BUILDING SERVICES SYSTEM EVALUATION AND DEVELOPMENT

Clara Obeid Sara Motwani
2nd year student MEng Engineering and Architectural Design
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1. INTRODUCTION

This report aims to analyze and develop a strategy for environmental systems in an assigned building. The building aims to provide optimal environmental solutions for the buildings after thoroughly analyzing simulations of the building taking into consideration external and internal building design conditions

2. PERFORMANCE SPECIFICATIONS

The performance specifications for the office areas, multi-use space and café are assessed. Table 1 describes the primary aspects like location and space occupancy that affect performance specifications. Table 2 describes the parameters that effect the internal design conditions as per the values prescribed in the CIBSE Guide A.

Location	**Belfast**		
Purpose	Office Areas	Multi-use Space	Cafe
Occupancy	800	550	150

Table 1. Project Information

Parameter	**Office Area**	**Multi-use space**	**Cafe**
Winter operative temperatures [°C]	**21**-23	**19**-21	**21**-23
Winter Clothing [clo]	0.85	1	1
Summer operative temperatures [°C]	22-**25**	21-**23**	24-**25**
Summer Clothing	0.7	0.65	0.65
Activity Met	1.2	1.4	1.1
Suggested Air Supply Rate [L/s/person]	10	10	10
Illuminance [lux]	300-500	300-500	50-200
Humidity (%)	40-60	40-60	40-60
Noise Criterions			
NR	NR30	NR35	NR35-NR40
dBA (background noise)	35	---	40-45
dBC (background noise)	60	---	65-70
Noise from mechanical and electrical services	NR35	NR40	NR40

Table 2. Performance specifications

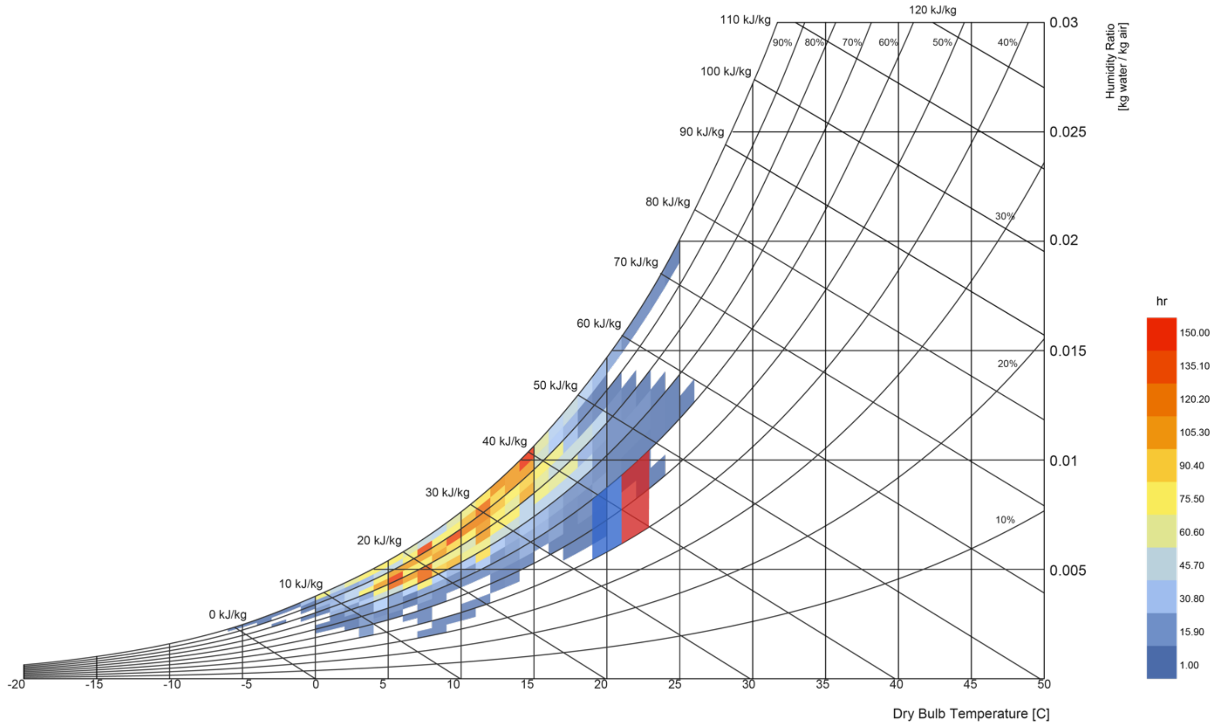


Figure 1. Psychometric Chart showing internal and external conditions for building comfort in Winter(Blue) and Summer (Red)

Considering the performance specifications mentioned above, a psychometric sketch of the boundary conditions is produced for the multi-use space. The outdoor conditions are represented as shown in the key mentioned alongside, the indoor conditions for comfort are represented in blue for the winter and red for the summer for the multi-use space. The indoor 40-60% relative humidity ensures a comfortable indoor environment for a mechanically ventilated space. The chart shows that the external temperatures are lower than required, hence, the cooling loads are likely to be low as fresh air is used to ventilate the space, while a sensible heating design strategy would be implemented throughout the year to achieve comfort.

3. HEATING AND COOLING LOADS

The building fabric for the assigned designed specifications is set-up onto Design Builder. The external envelope comprises of brick insulated walls with reinforced concrete and concrete decking for ground floor, the roof is designed to meet these standards and a glazing of suitable U-value is introduced. The values are taken from the standard 'Approved Document L for buildings other than dwellings' (HM Government, 2010).

Building Element	U-Value (W/m^{2}K)
Walls	0.26
Floor	0.18
Roof	0.18
Glazing	1.6

Table 3. Required U-values of the building elements (Approved Document L for buildings other than dwellings, HM Government, 2010).

The design target for the air permeability of the building envelope has been set as 5 $m^3/(h.m^2)$ at 50 Pa. Instead of converting the air permeability value, the units are modified to $m^3/(h.m^2)$ at 50 Pa on Design Builder, allowing to set the value directly. Setpoint and Setback temperature for environmental control have been set to maintain a 4ºC difference and the auxiliary energy has been set to 25 kWh/m^2.
The baseline HVAC system is a can coil unit (4-pipe) air-cooled-chiller with minimum efficiency standards being 93% efficiency for the heating system seasonal CoP and 4 for the cooling system seasonal CoP according to the Approved Document L for buildings other than dwellings (HM Government, 2010).

The sensible heating loads are considered and compared with the benchmarks as they account for the worst-case scenario (not accounting for latent cooling from occupants, which would reduce the heating load demands). However, the total cooling loads are considered, as they account for latent heat from the occupants and equipment, causing a higher demand in cooling.

The benchmarks for heating and cooling are taken from the BSRIA Rules of Thumb standard (BSRIA's Glenn Hawkins, 2011). The BSRIA standard for a multi-use space was taken to be the same as an office space because of relative similarity in function.

Purpose	**BSRIA Cooling (W/m^2)**	**BSRIA Heating (W/m^2)**	**Area (m^2)**	**Total Cooling Load (W/m^2)**	**Sensible Heating Load (W/m^2)**
Office Space	87	70	1406.25	58.10	4.96
Multi-use Space	87	70	843.75	124.42	1.23
Café	200	100	450	77.18	4.07

Table 4. Comparative table of Heating and Cooling loads with benchmarks in the different spaces

The minimum fresh air rate is set to 0 l/s/p causing heating loads to be extremely low as there is no fresh air intake. The cooling loads are higher than expected by the psychometric chart, which could be due to the high occupancy of the spaces. However, these values are for a baseline simulation prior to the implementation of any design strategy.

4. ANALYSIS OF ACTIVE BUILDING SYSTEMS

In designing an active building system for the office space of the given building, the key performance indicators of the space are initially identified. These include good air circulation, low noise levels, less space requirement, energy efficiency and sustainability. The potential system components are first identified and selected for the office spaces, then combined and assessed as a strategy scheme altogether.

System Components	**Advantages**	**Disadvantages**
Chilled Beams Displacement Ventilation	Minimal maintenance required Silent Operation Good indoor air quality achieved while using less fresh air than conventional systems	Insufficient cooling capacity for spaces with very high heat gains (>160 W/m^2) Ventilation **terminals take large floor and wall space** and is not suitable in areas of constant movement of people

Radiator Biomass Boiler Natural Ventilation	Simple, compact, low maintenance, low noise levels, good temperature control Virtually carbon neutral system	Radiators have a slow thermal response If natural ventilation strategy is poorly designed, it may result in excessive heat loss from radiators
Split System Mechanical Ventilation	Split systems provide complete heating and cooling solutions by providing heating by reversing refrigeration in addition to normal cooling No centralized plant space required Constant, reliable, and controlled air movements	Limited control over air movement in the space Split systems: Low cooling capacity (between 4-30 kW) **High energy consumption**
Variable Air Volume (VAV) Chiller Fan Convector	Good temperature control VAV can be relatively energy efficient due to the ability to adjust the speed of the fan convectors during low/moderate loads. Suitable for multiple zones Good air distribution	High capital, maintenance cost, **space requirement** and potential for **increased noise levels**

Table 5 Executive Comparison of Potential Environmental Systems for Office Space

The selected environmental strategy for the office space is a Radiator, Biomass Boiler and Natural Ventilation. This can be attributed to the fact that it fulfilled the performance indicators specified initially unlike the other systems that failed to meet some essential criterion (highlighted in the disadvantages) which hence were not chosen.

5. PROJECTED ENERGY PERFORMANCE ASSESSMENT

The environmental strategy is implemented in office zones in the model on Design Builder. The chosen HVAC system is closest to Radiator Heating + Boiler HW + Nat Vent strategy available in the Design Builder templates. One must note that the Biomass Boiler chosen in the strategy could not be found in the software, however, this does not affect the energy demand as biomass boilers have the same efficiency as water boilers, hence requiring the same amount of energy. The difference lies in the cost per kWh, and the carbon footprint which is significantly lower for Biomass boilers.

The domestic hot water DHW usually set as default on the software is turned off, as there is no information as to the building benefitting from such a system. Also, the air flow is set as 10L/s/person, as this is the minimum required fresh air intake.

Since we are interested in the fuel consumption of all the office spaces, and the software does not offer a breakdown of consumption per area but rather of the whole building, all the other zones are removed from the model and replaced with adiabatic blocks to isolate the office spaces and analyze the total fuel loads.

The project aims to reach the current operational energy targets and try to approach the 2030 target set by the RIBA 2030 Climate Challenge (RIBA, 2021).

RIBA 2030 suitable outcome metrics	New build, compliance approach	2025 Targets	2030 Targets
Operational Energy	130 kWh/m^2/year	75 kWh/m^2/year	<55 kWh/m^2/year

Table 6. RIBA 2030 Climate Challenge Non-Domestic Building Targets Energy benchmarks

According to the temperature, heat gains and energy consumption analysis from Design Builder:

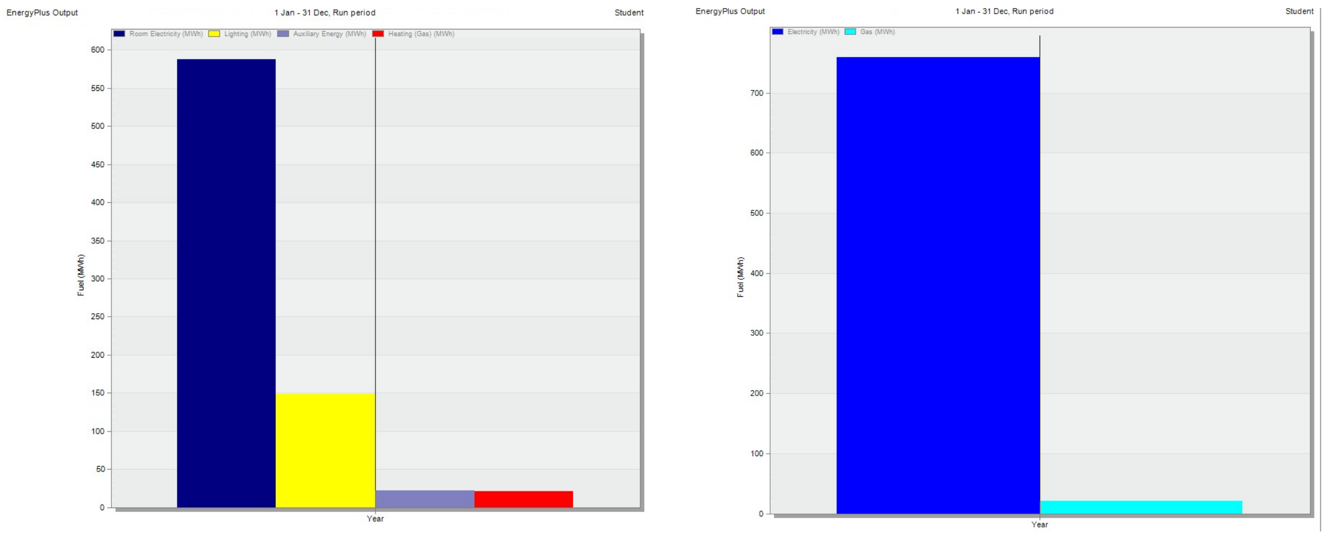


Figure 2. Temperature, Heat Gains and Energy Consumption Analysis of the Office spaces

	Energy Consumption GWh/year	
Use	Electricity	Gas
Room Electricity	588.16	
Lighting	128.75	
Auxiliary Energy	22.12	
Heating (gas)		21.12
Cumulative Energy Consumption	759.03	21.12
Total Energy Consumption	**780.15**	

Table 7. Energy Consumption Results for the Office areas in terms of Electricity and Gas use (GWh) from Design Builder

These values are converted into the required units to compare to the benchmarks mentioned previously, by dividing by the total offices area.

Zones	Area
Singular Office Area	1406.25 m²
All office areas (x5)	7031.25 m²

Table 8. Office Spaces Area

	Energy Consumption kWh/m²/year	
Use	Electricity	Gas
Room Electricity	83.65	
Lighting	18.31	
Auxiliary Energy	3	
Heating (gas)		3
Cumulative Energy Consumption	107.95	3
Total Energy Consumption	**110**	

Table 9. Energy Consumption Results for the Office areas in terms of Electricity and Gas use (kWh/m2/year) from Design Builder

It appears that the energy consumption of the office spaces after the implementation of the environmental strategy meets the current new build, compliance approach benchmark (110 kWh/m2/year<130 kWh/m2/year). However, it does not meet the 2025 benchmark of 75 kWh/m2/year, and since the design should aim to accommodate for future demands, it is vital to assess methods of energy use reduction. Observing the fuel breakdown, it appears that the highest energy load is related to the room electricity, which refers to the room equipment separate to lighting (computers, equipment, process etc). Since equipment schedule is already restricted to the occupancy schedule, it is optimised and can thus not be further reduced. A potential solution would be to use renewable energy to supply the necessary energy for the equipment. Also, the lighting energy demand (18.31 kWh/m2/year) can be reduced by implementing a more efficient lighting scheme, using lighting control, luminaires with lower energy demand, and an optimised use of daylight.

6. ALL-AIR SYSTEM DESIGN

6.1. Heating and Cooling loads

The client has asked for an all-air system to be used in the multi-use room. The psychometric processes are studied, and the selection of the required air handling units (AHU) is carried out.

The indoor temperatures are set from the performance specification in Section 2. The outdoor conditions are taken from the Design Builder weather data file, as the sensible loads are calculated using these same conditions, the calculations would hence yield a more coherent analysis of the all-air system.

	Summer			Winter		
	Temperature °C	Humidity (%)	Humidity Ratio (g/kg)	Temperature °C	Humidity (%)	Humidity Ratio (g/kg)
Indoor Conditions	23	50	8.258	19	50	6.847
Outdoor Conditions	24.9	52.5	10.36	3	80	3.845

Table 10. Indoor and Outdoor conditions of the multi-use room used for psychometric processes

The room sensible loads in winter and summer are obtained from the modelling package.

	Summer	Winter
Design Sensible Loads (kW)	84.2	2

Table 11. Design sensible loads in summer and winter for the multi-use space

It appears that the design will be governed by summer cooling as it requires significantly higher loads.

The latent loads related to occupants and infiltration are calculated, assuming 35W/person of latent loads corresponding to a seating inactive activity and indoor temperature of 23°C in summer, and 25W/person in winter for indoor temperature of 19°C (Taken from Table 6.3, CIBSE Guide A, 2015, (CIBSE, 2015)).
The infiltration of 5 $m^3/(h.m^2)$ at 50 Pa corresponds to 0.25ach for a given space size of 843.75m^2 (Taken from Table 4.16, Ventilation and Infiltration CIBSE Guide A 8th edition, (CIBSE, 2015)).

	Summer	Winter
Occupancy	550 people	
Latent load from people (kW)	19.25	13.65
Latent load from infiltration (kW)	1.25	-1.79
Total Latent loads (kW)	20.5	11.86

Table 12. Latent Loads in summer and winter for the multi-use space

The air mass flowrate is determined, assuming a supply temperature of 15 °C for overhead supply in summer (allowing 8 °C temperature difference between supply and room temperature as per CIBSE Guide B3, Section 3.2, (CIBSE, 2016)), from which the air volume flowrate is calculated.

Air Mass flowrate (kg/s)	10.31
Air Volume flowrate (m^3/s)	8.59

Table 13. Air Mass flowrate and air volume flowrate required for cooling and heating in summer and winter for the multi-use space

The air ventilation requires 10L/sec/person of fresh air. With occupancy of 550 people and volume of 2929.92m^3, this corresponds to 5500L/sec, 6.75 ach, or 19800 m^3/h.

	Summer	Winter
Air volume flowrate required for heating and cooling (m^3/h)	30 924	
Air volume flowrate required for fresh air ventilation (m^3/h)	19 800	

Table 14. Air volume flowrate required for cooling, heating and ventilation in summer and winter for the multi-use space

The apparatus dewpoint temperature is calculated, from which the coil temperature is determined. Indeed, a cooling coil with 4 rows of coil and speed of air passing at 2.5m/s can be assumed to have an effectiveness of 85% at the contact point. As the temperature of the cooling coil is too low to be directly emitted into the room, the air is reheated before being supplied, ensuring user comfort.
The psychometric processes required for the cooling and heating of the space are depicted in the charts below.

The loads are calculated without and with heat recovery, observing the decrease in load demands caused by using mixed air. The necessary amount of fresh air is compared against the flowrate required for heating and cooling, yielding 64% of fresh air to total flowrate required. This means that 36% of the air can be recirculated. The specific enthalpies are determined from the psychometric charts, hence obtaining the loads required by the cooler and heater.

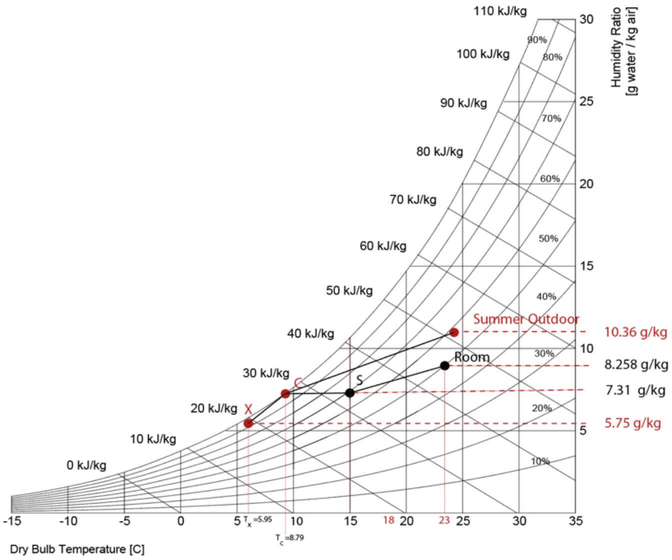


Figure 4. Summer design psychometric process without heat recovery

Cooler duty (kW)	223
Reheater duty (kW)	42.2
Total load (kW)	265.2

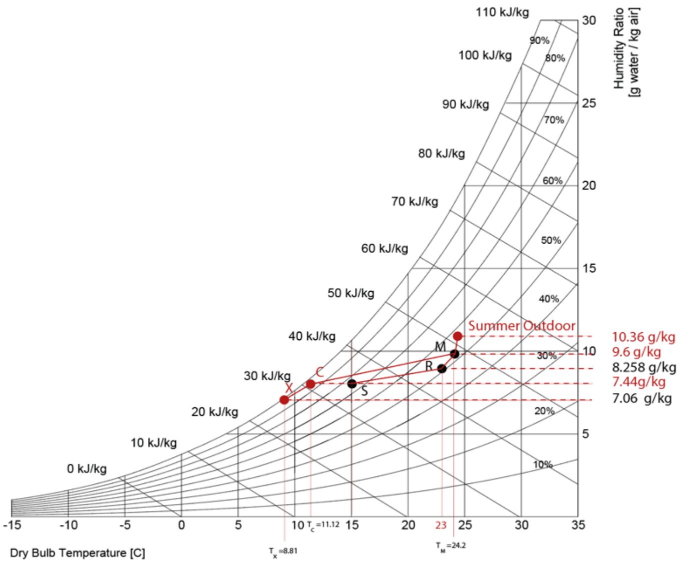


Figure 3. Summer design psychometric process with heat recovery

Cooler duty (kW)	194
Reheater duty (kW)	40
Total load (kW)	235

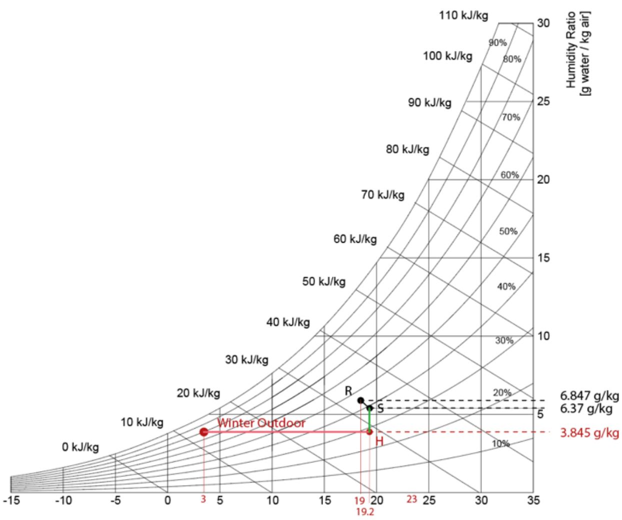


Figure 5 Winter design psychometric process without heat recovery

Heater duty (kW)	165
Humidifier duty (kW)	30.9
Total load (kW)	195.9

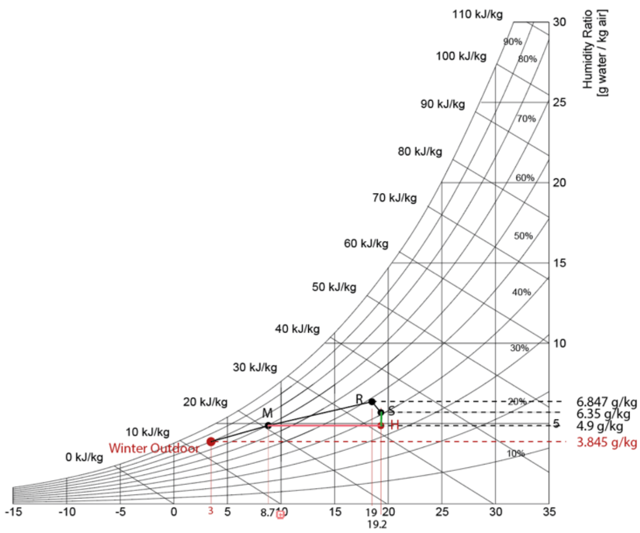


Figure 6. Winter design psychometric process with heat recovery

Heater duty (kW)	113.5
Humidifier duty (kW)	36
Total load (kW)	149.5

As expected, the cooler duty is more significant than the heater duty. The total loads decrease as the air is reused, requiring a total load of 235kW for cooling and 149.5kW in heating with heat recovery.

6.2 AHU Selection

The AHU selection is governed by the highest air volume flowrate required, corresponding to the cooling and heating loads (30924m^3/h) (Table 4).
Looking at the catalogue from SWEGON (SWEGON, n.d.), since the maximum air flow handled by an AHU corresponds to 14000 m^3/h, the space will require 3 AHU of capacity 10000 m^3/h. This capacity is achieved by the GOLD size 32 AHU.

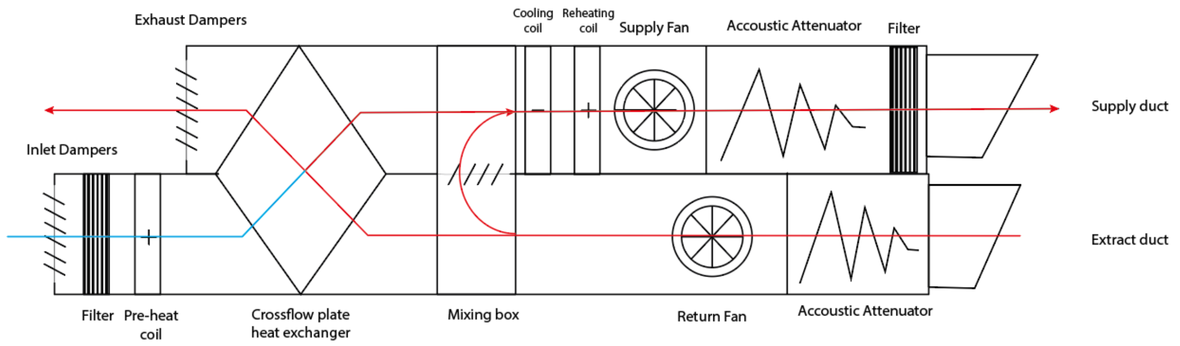


Figure 7 Selected AHU system design

Panel Filters are used as gross filters to protect downstream mechanical equipment in AHU and remove coarser particles. Medium efficiency bag filters are used to ensure good air quality for occupants.

Crossflow plate heat exchangers are used as heat recovery system since they cause no cross-contamination, are easily cleaned, have no moving parts, with a 50-80% efficiency of recovery, pressure drop varying from 25 to 370 Pa, and can be controlled by bypass.

Demand-controlled ventilation strategies such as CO2 detectors are implemented, reducing the energy use related to ventilation.

Hot water-based heating coil is used because the system already requires a boiler. Being in the north of the UK the AHU TBLA Air heater for hot water includes a thermo guard, protecting the unit from frost.

TBKC Air cooler is used (direct expansion, refrigerant cooling) since it will not require a separate chiller system. The air cooler has 4 rows of cooling coil with corresponding effectiveness of 85%, with two sections allowing for a better control of the flow.

The following data is extracted from the GOLD air handling system Complements and accessories Catalogue (SWEGON, n.d.).

According to the specifications and design of the AHU mentioned above, the sizing and pressure drop of the AHU is determined.

B (mm)	H (mm)	L (mm)	Weight (kg)	Clear space above the junction hood (mm)	Clear space in front of the unit (mm)
1185	1885	2300	1104	50	800

Table 15. Dimensions and space requirements of the Gold 32 AHU

AHU Gold 32		B (mm)	H (mm)	L (mm)	R (mm)		Weight
Air Heater with Thermo Guard		1578	715	310	25		49
TKBC Air cooler (direct expansion)	4 tube rows 2sections	1850	950	500	28	33	143

Table 16. AHU complements and accessories specifications

Air flow m^3/h	10,800
Damper TBSA-1-120-060-b-c	23 Pa
V Carbon filter TBFK-2-13700	93 Pa
Air heater, hot water TBLA-2-120-060-1-ccc With Thermoguard	76 Pa
Air cooler, direct expansion TBKC-120-060-4-c	59 Pa
Silencer TBDA-1-120-060-065	35 Pa
Hood TBHA-1-0909, outdoor air	34 Pa
Outdoor installation TBTA-1-30-2, ext air section	17 Pa
Crossflow plate heat exchangers	50 Pa
Total pressure drop (Pa)	387 Pa

Table 17. Air Handling Unit Pressure Drop

6.3. Duct Sizing

The duct sizing is computed using the constant pressure-drop method. The ducts decided to be used are rectangular ducts A suitable number of diffusers is selected keeping in mind the air volume flowrate.

Air Volume Flowrate (m^3/s)	8.59
No. of AHU	3
Air Volume Flowrate per AHU (m^3/s)	2.86

No. of Diffusers	21
Air Volume Flowrate per Diffuser (m^3/s)	0.41

Table 18. Air Volume Flow Rate Specifications for Duct Sizing

The position of the air diffusers is configured looking at the air volume flowrates and the typical throw distance of referenced diffusers (Waterloo, n.d.). They are arranged to avoid an overlap of diffuser throws to prevent any risk of down-drought. The extracts are designed and placed to insure maximum circulation in the space. *(Figure 8)*

Diffuser Type	Louvered Face Diffusers (DF DE core 41)
Total Pressure Drop (Pa)	9
Dimensions (mm)	525 x 525
Throw (m)	2

Table 19. Diffuser Specifications for Multi-use Space

The dimensions of each ducting section are decided taking into consideration the flowrate through each section. The diameter of a circular duct is obtained from Figure 4.2, CIBSE Guide C and converted to the dimensions of an equivalent rectangular duct using Table 4.16, CIBSE Guide C (CIBSE, 2007). Consequently, the velocity and pressure drop per unit length through each section is determined. *(Refer to Appendix 1)*

The dimensions of the ducts have been selected in keeping a constant height and varying width with the maximum allowable pressure drop of 1 Pa/m and velocities under 7.5 m/s (Table 4.16, CIBSE Guide C (CIBSE, 2007)) to satisfy the typical noise rating of NR 40 for a multi-use space as mentioned in the performance specifications.

The total pressure loss through each section is determined by adding pressure drops through each fitting in the section (in this case straight lengths and 90° elbow fittings), the discharge to space (pressure drop through the diffusers) and the velocity head which are given by:

Straight Length

$$\Delta P = L * \Delta P/l$$

Elbow Fitting

$$\Delta P = \zeta * \frac{1}{2} \rho v^2$$

Velocity Head

$$P_v = \frac{1}{2} \rho v^2$$

where,
L - Length of section
$\Delta P/l$ - Pressure drop per unit length of section
ζ – Pressure loss factor (obtained from h/w aspect ratio) from Table 4.115 CIBSE Guide C.
ρ – Density of air (taken 1.2 kg/m^3)
v – velocity through the section
(Refer to Appendix 2)

Section Index	Length L (m)	Cross Section w*h (mm)	Flow Rate q (m^3/s)	Velocity v (m/s)	Total Pressure Loss ΔP (Pa)
1	14.57	800 x 500	2.86	7.16	127.70
2	4.8	750 x 500	2.45	6.54	38.02
3	4.8	750 x 500	2.05	5.45	29.17
4	4.8	600 x 500	1.64	5.45	29.51
5	4.8	550 x 500	1.23	4.46	22.85
6	4.8	350 x 500	0.82	4.67	24.92
7	4.8	200 x 500	0.41	4.09	22.40
8	20.3	800 x 500	2.86	7.16	132.28
9	4.8	750 x 500	2.45	6.54	38.02
10	4.8	750 x 500	2.05	5.45	29.17
11	4.8	600 x 500	1.64	5.45	29.51
12	4.8	550 x 500	1.23	4.46	22.85
13	4.8	350 x 500	0.82	4.67	24.92
14	4.8	200 x 500	0.41	4.09	22.40
15	26.2	800 x 500	2.86	7.16	137.00
16	4.8	750 x 500	2.45	6.54	38.02
17	4.8	750 x 500	2.05	5.45	29.17
18	4.8	600 x 500	1.64	5.45	29.51
19	4.8	550 x 500	1.23	4.46	22.85
20	4.8	350 x 500	0.82	4.67	24.92
21	4.8	200 x 500	0.41	4.09	22.40

Table 20. Ductwork Section Assigned Dimensions and Total Pressure Loss

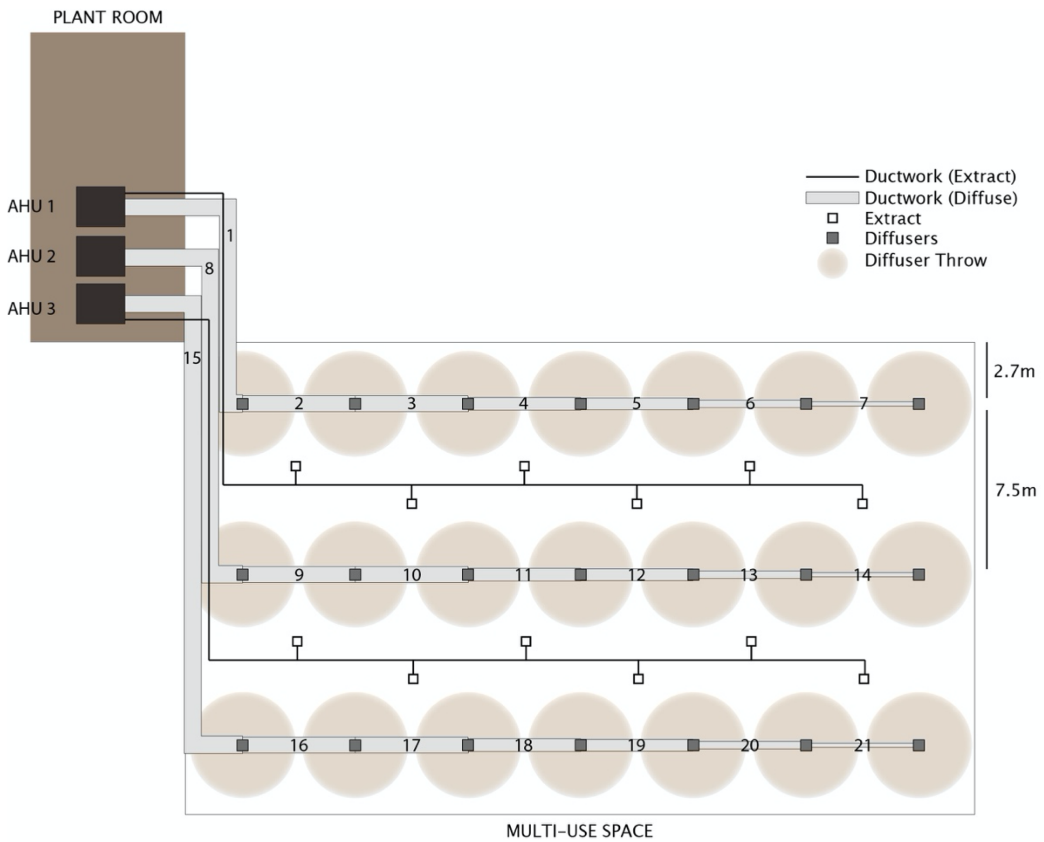


Figure 8 Ductwork Design of Multi-use Space

The index run for each circuit is calculated and the largest value of the total pressure loss is recorded. *(Refer to Appendix 3)*

Index Run Total Pressure Loss (Pa)	303.88

6.4. Fan Sizing

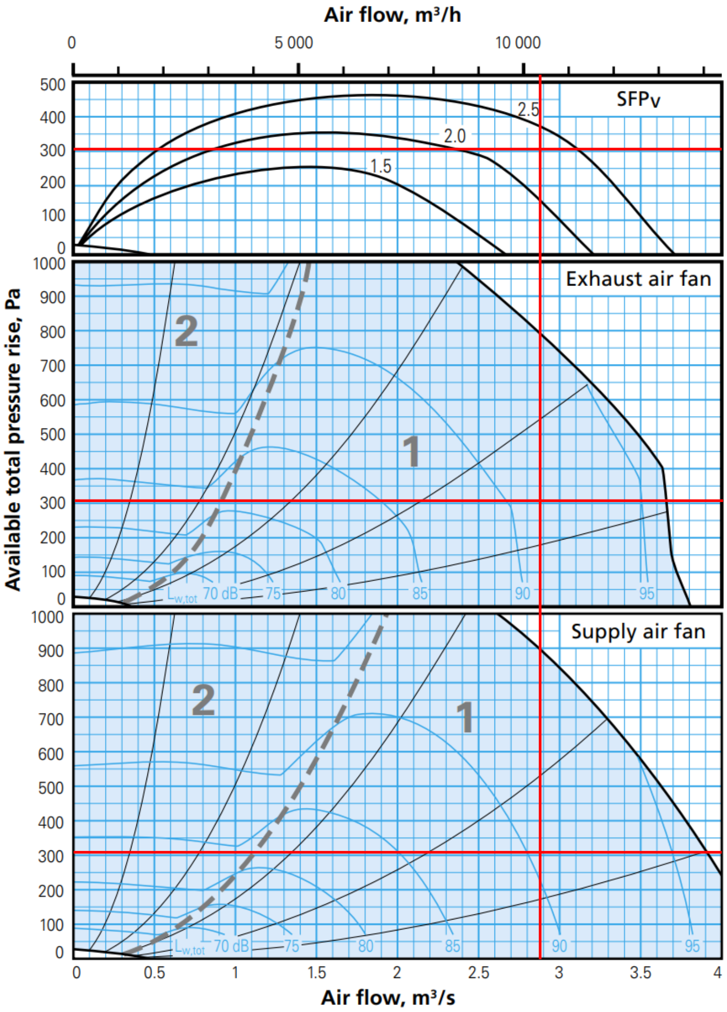


Figure 9. Total pressure - Air flow graph for Fan Sizing

The above shown figure for an AHU specified as GOLD Size 32 is used to determine the fan type to be used in the system. It uses the total pressure loss calculated from the index run (303.88 Pa) and the air volume flowrate per AHU (2.86 m^3/s) plotted in red. The intersections for both the supply and exhaust air fan appears to be within the darker region of the graph which indications that the AHU fans can withstand the index run pressure loss, and hence subsequently all smaller losses for the given flowrate. It is also noteworthy that both fans are under category '1' which indicates an acoustic advantage. The SFP_v (specific fan power) value appears to be between 2.0 and 2.5 W/l.s which is in fact between the SFP values of new buildings (2.0 W/l.s) and existing buildings (2.6 W/l.s).

7. LIGHTING DESIGN

Type of Lighting	$\bar{E}_m$ [lux]	UGR_L	U_0	R_a
General Lighting	300	22	0.40	80

Table 21. Lighting recommendation for places of public assembly - Trade fairs, exhibition halls taken from the BS Light and lighting. Lighting of workplaces (British Standards Institution BSI, 2021)

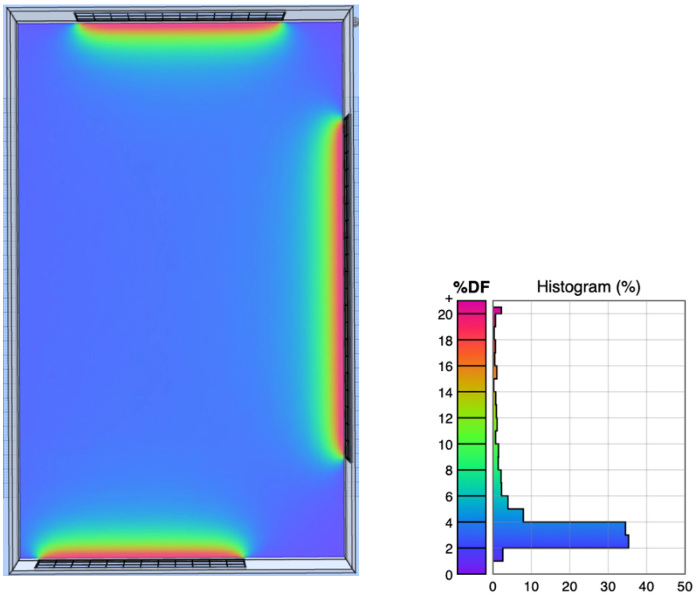
$\bar{E}_m$= Maintained illuminance on major surfaces [lux]
UGR_L= Unified Glare Rating
U_0= Illuminance uniformity
R_a= Colour Rendering Index

The type of lighting implemented within the multi-use space are Recessed LED display luminaires by Thorlux (Thorlux, n.d.). This lighting scheme was chosen as they are adjustable downlighter luminaires, with anti-glare reflector bezel. LEDs are chosen due to their energy efficiency, low radiated heat, and high level of brightness. The downlight was chosen as the spaced is used as an exhibition or lecture hall. Hence, the focus must be pointed towards the speaker or the exhibits rather than illuminating an entire working plane. Furthermore, the adjustability is essential in adapting to different activities within the space. The luminaire has appropriate lighting capacity of 3075-3305lm with 35W power capacity. Also, it, has a long lifetime expectancy of 50,000 hours, providing light of colour temperatures 3000K or 4000K associated with warm-neutral colours. It possesses a high colour rendering index CR90; as the area can be used as an exhibition space, it is important for the light to enable to experience valid and appropriate colour sensation.

Important considerations in the lighting scheme also include head-height cylindrical illuminance – As face-to-face communication is important in launches, exhibitions, and conferences, it is important for the lighting ratio between vertical and horizontal illuminance at head height to be considered, making facial features appear clearly and normally.

In terms of lighting control, the luminaires are controlled by motion sensors and daylight controls with manual override. This minimizes energy use, while allowing for occupants to control the lighting when necessary.

However, daylight is always prioritized and preferred, due to user satisfaction, enhanced performance and productivity, energy saving. Hence, daylight analysis is carried out.



	Min	Average	Max
Daylight Factor	1.4%	**4.7%**	23.9%

Figure 10 Daylight factor analysis and Average daylight factor calculation

To calculate the energy performance of the lighting scheme, the Lighting Energy Numeric Indicator (LENI) is carried out using the Energy performance of buildings – Energy requirements for lighting standard (EPB) (European Standard, 2017). For the typical office schedule, using the lighting scheme described above, the value corresponds to 6.64kWh/ m^2 per year. This is below the recommended maximum LENI of 12.79 kWh/ m^2 per year in new and existing buildings for 300 lux illuminance and 2500 total hours, according to the Non-Domestic Building Services Compliance Guide (HM Government, 2013).

8. ACOUSTIC DESIGN

This section addresses the acoustic properties of the multi-use space. In a typical acoustic study of a space the most important criteria are reverberation, speech intelligibility and clarity, loudness, diffusion, echo and focus, and background noise. This study only addresses the reverberation time of the space.

The reverberation time (RT) is the time required for the sound in a room to decay over a specific dynamic range, usually taken to be 60 dB, when the sound source is interrupted. The Sabine formula relates the RT to the room properties, referring to the sound absorption coefficients of the internal surfaces (Appendix 4).

$$RT_{60} = \frac{0.16V}{A}$$

Where V is the volume of the room [m^3]

A is the total absorption in the room [m^2sabins] and is defined as: $A = \sum \alpha_i * S_i$ where α_i is the absorption coefficient of a surface in the room [sabins] and S_i is the area of the surface [m^2].

The reverberation time is calculated over frequencies from 125Hz to 4000Hz.

Types of space	Opera Theatres/Concert halls for light music	Speech Auditoria/ Large Lecture Halls	Assembly Halls
RT60 (seconds)	1.00 -1.70	0.40 - 1.00	0.80 -1.00

Table 22. Target Reverberation Times RT60 for a different types of space use (Resonics, 2020) (Designingbuildings.co.uk, 2013)

The design aims to obtain a reverberation time of 1 second, as it is the average target value of reverberation time for the different types of uses of the multi-use room.

Parameter	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
Total Absorption of room surfaces [m^2 Sabins]	397.3	429	426.5	463	490.6	477.7
Volume of room [m^3]	3037.5					
RT60 (seconds)	1.22	1.13	1.14	1.05	0.99	1.02
Average RT60 (seconds)	1.09					

Table 23 Reverberation Time of the multi-use space for 6 frequency bands across 125Hz- 4kHz using Sabine's Method

The average reverberation time of the multi-use space (1.09s) meets the design criteria set for the different activities of the space.

9. CONCLUSION

This report covers the baseline environmental analysis of a given building and develop and suitable active building strategy. However, there is scope for improvement and further development from what is already discovered in this report. Firstly, there was a sense of ambiguity when researching for performance specifications and load standards for a multi-use space due to diminutive information for this specific space so a single space with similar function was assumed. This could have been improved by looking at several different spaces with similar function and taking ballpark values. In selecting an active environmental system for the office space and modelling it in DesignBuilder, options of different system combinations was limited. The lighting scheme designed could have been further analyzed in DesignBuilder to observe changing load demands and similarly, acoustics could be modelled in ISIMPA or an alike software.

10. WORK PLAN

Date	Time Planned	Areas Covered	Tasks	Execution Evaluation
18/02/22	2 h	• Work Plan	Brief read, Work Plan for project devised assessing various sections and the time to complete the requirements	All tasks were completed. The initial work plan was very altered, and further steps ahead were less planned than at the beginning.
19/02/22	4 h	• Performance Specifications • Psychometric Sketches	Defining internal environment, gathering information from the standards and tables, producing psychometric sketches for internal comfort (comparing target values for internal with external environmental conditions)	The research of the performance specifications took longer than expected due to the uncertainty regarding the multi-use space and its benchmarks.
24/02/22 - 04/04/22	6 h	• Design Builder Model	Defining building fabric, internal-external conditions and setting occupational hours in the software	Defining the conditions of the model were gone through multiple times as some parameters were sometimes omitted and necessary to alter, such as running the baseline model with 0l/s/person fresh air.
26/02/22	6 h	• Heating and Cooling Loads	Running design builder simulation and analysing the results	Running the simulation and the analysis of the result was straightforward.
26/03/22 - 27/03/22	10h	• Lighting Scheme	Defining lighting scheme, calculating daylight factor, and calculating the LENI	The process was straightforward. The research of the possible lighting schemes were the most time consuming, as there was no guide about specifications of the luminaires in different spaces and had to seek for information from providers directly.
26/03/22	5h	• Acoustics design	Calculating the reverberation time of the multi-use space	This step was straightforward, however, it took time to find the appropriate benchmarks for a space with such different uses, as well as to reach the required RT60 with the dimensions of the room.
02/03/22 - 06/04/22	20 h	• Executive comparison of active	Listing and assessing different active environmental systems, drawing comparisons, choosing the best option	This process took significantly longer than expected, and was accorded too much time to complete.

		environmental systems		The initial approach was comparing all the systems available then selecting the ones applicable to the spaces and then combining them to provide a system combination.
03/04/22 - 07/04/22	20 h	• All-Air System design	Calculating the heating and cooling loads of the all air system Selecting the AHU required Duct Sizing and Fan sizing	The process was very time consuming. The loads were computed many times, causing the ducting scheme to be redesigned. The ducting scheme was also time consuming and not as straightforward.
06/04/22	10 h	• Applying chosen system to Design Builder	Selecting and justifying the input data, comparing the calculated energy performance against appropriate benchmarks, exploring significant differences	The process was redone twice, as the approach initially taken was deemed wrong.
06/04/22	5h	• Report edit and formatting	Rewriting parts of the report, revisiting sections	The report was written as each step was carried out. However, some missing points were added on as touch ups were needed. This seemed like a successful approach in writing up the report.
07/04/22	30mins	• Referencing	Referencing sources and guides	This process was quick and straightforward.
07/04/22	1h	• Confirmation of authorship	Writing up the statement confirming each author's contribution to the paper.	

Overall, the report exceeded the time expected by a great margin.
The original workplan was not met, the expected dates to complete the report were surpassed and delayed due to deadlines in other modules.
The time schedule and separation of tasks could be significantly improved, as there was not enough organization and strictness with respect to the timetable. The outcome is however satisfactory, and all the points mentioned in the brief were addressed.

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12. APPENDIX

Section	Length (m)	q (m^3/s)	Diameter (mm)	Rectangular duct w × h (mm)	v (m/s)	ΔP/l (Pa/m)	Pressure
	4.85	2.86	693.00	800 x 500	7.16	0.80	3.88
	9.30	2.86	693.00	800 x 500	7.16	0.80	7.44
1.00	0.42	2.86	693.00	800 x 500	7.16	0.80	0.34
2.00	4.80	2.45	672.00	750 x 500	6.54	0.70	3.36
3.00	4.80	2.05	672.00	750 x 500	5.45	0.49	2.35
4.00	4.80	1.64	603.00	600 x 500	5.45	0.56	2.69
5.00	4.80	1.23	577.00	550 x 500	4.46	0.40	1.92
6.00	4.80	0.82	459.00	350 x 500	4.67	0.59	2.83
7.00	4.80	0.41	341.00	200 x 500	4.09	0.70	3.36
	4.00	2.86	693.00	800 x 500	7.16	0.80	3.20
	15.00	2.86	693.00	800 x 500	7.16	0.80	12.00
8.00	1.30	2.86	693.00	800 x 500	7.16	0.80	1.04
9.00	4.80	2.45	672.00	750 x 500	6.54	0.70	3.36
10.00	4.80	2.05	672.00	750 x 500	5.45	0.49	2.35
11.00	4.80	1.64	603.00	600 x 500	5.45	0.56	2.69
12.00	4.80	1.23	577.00	550 x 500	4.46	0.40	1.92
13.00	4.80	0.82	459.00	350 x 500	4.67	0.59	2.83
14.00	4.80	0.41	341.00	200 x 500	4.09	0.70	3.36
	3.20	2.86	693.00	800 x 500	7.16	0.80	2.56
	20.80	2.86	693.00	800 x 500	7.16	0.80	16.64
15.00	2.20	2.86	693.00	800 x 500	7.16	0.80	1.76
16.00	4.80	2.45	672.00	750 x 500	6.54	0.70	3.36
17.00	4.80	2.05	672.00	750 x 500	5.45	0.49	2.35
18.00	4.80	1.64	603.00	600 x 500	5.45	0.56	2.69
19.00	4.80	1.23	577.00	550 x 500	4.46	0.40	1.92
20.00	4.80	0.82	459.00	350 x 500	4.67	0.59	2.83
21.00	4.80	0.41	341.00	200 x 500	4.09	0.70	3.36

Appendix 1. Determining Duct Dimensions, Air Velocity and Pressure drop per unit length

SECTION 1											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	2.86	693.00	800 x 500	0.40	14.57	0.80			7.16		11.66
Elbow at 90 Degree							0.63	1.24	7.16	30.76	38.14
Elbow at 90 Degree							0.63	1.24	7.16	30.76	38.14
Discharge to Space											9.00
Velocity Head									7.16	30.76	30.76
Total ΔP											127.70

SECTION 2											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	2.45	672.00	750 x 500	0.38	4.80	0.70			6.54		3.36
Discharge to Space											9.00
Velocity Head									6.54	25.66	25.66
Total ΔP											38.02

SECTION 3											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	2.05	672.00	750 x 500	0.38	4.80	0.49			5.45		2.35
Discharge to Space											9.00
Velocity Head									5.45	17.82	17.82
Total ΔP											29.17

SECTION 4											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	1.64	603.00	600 x 500	0.30	4.80	0.56			5.45		2.69
Discharge to Space											9.00
Velocity Head									5.45	17.82	17.82
Total ΔP											29.51

SECTION 5											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	1.23	577.00	550 x 500	0.28	4.80	0.40			4.46		1.92
Discharge to Space											9.00
Velocity Head									4.46	11.93	11.93
Total ΔP											22.85

SECTION 6											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	0.82	459.00	350 x 500	0.18	4.80	0.59			4.67		2.83
Discharge to Space											9.00
Velocity Head									4.67	13.09	13.09
Total ΔP											24.92

SECTION 7											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	0.41	341.00	200 x 500	0.10	4.80	0.70			4.09		3.36
Discharge to Space											9.00
Velocity Head									4.09	10.04	10.04
Total											22.40

SECTION 8											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	2.86	693.00	800 x 500	0.40	20.30	0.80			7.16		16.24
Elbow at 90 Degree							0.69	1.24	7.16	30.76	38.14
Elbow at 90 Degree							0.69	1.24	7.16	30.76	38.14
Discharge to Space											9.00
Velocity Head									7.16	30.76	30.76
Total ΔP											132.28

SECTION 9											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	2.45	672.00	750 x 500	0.38	4.80	0.70			6.54		3.36
Discharge to Space											9.00
Velocity Head									6.54	25.66	25.66
Total ΔP											38.02

SECTION 10											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	2.05	672.00	750 x 500	0.38	4.80	0.49			5.45		2.35
Discharge to Space											9.00
Velocity Head									5.45	17.82	17.82
Total ΔP											29.17

SECTION 11											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	1.64	603.00	600 x 500	0.30	4.80	0.56			5.45		2.69
Discharge to Space											9.00
Velocity Head									5.45	17.82	17.82
Total ΔP											29.51

SECTION 12											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	1.23	577.00	550 x 500	0.28	4.80	0.40			4.46		1.92
Discharge to Space											9.00
Velocity Head									4.46	11.93	11.93
Total ΔP											22.85

SECTION 13											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	0.82	459.00	350 x 500	0.18	4.80	0.59			4.67		2.83
Discharge to Space											9.00
Velocity Head									4.67	13.09	13.09
Total ΔP											24.92

SECTION 14											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	0.41	341.00	200 x 500	0.10	4.80	0.70			4.09		3.36
Discharge to Space											9.00
Velocity Head									4.09	10.04	10.04
Total											22.40

SECTION 15											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	2.86	693.00	800 x 500	0.40	26.20	0.80			7.16		20.96
Elbow at 90 Degree							0.69	1.24	7.16	30.76	38.14
Elbow at 90 Degree							0.69	1.24	7.16	30.76	38.14
Discharge to Space											9.00
Velocity Head									7.16	30.76	30.76
Total ΔP											137.00

SECTION 16											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	2.45	672.00	750 x 500	0.38	4.80	0.70			6.54		3.36
Discharge to Space											9.00
Velocity Head									6.54	25.66	25.66
Total ΔP											38.02

SECTION 17											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	2.05	672.00	750 x 500	0.38	4.80	0.49			5.45		2.35
Discharge to Space											9.00
Velocity Head									5.45	17.82	17.82
Total ΔP											29.17

SECTION 18											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	1.64	603.00	600 x 500	0.30	4.80	0.56			5.45		2.69
Discharge to Space											9.00
Velocity Head									5.45	17.82	17.82
Total ΔP											29.51

SECTION 19											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	1.23	577.00	550 x 500	0.28	4.80	0.40			4.46		1.92
Discharge to Space											9.00
Velocity Head									4.46	11.93	11.93
Total ΔP											22.85

SECTION 20											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	0.82	459.00	350 x 500	0.18	4.80	0.59			4.67		2.83
Discharge to Space											9.00
Velocity Head									4.67	13.09	13.09
Total ΔP											24.92

SECTION 21											
Fitting	q (m^3/s)	d (mm)	w*h (mm)	A (m^2)	L (m)	ΔP/l (Pa/m)	Aspect Ratio	Pressure Loss factor	v (m/s)	Velocity Pressure Pv	ΔP (Pa)
Straight Length	0.41	341.00	200 x 500	0.10	4.80	0.70			4.09		3.36
Discharge to Space											9.00
Velocity Head									4.09	10.04	10.04
Total											22.40

Appendix 2 Total Pressure Loss Calculations for Sections 1-21

INDEX RUN DUCT 1		
Circuit Index	Sections	ΔP (Pa)
Circuit 1	1,2	165.72
Circuit 2	1,2,3	194.90
Circuit 3	1,2,3,4	224.40
Circuit 4	1,2,3,4,5	247.26
Circuit 5	1,2,3,4,5,6	272.18
Circuit 6	1,2,3,4,5,6,7	294.57
INDEX RUN DUCT 2		
Circuit Index	Sections	ΔP (Pa)
Circuit 1	8,9	170.31
Circuit 2	8,9,10	199.48
Circuit 3	8,9,10,11	228.99
Circuit 4	8,9,10,11,12	251.84
Circuit 5	8,9,10,11,12,13	276.76
Circuit 6	8,9,10,11,12,13,14	299.16
INDEX RUN DUCT 3		
Circuit Index	Sections	ΔP (Pa)
Circuit 1	15,16	175.03
Circuit 2	15,16,17	204.20
Circuit 3	15,16,17,18	233.71
Circuit 4	15,16,17,18,19	256.56
Circuit 5	15,16,17,18,19,20	281.48
Circuit 6	15,16,17,18,19,20,21	303.88

Appendix 3 Index Run for Ductwork System

Element	Area [m^2]	Material	Absorption Coefficients					
			125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
Walls	307.2	Plaster Gypsum	0.01	0.02	0.02	0.03	0.04	0.05
Ceiling	843.75	Plasterboard 12mm in suspended ceiling grid	0.15	0.11	0.04	0.04	0.07	0.08
Floor (no seat)	293.75	Wooden Parquet	0.04	0.04	0.07	0.06	0.06	0.07
Seats Occupied	550	Cushioned Seats and Backs, 2/3 occupied	0.44	0.56	0.65	0.72	0.72	0.67
Doors	6	Solid Wood Panels	0.35	0.39	0.44	0.49	0.54	0.57
Windows	118.8	Double Glazed 2-3mm glass 10mm gap	0.1	0.07	0.05	0.03	0.02	0.02

Appendix 4. Table showing the various elements within the multi-use space, their surface area, material and absorption coefficients

13. AUTHORS CONTRIBUTION

This report was carried out by Clara Obeid and Sara Motwani, the following sections were addressed by:

Clara Obeid	**Sara Motwani**
Performance Specifications	Introduction
Design Builder Model	Internal Conditions Psychometric charts
Projected energy performance of the system	Heating and Cooling loads
All-air system heating and cooling loads	Comparison of the environmental systems
Psychometric Processes of the AHU	Ducted System Design
Air handling unit selection	Ductwork Index Pressure Loss
Lighting Scheme	Fan Sizing
Acoustic Design	Conclusion
General formatting and editing	General formatting and editing
References	Workplan
Workplan	
Authors Contribution	