, the zones were attached to fan coil units without the fans. This was accomplished by setting all fan energy ratios and pressure drops to zero. Like the VAV system the fan coil units were set to receive outdoor air from the energy recovery unit. However, in this case, the energy recovery unit is assigned a ‘dummy zone’ that mimics the latent loads in the building while the latent loads are removed from the fan coil units. This allows the sensible and latent loads to be decoupled.

3.5. Results & Recommendations

3.5.1. Energy Simulation Results

The simulation results of the chilled beam system have been summarized into the following tables. Although there is an energy savings in the model, it is not as significant as expected. This could be because the previous system incorporates efficient equipment and systems or because the controls used in the simulation are not as sophisticated as those required to perfectly represent the chilled beam system.

Energy Simulation Summaries	
Enduse	**KWh**
Space Cooling	166400
Heat Rejection	7500
Space Heating	84600
Hot Water	44500
Vent Fans	39400
Pumps & Auxillary	316400
Misc Equipment	277700
Lighting	482700
Total	1419200

Table 3-1 - Chilled Beam Energy Simulation Summary

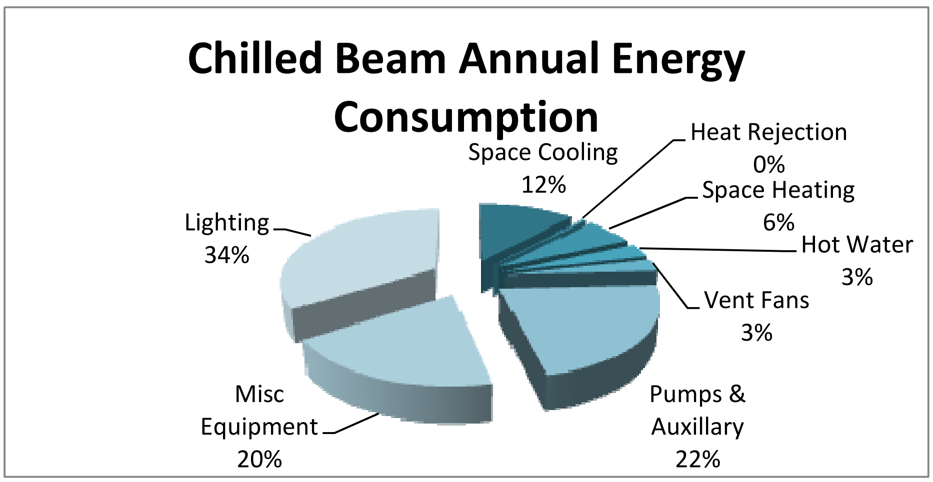

Figure 3-3 - Chilled Beam Energy Consumption by Enduse

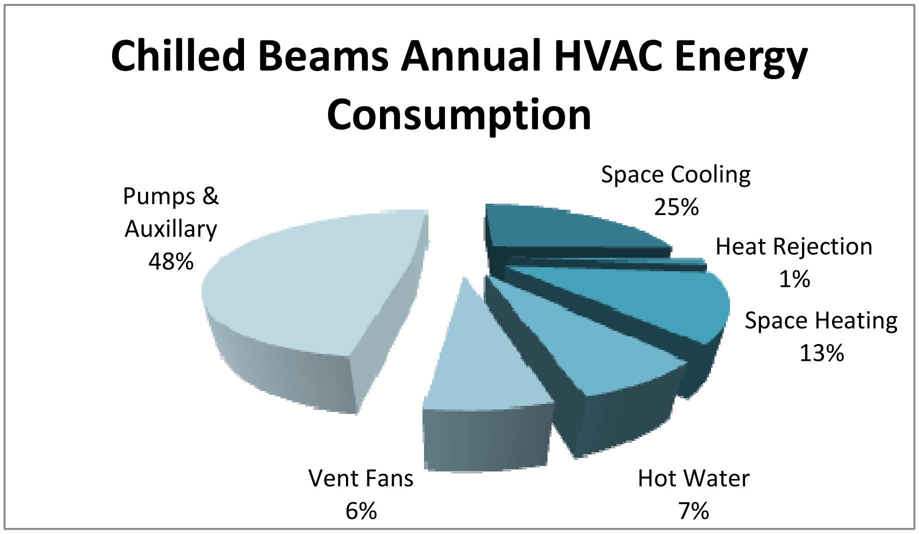

Figure 3-4 - Chilled Beams HVAC Energy Consumption

3.5.2. Chilled Beam Sizing Overview

Once peak loads were calculated in each zone, the Halton Hit Design program was used to size the chilled beams. Each zone parameters were put into the program along with the required ventilation flow rate. If the cooling capacity of the beam did not exceed the load in the space, additional passive beams were sized to make up the difference. The heating loads of each zone were also compared to the heating capacities of the beams at the required air flow. There were no beams that were undersized for the loads. Since these beams will be used in a shell and core design, all beams will be equipped with dampers so adjustments in the ventilation flow rate may be made as loads are shifted within the zones. A complete list of beam assignments for each zone is provided in the appendices along with an example cut sheet for each type of chilled beam utilized in this design.

3.5.3. Initial Cost Estimate

The initial cost estimate of the chilled beams system is compromised of the chilled beams added to each zone as well as the boiler that was added to produce the hot water for the heating coils.

Chilled Beam Initial Cost				
Component Description	Materials Cost	Unit	Total Units	Cost
Chilled Beam	$ 200.00	LF	7940	$ 1,588,000.00
Boiler	$ 10,300.00	Ea	1	$ 10,300.00
				$ 1,598,300.00

Table 3-2 - Chilled Beam Initial Cost Summary

3.5.4. VAV/Chilled Beam Cost Comparison

Based on a $0.1199 utility rate, the annual energy savings with the chilled beam system comes out to $18848.00 annually. However with the initial cost difference being $1,347,166.00, the simple pay back period is roughly 61 years.

3.5.5. Recommendation

Based on the simulations performed there is an attractive reduction in the annually energy cost with the chilled beam system, however, it seems that the payback period is much too long to suggest that the chilled beam system is more economical than the current design.

4. BREADTH WORK – SHADING DEVICES & ELECTRICAL EFFECTS

4.1. Shading Devices Overview

Even though the building envelope passed the ASHRAE 90.1 standards, solar gain from the curtain wall is still a fairly large part of the space cooling loads. Because of this observation, a third energy analysis has been completed with the addition of mylar shades. Although the shades are transparent and allow occupants to clearly see through the window, as shown in Figure 4-1 , the shades still block roughly 90% of the solar loads from entering the space. In the winter, the interior coating of the shade can keep 25% of the internal heat gains from exiting the building through the façade.

Figure 4-1 - Transparent Mylar Shade

4.2. Calculation Results

The chilled beams model was adjusted to include the shading devices on the two curtain wall facades. As a result the annual energy consumption did decrease in many aspects as seen in the following summaries.

Energy Simulation Summaries	
Enduse	**KWh**
Space Cooling	157400
Heat Rejection	7100
Space Heating	89800
Hot Water	44500
Vent Fans	39300
Pumps & Auxillary	294800
Misc Equipment	277700
Lighting	482700
Total	1393300

Table 4-1 - Energy Simulation Summary with Solar Shading

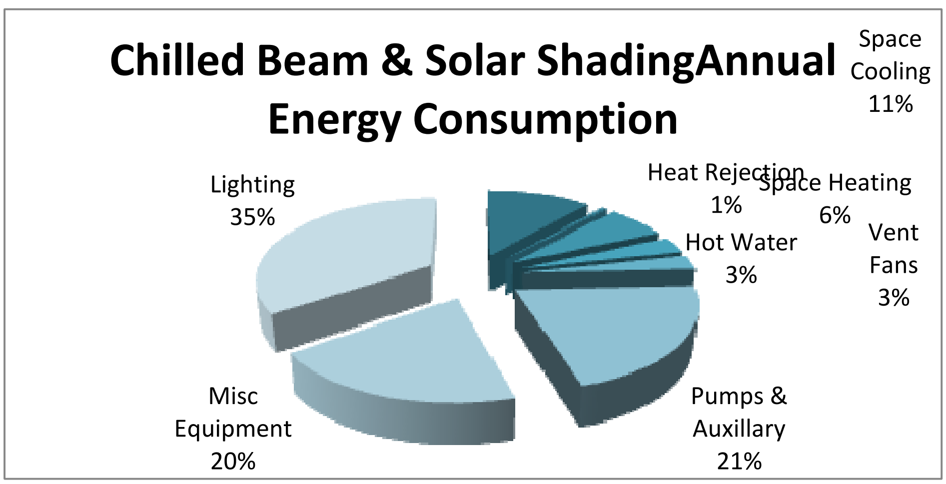

Figure 4-2 - Chilled Beam & Solar Shading Enduse Energy Summary

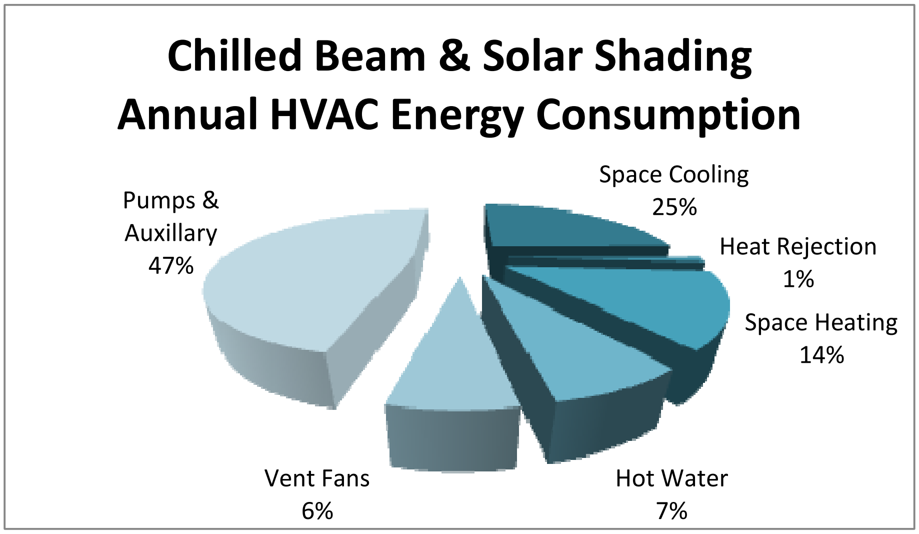

Figure 4-3 - Chilled Beam and Solar Shading HVAC Energy Summary

From the energy consumption reports obtained from the energy analysis it was found that the number of passive chilled beams could be reduced by 58% with the solar shading. The resulting initial cost estimate is summarized in Table 4-2 below.

Chilled Beam Initial Cost				
Component Description	Materials Cost	Unit	Total Units	Cost
Chilled Beam	$ 200.00	LF	7160	$ 1,432,000.00
Solar Shades	$164	43.75 SF	514.8	$ 84,427.20
Boiler	$ 10,300.00	Ea	1	$ 10,300.00
				$ 1,526,727.20

Table 4-2 - Chilled Beam & Solar Shading Initial Cost Estimate

With this initial cost and a resulting annual energy savings of $21,996.00, the simple payback of the chilled beam system with solar shading reduces to 58 years. This payback period is still far too long to consider a system such as this.

4.3. Daylighting

From assessing any of the previous energy simulations, it is apparent that a large part of the energy usage goes towards lighting. By providing day lighting controls to utilize the light already being introduced into the space, it is possible to decrease energy consumption due to lighting while improving productivity of the occupants. Since the majority of the building can be used as an open office plan, many of the occupants could potential benefit from the positive aspects to a daylighting scheme.

When implementing daylighting into the energy calculations provided in the first section, area lighting energy consumption is reduced to 75% of the original load. Overall the energy consumption was reduced to 90%. The following figures illustrate the energy consumption comparison between the VAV design and the daylighting design as well as the affects daylight has on the enduse summary.

Energy Simulation Summaries		
Enduse	VAV	Daylighting
Space Cooling	124400	116100
Heat Rejection	7000	6500
Space Heating	154200	155900
Hot Water	44500	44500
Vent Fans	242700	230500
Pumps & Auxillary	243200	236200
Misc Equipment	277700	277700
Lighting	482700	364200
Total	1576400	1431600

Table 4-3 - VAV / Daylighting Comparison

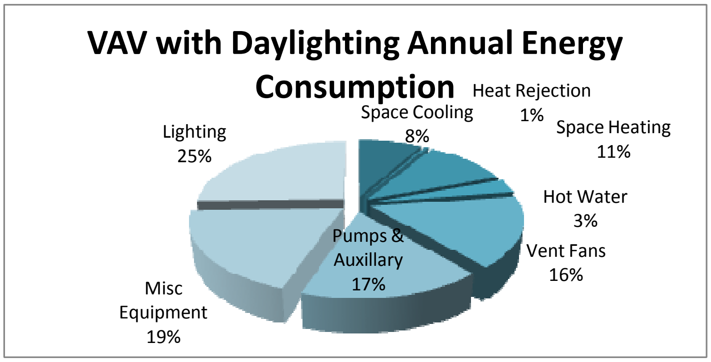

Figure 4-4 - Daylightin Energy Enduse Consumption

In addition to the savings in energy building occupants may see improved health and productivity. There are multiple studies that suggest that improved indoor air conditions can lead to fewer sick days and increased productivity. However, since it is difficult to predict the amount of increased productivity in a building implementing these findings onto a cost analysis may not be possible. In this case the energy savings per year amounts to $17,361 and the additional cost for the controls is anywhere from $0.50 to $0.75 per square foot. This would result in a pay off period between four and six year. A system such as this has great potential to benefit owners and occupants of buildings.

5. REFERENCES

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- Past Penn State AE Thesis Technical Reports
- Halton Design Guidelines & Product Documents
- www.gard.com Design message board

6. ACKNOWLEDGEMENTS

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The professionals at Vanderweil Engineers for providing me with multiple thesis buildings. A special thanks to Sam Bohsali and Brandon Harwick for being great teachers over the past two years.

7. Appendices

7.1. LEED

LEED Certification Categories	
Number of Points	**Rating**
0-22	No Rating
23-27	Certified
28-33	Silver
34-44	Gold
45-60	Platinum

LEED NC 2.2

	Credit	Title	Status	Points
Sustainable Sites	SSp1	Construction Activity Pollution Prevention	Y	Req
	SSc1	Site Selection	Y	1
	SSc2	Development Density & Community Connectivity	Y	1
	SSc3	Brownfield Redevlopment	N	0
	SSc4.1	Alternative Transportation, Public Transportation Access	Y	1
	SSc4.2	Alternative Transportation, Bicycle Storage & Changing Rooms	M	0
	SSc4.3	Alternative Transportaion, Low-Emitting & Fuel-Efficient Vehicles	M	0
	SSc4.4	Alternative Transportation, Parking Capacity	M	0
	SSc5.1	Site Development, Protect or Restore Habitat	N	0
	SSc5.2	Site Development, Maximize Open Space	N	0
	SSc6.1	Stormwater Management, Quantity Control	M	0
	SSc6.2	Stormwater Management, Quality Control	M	0
	SSc7.1	Heat Island Effect, Non-Roof	Y	1
	SSc7.2	Heat Island Effect, Roof	Y	1
	SSc8	Light Pollution Reduction	N	0
	SSc9	Tenant Design & Construction Guidelines	Y	1
			Total	6

LEED NC 2.2

	Credit	Title	Status	Points
Water Efficiency	WEc1.1	Water Efficient Landscaping: Reduce by 50%	Y	1
	WEc1.2	Water Efficient Landscaping: No Potable Water Use or No Irrigation	Y	1
	WEc2	Innovative Wastewater Technologies	M	0
	WEc3.1	Water Use Reduction: 20%	Y	1
	WEc3.2	Water Use Reduction: 30%	Y	1
			Total	4

LEED NC 2.2

	Credit	Title	Status	Points
Energy & Atmosphere	EAp1	Fundamental Commissioning of the Building Energy Systems	Y	Req
	EAp2	Minimum Energy Performance	Y	Req
	EAp3	Fundamental Refrigerant Management	Y	Req
	EAc1	Optimize Energy Performance	Y	5
	EAc2	On-Site Renewable Energy	M	0
	EAc3	Enhanced Comminssioning	Y	1
	EAc4	Enhanced Refrigerant Management	Y	1
	EAc5	Measurement & Verification	N	0
	EAc6	Green Power	M	0
			Total	7

LEED NC 2.2

	Credit	Title	Status	Points
Materials & Resources	MRp1	Storage & Collection of Recyclables	Y	Req
	MRc1.1	Building Reuse, Maintain 75% of Existing Shell	N	0
	MRc1.2	Building Reuse, Maintain 100% of Existing Shell	Y	1
	MRc1.3	Building Reuse, Maintain 50% of Interior Non-Structural Elements	Y	1
	MRc2	Construction Waste Management	N	0
	MRc3	Resource Reuse	Y	1
	MRc4	Recycled Content	Y	1
	MRc5	Regional Materials	N	0
	MRc6	Rapidly Renewable Materials	N	0
	MRc7	Certified Wood	N	0
			Total	4

LEED NC 2.2

	Credit	Title	Status	Points
Indoor Environmental Quality	EQp1	Minimum IAQ Performance	Y	Req
	EQp2	Environmental Tobacco Smoke (ETS) Control	Y	Req
	EQc1	Outdoor Air Delivery Monitoring	Y	1
	EQc2	Increased Ventilation	M	0
	EQc3.1	Construction IAQ Management Plan, During Construction	Y	1
	EQc3.2	Contstruction IAQ Management Plan, Before Occupancy	Y	1
	EQc4.1	Low-Emitting Materials, Adhesives & Sealants	Y	1
	EQc4.2	Low-Emitting Materials, Paints & Coatings	Y	1
	EQc4.3	Low-Emitting Materials, Carpet Systems	Y	1
	EQc4.4	Low-Emitting Materials, Composite Wood & Agrifiber	Y	1
	EQc5	Indoor Chemical & Pollutant Source Control	Y	1
	EQc6.1	Controllability of Systems, Lighting	N	0
	EQc6.2	Contrallability of Systems, Thermal Comfort	N	0
	EQc7.1	Thermal Comfort, Design	Y	1
	EQc7.2	Thermal Comfort, Verification	Y	1
	EQc8.1	Daylighting & Views, Daylight 75% of Spaces	M	0
	EQc8.2	Daylighting & Views, Views for 90% of Spaces	Y	1
			Total	**11**

7.2. Chilled Beam Sizing Summary

Level	Zone Name	Floor Area (SF)	OA (cfm)	OA (L/s)	Cooling Load (Btu/h)	Heating Load (Btu/h)	Cooling Cap (Btuh)	Heating Cap (Btuh)	# Active Beams	Passive Needed	# Passive Needed	Btu/h	Total Cooling Cap	Enough Cooling Provided
G	WP	1845	377	178	41653	19169	26109	29040	30	Y	15	15620.136	41729	Y
	SP	1215	180	85	9020	4951	13382	15395	18	N	0	0	13382	Y
	EP	1845	352	166	33595	24186	22768	26242	30	Y	15	11048.056	33816	Y
	NP	1215	242	114	19286	13616	16425	17998	18	Y	5	3954.508	20380	Y
	Core	7128	469	221	31792	0	32724	0	44	N	0	0	32724	Y
2	WP	1845	320	151	46207	21796	22417	25928	30	Y	15	24105.78	46523	Y
	SP	1215	191	90	29821	12359	13382	15395	18	Y	10	16479.96	29862	Y
	EP	1845	371	175	25060	17904	25522	28436	30	N	0	0	25522	Y
	NP	1215	191	90	20243	15208	13382	15395	18	Y	5	6892.24	20274	Y
	Core	7128	795	375	32228	0	53575	0	55	N	0	0	53575	Y
3	WP	1845	320	151	46207	21796	22417	25928	30	Y	15	24105.78	46523	Y
	SP	1215	191	90	29821	12359	13382	15395	18	Y	10	16479.96	29862	Y
	EP	1845	371	175	25060	17904	25522	28436	30	N	0	0	25522	Y
	NP	1215	191	90	20243	15208	13382	15395	18	Y	5	6892.24	20274	Y
	Core	7128	795	375	32228	0	53575	0	55	N	0	0	53575	Y
4	WP	1845	320	151	46207	21796	22417	25928	30	Y	15	24105.78	46523	Y
	SP	1215	191	90	29821	12359	13382	15395	18	Y	10	16479.96	29862	Y
	EP	1845	371	175	25060	17904	25522	28436	30	N	0	0	25522	Y
	NP	1215	191	90	20243	15208	13382	15395	18	Y	5	6892.24	20274	Y
	Core	7128	795	375	32228	0	53575	0	55	N	0	0	53575	Y
5	WP	1845	320	151	46207	21796	22417	25928	30	Y	15	24105.78	46523	Y
	SP	1215	191	90	29821	12359	13382	15395	18	Y	10	16479.96	29862	Y
	EP	1845	371	175	25060	17904	25522	28436	30	N	0	0	25522	Y
	NP	1215	191	90	20243	15208	13382	15395	18	Y	5	6892.24	20274	Y
	Core	7128	795	375	32228	0	53575	0	55	N	0	0	53575	Y
6	WP	1845	320	151	46207	21796	22417	25928	30	Y	15	24105.78	46523	Y
	SP	1215	191	90	29821	12359	13382	15395	18	Y	10	16479.96	29862	Y
	EP	1845	371	175	25060	17904	25522	28436	30	N	0	0	25522	Y
	NP	1215	191	90	20243	15208	13382	15395	18	Y	5	6892.24	20274	Y
	Core	7128	795	375	32228	0	53575	0	55	N	0	0	53575	Y

Level	Zone Name	Floor Area (SF)	OA (cfm)	OA (L/s)	Cooling Load (Btu/h)	Heating Load (Btu/h)	Cooling Cap (Btuh)	Heating Cap (Btuh)	# Active Beams	Passive Needed	# Passive Needed	Btu/h	Total Cooling Cap	Enough Cooling Provided
7	WP	1845	320	151	46207	21796	22417	25928	30	Y	15	24105.78	46523	Y
	SP	1215	191	90	29821	12359	13382	15395	18	Y	10	16479.96	29862	Y
	EP	1845	371	175	25060	17904	25522	28436	30	N	0	0	25522	Y
	NP	1215	191	90	20243	15208	13382	15395	18	Y	5	6892.24	20274	Y
	Core	7128	795	375	32228	0	53575	0	55	N	0	0	53575	Y
8	WP	1845	320	151	46207	21796	22417	25928	30	Y	15	24105.78	46523	Y
	SP	1215	191	90	29821	12359	13382	15395	18	Y	10	16479.96	29862	Y
	EP	1845	371	175	25060	17904	25522	28436	30	N	0	0	25522	Y
	NP	1215	191	90	20243	15208	13382	15395	18	Y	5	6892.24	20274	Y
	Core	7128	795	375	32228	0	53575	0	55	N	0	0	53575	Y
9	WP	1845	320	151	46207	21796	22417	25928	30	Y	15	24105.78	46523	Y
	SP	1215	191	90	29821	12359	13382	15395	18	Y	10	16479.96	29862	Y
	EP	1845	371	175	25060	17904	25522	28436	30	N	0	0	25522	Y
	NP	1215	191	90	20243	15208	13382	15395	18	Y	5	6892.24	20274	Y
	Core	7128	795	375	32228	0	53575	0	55	N	0	0	53575	Y
10	WP	1845	320	151	46207	21796	22417	25928	30	Y	15	24105.78	46523	Y
	SP	1215	191	90	29821	12359	13382	15395	18	Y	10	16479.96	29862	Y
	EP	1845	371	175	25060	17904	25522	28436	30	N	0	0	25522	Y
	NP	1215	191	90	20243	15208	13382	15395	18	Y	5	6892.24	20274	Y
	Core	7128	795	375	32228	0	53575	0	55	N	0	0	53575	Y
11	WP	1845	320	151	46207	21796	22417	25928	30	Y	15	24105.78	46523	Y
	SP	1215	191	90	29821	12359	13382	15395	18	Y	10	16479.96	29862	Y
	EP	1845	371	175	25060	17904	25522	28436	30	N	0	0	25522	Y
	NP	1215	191	90	20243	15208	13382	15395	18	Y	5	6892.24	20274	Y
	Core	7128	795	375	32228	0	53575	0	55	N	0	0	53575	Y
Total		145728	20297		1670936	734592	1394184	940207	1650		335		1899587	

7.3. Chilled Beam Data Sheet