V. Mechanical Depth

a. Existing Conditions

Approach and Strategy

Figure 5.1 Palestra Under Construction

The Palestra Building is the result of a business collaboration between Insignia Richard Ellis Development and Blackfriars Investment. The team wanted to create an iconic landmark office building in southern London as an effort to spur regeneration in the area. In addition to an exciting and contemporary design, great efforts were made to develop the most efficient building from an engineering standpoint as well. With the complex structural systems incorporated throughout the building with the 'dancing columns' and 9 meter cantilever, careful integration of the building services distribution systems was imperative. Due to the 'glass box' nature of the design, a detailed solar shading study was completed to ensure system efficiency with minimal impact on the views from the office space.

Key Objectives

- At least 280,000 square feet of office space
- High Asset Value
- Flexible design to meet current and future business needs
- Design should comply with design specification set forth by Insignia Richard Ellis
- Flexible enough to allow for multi-tenant occupiers, up to four per floor
- Minimal impact on Building Services as office layouts are modified
- Cost Effective and Economic design
- Energy Efficient with Low Operating Costs

Occupied Environment

Temperature: The air and radiant temperatures shall meet the occupant's perception of their thermal environment comfort zone.

Air Movement: In order to meet the fresh air requirements for comfort while avoiding draughts the air velocity shall be limited to 0.15m/s in the winter and 0.25 during summer conditions.

Indoor Air Quality: To maintain appropriate contaminant levels (including C02) from office equipment and equipment the ventilation system shall be designed for 10-16L/s per person.

Humidity: Due to the moderate climate found in London, England the only critical season is winter when the humidity level can fall below 30%.
Acoustics: Too much background noise can be distracting, however a moderate amount has been proven to enhance concentration and disguise general conversations.

Lighting: Adequate levels of lighting must be provided throughout the building, yet it must be of the appropriate quality and also coordinate with the day lighting studies.

In addition to these specific strategies it is important to note that when utilizing air as the predominant means for heating and cooling internal spaces you will be able to satisfy up to 80% of the occupants. And through the fan coil unit layout chosen for the Palestra building limits the amount of humidity control the occupants will have, however the humidity levels should remain between 35-65% most of the year. However individual user controls will also be provided to account for the psychological aspect of how an occupant perceives his/her thermal environment.

Additional design criteria are summarized in Table 5.1.

Table 5.1 Design Criteria

Design Parameter					Comments
Outdoor temperature	Winter -4°C sat	Summer 29°C db, 20°C wb			
Internal temperature	Offices 22°C ± 2	Toilets & Stairs 18°C min (Winter)	22 °C ± 2	Toilets & Stairs uncontroll ed (summer)	The internal temperatures specified are more onerous than the BCO recommendations and will increase the building maximum demand and year round energy consumption.
Air Movement	Winter 0.15m/s max Summer 0.25m/s max				To avoid stratification when heating is required the 0.15 m/s criteria can be relaxed for systems supplying at high level.
Relative Humidity	35 – 65% areas conditioned by fancoil systems (expected levels – note the humidity levels are not controlled). Other areas no control.				Initial installation will not contain humidity control. Space shall be provided within the office area AHU on the roof for future tenant installation of humidification system.

Heating and Cooling Loads

The system was designed to handle 1796 kW of heating loads and 3871 kW of cooling to the building. The heating is supplied through a central gas-fired boiler plant located on the roof, while the cooling is provided through a central air-cooled chiller plant also located on the roof. For a further breakdown of the loads please refer to Appendix A.

Air-Side Systems

The air-side ventilation system in the Palestra Building consists of a constant volume system served by seven different air handling units. Four of the AHUs are located on the roof, two are located in the basement plant room, and one is located in the level 1 mechanical space.

Air Handling Units 1 and 2 are located on the roof and supply air to 16107m^2 of open plan office space disbursed evenly throughout the twelve levels at a rate of 38,139.84 cfm. Each AHU maintains a negative pressure of 500 Pa, and includes a heat exchanger in the form of a heat wheel, a cooling coil, a heating coil, a panel filter of grade G4, and a variable frequency drive supply and extract fan.

Air Handling Units 3 and 4 service the building's water closets and are also located in the roof ventilation plant. Unit 3 supplies air to 498m2 of toilets on the west side of the building, and Unit 4 supplies ventilation to 627m2 of toilet space on the east side. Each unit is sized to supply 6,420.21cfm to their respective areas. These are constant volume systems, and each includes a frost coil, cooling coil, heating coil, as well as supply and extract fans.

Air Handling Units 5 and 6 are located in the basement plant room. Units 5 and 6 are design to serve as extract systems for the toilets as well as the sprinkler plant and boiler rooms. Each unit includes a panel filter of grade G4, a cooling coil, and a heating coil. Units 5 and 6 were designed to provide adequate smoke clearance to these vital mechanical spaces with a flow of 6,356.64 cfm. Approved Document F requires a minimum of 12 m/s face velocity for ventilation extract in the case of fire.

Air Handling Unit 7 is located in the Ground Floor mechanical room and solely supplies air to the reception area, 772m2, at a constant volume flow rate of 7,627.97 cfm. This unit contains a heating coil, cooling coil, a panel filter of grade G4, as well as, supply and extract fans.

Water-Side Systems

The Palestra Building's water-side systems consist of a centralized boiler and chiller plant. Cooling is provided through a chiller plant located on the roof and consisting of seven 537 kW packaged air-cooled chiller units, six of which run at full load daily, while the seventh serves as a backup unit. The total estimated cooling load for the building is 3,291 kW. Chilled water is provided to the building at 7ºC and returned to the plant at 12ºC. These units run the building's chilled water system fed to the fan coil units and cooling coils in the air handling plant. The primary and secondary constant temperature pumps and circuits are located on the room next to the chiller units.

Heating is provided through a natural gas-fired central boiler system. The boiler room is located in the basement, and runs on four 800 kW boilers, three of which run at 100% to meet the daily demands while the fourth is a backup during times of maintenance or it can be used as a 'booster boiler' to generate the morning warm-up. The estimated heating load for the building is 2,135 kW. These boilers serve a low temperature hot water system fed to AHU ventilation systems, fan coil units, and heater batteries and operate with an 11ºC differential.

In addition to these systems there are 314 fan coil units placed on a grid system throughout the building to maximize thermal comfort. The grid layout reiterates the design goal to create office spaces that will meet the needs of current and future tenants. Depending on the desired office layout of the tenant more FCUs can be added for increase climate control for the employees. This is based on a four-pipe fan coil system used on each office level, including water-side controls for responsible operation, room temperature sensors, and variable speed heating and chilled water pumps to conserve energy.

Critique of System

The existing mechanical systems in the Palestra Building were well-designed and efficient, with the emphasis maintained on the ability of the system to be flexible, catering to its tenants (current and future), as well as creating a high level of reliability and redundancy.

The centralized boiler and chiller plant will be very useful in the coming years as more efficient technologies come along. Having all of the systems in one location will make it easy to replace them at once rather than disrupting locations throughout the building as would be require with localized heating and cooling systems.

In order to maximize the versatility and flexibility of the rentable office space the design team created open floor office plans with fan coil units placed on a grid system. This allows the space to function well with minimal walls and obstructions. However if the tenants desire more of a closed office layout, or would like to provide their employees with more personalized control over their environment more fan coil units may be added to this grid, with additional capacity on AHU-3 and AHU-4 to handle these possible loads.

Accessibility to the main plant rooms was also well-designed with thought put into how future replacements for all of the equipment will be moved in and out. The fan coil units throughout the design are located in the suspended ceiling and can be accessed by removing the acoustic ceiling tiles.

The design team also made a smart choice in selecting the 4 pipe fan coil system, and providing gas heating versus a 2 pipe unit using electric heating. Not only does Gas provide a much lower life cycle cost, but it is releases fewer emissions into the environment thus earning more ‘Green’ points which was a prime objective with the Palestra Building.

With all the benefits of the system and the forward thinking of the design team, there is no set means to control the humidity levels in the building. It is noted that London, England is a very moderate climate with minimal humidity issues through the spring, summer and fall seasons. However, there is a tendency for the humidity level to drop below 35% during the winter months. Accommodations have been made to allow for future installment of humidifiers in the Air Handing system as needed. Investigation into the feasibility of a dedicated outdoor air system could be a possible response to the humidity control issues. A closer look at what efficiency was compromised in order to maximize the flexibility would also be valuable, and how much efficiency the Building Management System can compensate for.

Alternatives Considered

Several schemes for a mechanical redesign of the Palestra Building were contemplated during the research of existing systems. These included a Combined Heat and Power plant, Day lighting Aperture Optimization, and possibly reducing the number of air handling units.

Building Combined Heat and Power (BCHP) is becoming increasingly popular as a means to increase system efficiency and thus decrease emissions by fully burning more of the energy inputted. With the new emission regulations outlined in Approved Document L and the increasing rates for electricity this seemed to be an interesting solution. However BCHP requires a large amount of waste heat and a fairly constant demand load to be most successful. One possibility was to coordinate a system between Palestra and the surrounding residential buildings to balance each buildings' demand peaks, as well as provide the necessary amount of waste heat. The Palestra already shares an electrical substation in its basement with several surrounding buildings, so this would have been a continuation of the current setup. This proposal would require extreme coordination with many stakeholders, and also require a large amount of floor space in the Palestra Building which is at a premium. The commitment on behalf of Palestra's owner would significantly increase, which may not be of interest to them regardless of the long term gains.

Maximizing the benefits of day lighting can have a large impact on the energy efficiency of a building, especially within the Palestra Building's 'glass box' design. By increasing the window efficiency and minimizing the glazing area the overall design could benefit from the increased insulation. However, due to the extensive research already done in this area by the design team, there is little probability that a better design could be achieved without sacrificing the design's architectural integrity. Therefore the efforts of this research would be better served investigating other topics.

Reducing the number of air handling units was also a consideration. Currently there are seven units servicing the building. Two units are dedicated to servicing the toilet areas, two serve as extracts to the toilets and plant spaces, one supplies the basement and lobby, and two additional units service all of the office space. It seems a bit imbalanced to have two units supplying over 80% of the floor area, while five smaller units were included in the design to serve such little area. However, this design does have excellent redundancy and it has additional capacity to meet future demands according to the tenant and office layout. In the end due to the lack of operable windows in the design, and the need for the system to meet current and future occupant demands to maximize desirability and profit it was decided that this system is effective as currently designed.

b. Chiller Plant Optimization

i. Proposed Redesign: IC Engine-driven Chiller Plant

Proposed Redesign and Justification

Building design in the United Kingdom is currently undergoing some significant changes with respect to emissions and energy consumption. Across the country there has been a dramatic increase in natural gas consumption over the past decade as electric generation has become more dependent on gas. Compared to other energy resources available gas is still the cheapest and most efficient option for consumers. Following the publication of the Fuel Poverty Strategy in 2001 the leaders of the country have been encouraging increased coverage of the gas network. In a recent publication from the Department of Trade and Industry in the UK, The Fuel Poverty Strategy reported that the lack of access to gas mains was the main cause of fuel poverty in 54% of the households included in the study. This is a dramatic example of the value of gas-driven systems in the UK today. Thus it was deemed beneficial to look into a natural gas-based system for the Palestra building.

The largest electrically-driven plant in this urban development is the existing chiller plant. The current design includes seven 535 kW air-cooled screw chillers produced by McQuay. This report will look at the advantages and disadvantages of replacing the electric chiller plant with an IC engine-driven plant coupled with the current gas-fired boiler plant.

The current chiller plant in the Palestra Building utilizes electric chillers and provides 18% additional capacity on the system. While this system functions well in the space, it accumulates large operating costs in order to meet the peak electric loads during the day. The current spark gap between peak electric and gas utility costs is over 3 pence per kilowatt-hour. A gas-based system not only allows for greater efficiency onsite, but the use of current and future technologies such as thermal storage and other forms of heat recovery. That flexibility

could prove beneficial in the future as the Emission Regulations in the UK become more and more strict. Flexibility was one of the driving factors throughout the rest of the design, and should be carried through here.

A hybrid system with IC engines and gas turbines was also considered but due to the low base load for the building it will not be included in these calculations. Although the building is not fully operating yet, the calculations have been based on a previous project with a similar expected load profile. Thus it was deemed more worthy to analyze an IC engine driven chiller plant.

Calculations

Trace™ 700 was used for all of the energy simulations. Trace™ 700 is a software program developed and distributed by Trane®, with the ability to model HVAC systems, economic and utility constraints to easily compare design alternatives.

Table 5.2 Tecogen Gas Engine Driven Chiller

Type	Water-Cooled
Series	STx Series
Model	CH-200x
No.	7
Full Load Rating	200 ton
Fuel Consumption	42.36 m^3/h
Chilled Water Flow	1.81 m^3/min
Physical Data	
Length	4.214 m
Width	1.32 m
Height	2.057 m
Weight	9842 kg

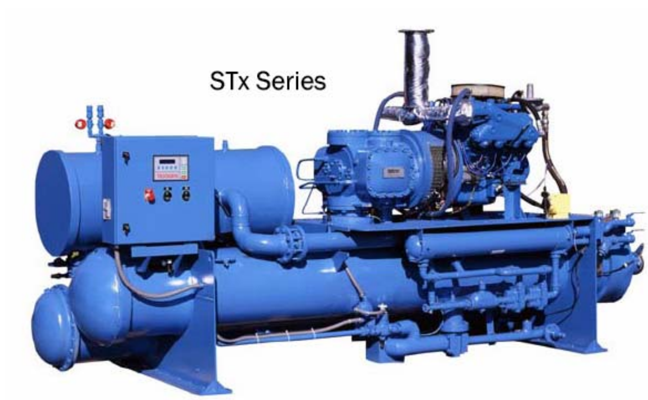


Figure 5.2 Tecogen Chiller

Here five 200 ton (703kW) water-cooled IC engine chillers were selected to meet Palestra's cooling load of 3,291 kW. This size allows for moderately-sized chiller unit, while maintaining high percentage loads, redundancy, and additional cooling capacity that is built into the current design. However with fewer units each weight more than double the original electric units it was important to keep the necessary amount of equipment to a minimum for structural purposes.

Table 5.3 Utility Rates - London, England

Electric	
Day	4.592 p/kWh
Night	2.658 p/kWh
Supply Point Charge	55.88 £/month
Availability Charge	106 p/kVA
Gas	
per unit	1.515 p/kWh
Water	
per unit	88.85 p/m^3
Fixed cost for connection	860 £/year

***p, pence**

The design conditions were inputted in accordance with Table 5.1 and Table 5.3. Due to the fact that Palestra is still under construction the utility rates listed are based on another project of similar size and scope.

Results

Table 5.4 Trace™ Energy Consumption Data

	Original Electric Scheme		Proposed Engine Scheme	
Monthly Energy Consumption	Energy, kWh	Cost, £	Energy, kWh	Cost, £
Electric	20,394,152 kWh	£937,840.56	12,803,427 kWh	£589,274.44
Gas	8,288,669 kWh	£14,622.22	8,182,627 kWh	£14,435.56
Water	--	--	4,285 kL	£11,325.56
Total Monthly Utility Cost		£952,462.78		£615,035.56
Total Yearly Consumption	69,913,486 kWh		47,027,416 kWh	
Life Cycle Cost		**£17,704,689.24**		**£16,163,972.20**

The existing heating and airside systems were integrated with the new chiller plant, and the energy and cost simulation results are summarized in Table 5.4. As compared to the original electric scheme the gas engine driven plant decreased the yearly energy consumption by 33%. There are significant savings in electrical usage, reducing monthly consumption by 7,590,725 kWh and £348,566, which could continue to increase as the price of electricity rises relative to the natural gas rate. On the whole the life cycle costs can be reduced by an additional 8.7%.

Table 5.5 Electric versus IC Engine Chiller Costs

Type	Electric Air-Cooled Screw	Water-Cooled Engine Driven
Cost Per Unit	£51,320.00	£103,625.00
No. Units	7	5
Total Cost	**£359,240.00**	**£518,125.00**

Despite the energy savings, it is important to note the difference in first cost for each system (Table 5.5). While an electric air-cooled screw chiller costs approximately £360,000, an engine driven chiller is almost £520,000. However, the 44% in capital cost is more than accounted for by the energy savings as shown in the Life Cycle Cost reductions.

Overall, the gas-engine driven chiller plant could provide significant savings for both Palestra's owner and tenants. And with the long term energy crisis in the United Kingdom, a gas-based system is a smart choice. The other considerations that should be taken into account are the weight of the new equipment and its structural impact on the building, the increase in acoustic levels due to the engines, and the actual first costs. Many times the Utility or government programs will supplement your initial costs when you select an energy friendly product.

b. **Ventilation Optimization**

i. Proposed Redesign: Dedicated Outdoor Air System with Chilled Beams

Proposed Redesign and Justification

The second proposed design is the installation of a dedicated outdoor air system (DOAS) supplemented with chilled beams throughout the occupied spaces. DOAS not only reduces the ductwork and equipment sizes, but also increases humidity control and reduces energy and first costs. This system meets the latent loads by providing dry outdoor air at low temperatures, while the sensible load is accounted by using the chilled ceiling beams. An additional benefit of this system is the increased indoor air quality. DOAS could prove to solve several of the design challenges that faced the Palestra Building regarding its urban location and lack of humidity controls.

In a 100% outdoor air system such as this the air handling units (AHU) are sized to provide the minimum amount of fresh air required based on function and occupancy of the space. These guidelines are set forth in ASHRAE Standard 62, and those values for Palestra are listed in Table 5.7. In addition an enthalpy wheel is installed in each AHU to maximize heat recovery while also providing excellent humidity control where there currently is none. This equipment will meet all of the building's latent load, and 38% of the sensible load. The remainder of the sensible load will be controlled by chilled beams suspended from the ceiling within the open office spaces, as shown in Figure 5.3.

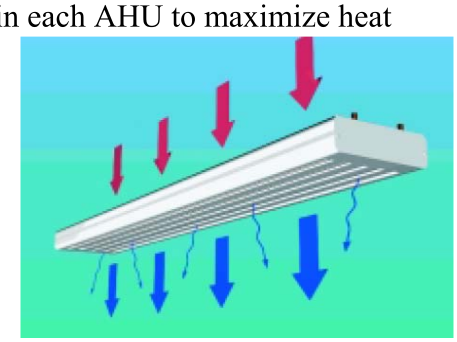
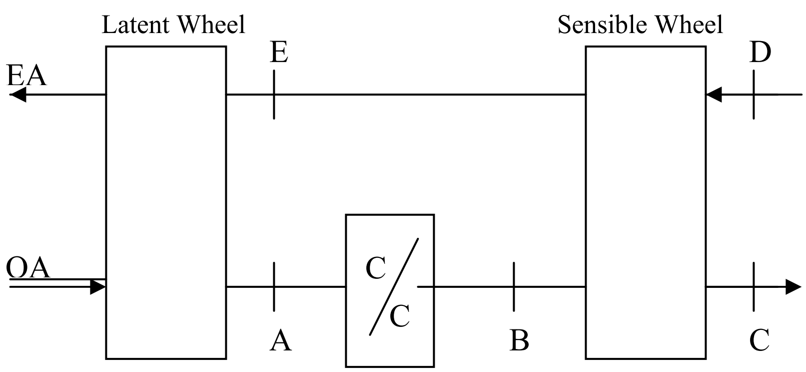


Figure 5.3 Chilled Beam Diagram

The greatest fault with DOAS is the likelihood for condensation to form if the supply air temperature would drop below the dew point of the space. Fortunately in the UK where the weather is quite mild compared to most regions in the United States, the chance of that happening is greatly decreased.

Calculations

Specifying Set points in Office Air Handling Units



Latent Load:

Occupancy = 1100 people per unit

Q_latent = .0586 kW/person

Q_lat = .0586kW*1100 = 64.46kW (220,000 Btu/h)

Outdoor Air Conditions:

Dry Bulb Temperature = 32ºC

Humidity Ratio = 0.015 kg/kg

Space Air Conditions (Point D):

Dry Bulb Temperature = 26ºC

Humidity Ratio = .0093 kg/kg (65 gr/lbma)← moisture content of dry air

Supply Air Temperature: 22ºC

Enthalpy Wheel Selection:

Manufacturer: Novelaire Technologies

Model: ECW1086

Volume Flow Rate = 7644.7 L/s (16200 cfm)

Latent Effectiveness → $\varepsilon_l = 0.76$

Sensible Effectiveness → $\varepsilon_s = 0.79$

Pressure Drop → $\Delta p = 0.74$ inches wg

Face Velocity = 520 sfpm = 2.62 m/s

Design Conditions at Point A:

$W_{OA\text{-}EW} = -\varepsilon_l *(W_{OA} - W_{EA\text{-}SW}) + W_{OA}$

= -(.76)*(0.15 kg/kg– 0.0093 kg/kg) + 0.015 kg/kg

= 0.0107 kg/kg

$DBT_{OA\text{-}EW} = -\varepsilon_s *(DBT_{OA} - DBT_{EW\text{-}SW}) + DBT_{OA}$

= -(.79)*(32ºC – 23.2ºC) + 32ºC

= 25.05ºC

Design Conditions at Point C:

$Q_{latent} = .68*cfm*\Delta W$

$W_{SA} = W_{RA} - (Q_{latent}/(.68*cfm))$

= 65 gr/lbma – (220,000Btu/h/(.68*16200cfm))

=45.03 gr/lbma = 0.00643 kg/kg

$DBT_C = 22$ºC

Design Conditions at Point B:

$W_B = -Q_{latent}/(.68*cfm) + W_{space}$

= (-220,000Btu/h)/(.68*16200cfm) + 65 gr/lbma

= 45.03 gr/lbma = 0.00643 kg/kg

[Check: $W_B = W_C$, correct]

DBT_B = 19.2ºC

Selecting the Number of Chilled Beams Required

The process used to determine the appropriate square footage of chilled beams in the Palestra Building is described in “Ceiling Radiant Cooling Panels as a Viable Distributed Parallel Sensible Cooling Technology Integrated with Dedicated Outdoor Air Systems” by Dr. Stanley A. Mumma and Christopher L. Conroy.

Step 1: Room Design Conditions

Room Dry Bulb Temperature

-Winter: 22°C

-Summer: 26°C

Relative Humidity: 40-60%

Room Dew Point Temperature: 8-17°C

Step 2: Minimum Rate of Heat Removal Required

Figure 5.4 is taken from the afore mentioned published research by Dr. Mumma and Christopher Conroy and describes the rate of heat removal from the conditioned space based on the room’s design dry bulb temperature and relative humidity level.

If 60% RH → 32 W/m^2

If 40% RH → 95 W/m^2

Figure 5.4

Information Pertinent to the CRCP Cooling Selection

Column 1	2	3	4	5	6	7
Room design DBT °F (°C)	Room design % RH	Room design DPT °F (°C)	DOAS supply DPT with 20 scfm/person °F (°C)	Panel t_{fi} room DPT+3°F °F (°C)	Mean panel temp. assuming t_{fi}+5°F °F (°C)	Q_s, Btu/h·ft^2 (W/m^2)
72 (22)	40	46 (8)	37 (3)	49 (9)	54 (12)	30 (95)
72 (22)	60	57 (14)	51 (11)	60 (16)	65 (18)	10 (32)
78 (26)	40	52 (11)	44 (7)	55 (13)	60 (16)	30 (95)
78 (26)	60	63 (17)	58 (14)	66 (19)	71 (22)	10 (32)

Step 3: Calculate Amount of Sensible Cooling Chilled Beams must provide.

Office Area: 31,606m^2

Occupancy: 2202

Combined Sensible Load: 45 W/m^2

Building's Total Sensible Load:

Q_total = 45 W/m^2 * 31,606m^2 = 142,270 W

Outdoor Air Supply: 16 L/s per person

Ventilation Rate:

m_dot = 16 L/s/person*2202 = 35,232 L/s

Sensible Load Met by DOAS:

Q_DOAS = m_dot*Cp*ΔT

Q_DOAS = (35,232L/s)*1.2*(26-13) = 549,619 W

Sensible Load to be met by Chilled Beams:

Q_Beams = Q_total – Q_DOAS = 872,650 W

Step 4: Select Appropriate Chilled Beam

Halton – CLL @ 275 W/m^2 > Minimum Required Rate (32 W/m^2, 95 W/m^2)

Area of Beam Coverage = Q_Beam * Area
= 275 W/m^2 * 31,606 m^2
= 3173.28 m^2
Beam Coverage per Floor = 3173.28 m^2 / 11 = 288.48 m^2

No. Beams per Floor = Floor Beam Area/ Beam Area
= 288.48 m^2 / 4.018 m^2
= 71.80 = **72 Beams per floor**

Total Chilled Beams Needed: 718 Beams

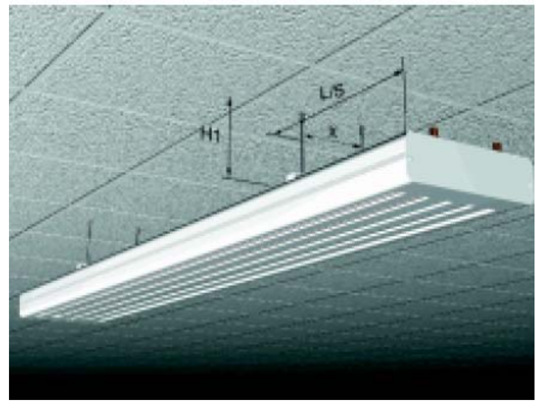


Figure 5.5 Halton CLL Chilled Beam

Table 5.6 Chilled Beam Specification

Brand	Halton
Model	CLL/2- 780-4100; AC=CP/CLL-S,BV
Cooling Capacity	275 W/m^2
Length	4100 mm
Width	780 mm
Height	80 mm

Re-sizing the Air Handling Units

As stated previously, each air handling unit was resized to the minimum outdoor air ventilation required for the type of space each unit serves. That data for each unit is summarized in Table 5.7.

Table 5.7 AHU Resizing

	Original Scheme	Proposed DOAS Scheme	% Difference
AHU -1	18977 L/s	7644.7 L/s	-59.78%
AHU -2	18346 L/s	7600.12 L/s	-58.57%
AHU -3	2332.7 L/s	237.6 L/s	-89.81%
AHU -4	3204 L/s	280.8 L/s	-91.24%
AHU -7	1026 L/s	923.5 L/s	-9.99%

Note that there is a significant decrease in the sizing of Air Handling Units 3 and 4 serving as supply and extract for the toilets. These units were intentionally oversized originally to account for the additional loads that the tenants would install as well. For example, one tenant is planning to install a data center space, and the additional ventilation needs for that area will be accounted for by these units. For the purpose of this report the new AHUs were resized for the existing, permanent load. For actual application, the extra tenant loads should be accounted for.

Results

Table 5.8 Trace™ Energy Consumption Data

	Original Ventilation Scheme		Proposed DOAS Scheme	
Monthly Energy Consumption	Energy, kWh	Cost, £	Energy, kWh	Cost, £
Electric	20,394,152 kWh	£937,840.56	13,608,401 kWh	£626,238.89
Gas	8,288,669 kWh	£14,622.22	1,242,134 kWh	£2,191.11
Water	--	--	--	--
Total Monthly Utility Cost		£952,462.78		£628,430.00
Total Yearly Consumption	69,913,486 kWh		42,136,788 kWh	
Life Cycle Cost		**£17,704,689.24**		**£15,878,842.97**

The new ventilation system was integrated with the existing chiller and boiler plants. The data from the Trace™ simulation is summarized in Table 5.8, with the cost values based on the utility rates noted in Table 5.3. By reducing the size of each air handling unit and replacing the fan coil units with chilled beams the life cycle cost was reduced by 10.31%, saving over 2.7 million kWh annually and £3,888,384.

Table 5.9 Fan Coil versus Chilled Beam First Costs

	Fan Coil Unit Type 1 - Perimeter	Fan Coil Unit Type 2 - Internal	Fan Coil Unit Type 3 - Lobby	Chilled Beam
Cost per Unit	£885.00	£743.00	£743.00	£500.00
No. Units	343	394	22	991
Sub Total	£303,555.00	£292,742.00	£16,346.00	£495,500.00
		Total Cost	**£612,643.00**	**£495,500.00**
		% Savings	**-19.12%**	

*Total Cost denotes first cost excluding installation fees

Table 5.10 AHU First Cost Savings

	Existing AHUs					
	AHU 1	AHU 2	AHU 3	AHU 4	AHU 7	**Total Costs**
Size, L/s	18977	18346	2332.7	3204	1026	
Size, cfm	40041	38710	4922	6760	2165	
Cost per Unit	£85,000.00	£85,000.00	£13,781.00	£13,781.00	£16,700.00	**£214,262.00**

	Proposed AHUs				
	AHU 1	AHU 2	AHU 3+4 (Combined)	AHU 7	
Size, L/s	7644.7	7600.12	518.4	923.5	
Size, cfm	16130	16036	1094	1949	
Cost per Unit	£47,880.00	£47,880.00	£10,845.00	£7,965.00	**£114,570.00**

Tables 5.9 and 5.10 take a look at the savings in First Costs when using reduced Air Handling Units and Chilled Beams versus the existing AHUs with fan coil units. There is a 19% reduction in cost when using a Chilled Beam system versus fan coil units. And there are more significant savings when reducing the Air Handling Units so dramatically, thus reducing the life cycle costs even further.

The benefits of a Dedicated Outdoor Air system are overwhelming for application in the Palestra building, and would be an excellent design alternative. The current constant air volume system with fan coil units isn't terribly different from a pure DOAS, making a future renovation quite feasible.

c. Comparison and Results

Both mechanical design alternatives studied in this report had favorable results to improve both the energy efficiency and economic value of the Palestra Building. The Gas Driven Chiller plant saved over 7 million kWh and 9.54% in Life Cycle costs, while the DOAS design with parallel chilled beams reduced the annual energy consumption by 2.7 million kWh and 9.16% in Life Cycle Costs.

Due to the success of each proposed system, a 'hybrid' design was then simulated in Trace™ as well. This integrated a Dedicated Outdoor Air System and chilled beams with a gas engine driven chiller plant and the existing gas-fired boiler plant. The results of those calculations are summarized in Table 5.11.

Table 5.11 Trace™ Energy Consumption Data

	Original Scheme		Proposed DOAS+Engine Chiller Scheme	
Monthly Energy Consumption	Energy, kWh	Cost, £	Energy, kWh	Cost, £
Electric	20,394,152 kWh	£937,840.56	12,669,017 kWh	£583,102.22
Gas	8,288,669 kWh	£14,622.22	2,770,855 kWh	£4,888.33
Water	--	--	19,061 kL	£14,794.44
Total Monthly Utility Cost		£952,462.78		£602,785.00
Total Yearly Consumption	69,913,486 kWh		40,927,536 kWh	
Life Cycle Cost		**£17,704,689.24**		**£15,899.365.13**

When combined the owners of the Palestra Building could reduce the Life Cycle cost by 10.2% and save over £349,677 a month in energy costs. Over the life span of a building this could be an excellent investment. In addition to the economic benefits there should be improved thermal comfort and humidity control, and opportunities to incorporate new technologies and forms of heat recovery as needed.