BUILDING SERVICES SYSTEM EVALUATION AND DEVELOPMENT

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BACR0167 Environmentally Responsible Building System
Academic Year 2020 – 2021

INTRODUCTION

This report aims at advising on the building service system for a project required by our client. The project is a concept modular building located at Elmdon Park, Birmingham, with South-facing glazing in the meeting space and North-facing glazing in the office space. There is an estimated number of 100 occupants in the presentation module.

I. MODULES

1. *Modules – Dimensions, Adjacency*

Referencing occupancy density of suitable categories in ASHRAE 90.1 and 62.1 (2007), below is a summary of approximation of module sizes.

	occupancy density (people/m^2)	occupancy density (m^2/person)	no. of occupants	area taken (m^2)	Estimation of area of sapce (m^2)
Community	1.61	0.62	~150	150	
Open plan office	0.054	18.5	10	185	190
Meeting	0.54	1.85	10	18.5	20
Artefact	0.43	2.33	15	20	
Presentation	0.7	1.43	100	143	150

Table 1. Design conditions of modulesw

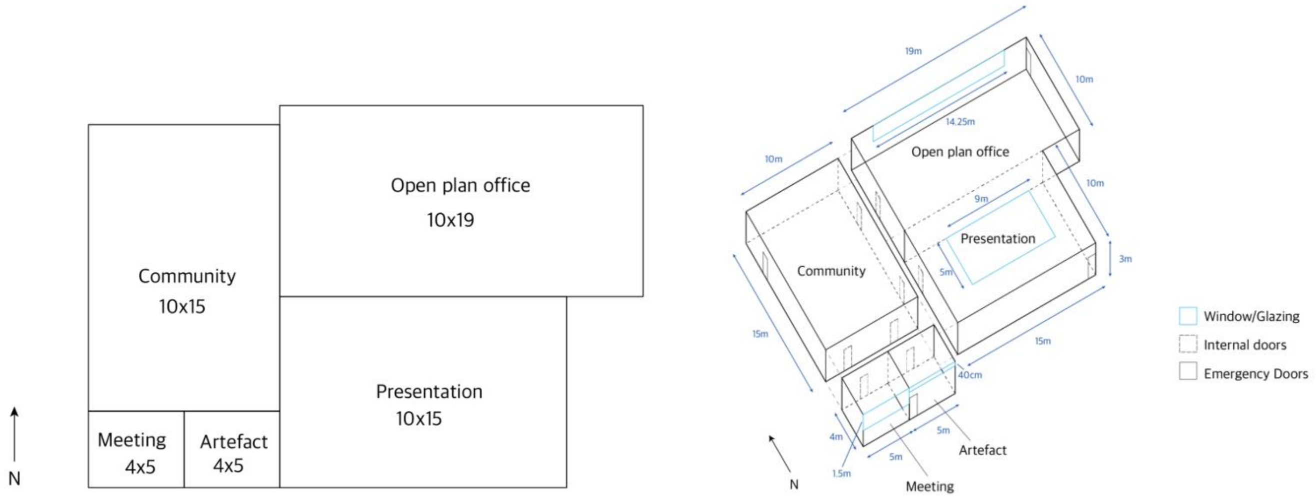


Figure 1. Module Plan & Dimensions

2. Performance Specification

The following tabulated values (CIBSE guide A, Section 1, table 1.5) are reference and essential parameters needed to determine the internal environment, heating and cooling load for the 4 modules, therefore informing effective analysis and design.

	Heat gain related					
	Lighting power density (W/m2)	Equipment power density (W/m2)	Activity (met)	Suggested air supply rate (L/s)	Illuminance level (lux)	Noise Rating
Presentation	5	5	1	10	150	30-35
Open plan office			1.2	10	300-500	30-35
Meeting			1.1	10	300-500	25-30
Artefact			1.4	10	Depends on types of artefact, around 200	30-35

Table 2 . Paramters for performance specification

II. EXTERNAL & INTERNAL DESIGN CONDITION

1. External design condition

External temperature and humidity can be obtained from CIBSE Guide B1 (table 2.4 & 2.6), referencing the values under 99.6% criterion for Birmingham.

	Winter	Summer
Dry Bulb (C)	-5.4	26.1
Wet Bulb (C)	-5.6	19.2
RH (%)	94.97	52.5
Moisture (g/kg)	2.28	11.1

Table 3. Winter & Summer External Design Condition

2. Internal design condition

Referencing CIBSE Guide A (table 1.5) and psychometric chart, different internal design conditions can be assigned to each module. The designed internal temperature of each module allows a 3-5 °C dead-band between summer and winter set points, thus reducing the risk of unnecessary changeover from cooling mode to heat (and vice versa), which also avoids wasting energy consumption and costs.

	Temperature C	Humidity %	Moisture g/kg
Presentation	19	50	6.85
Open plan office	21	50	7.76
Meeting	22	50	8.26
Artefact	19	50	6.85
Community	20	50	7.29

	Temperature C	Humidity %	Moisture g/kg
Presentation	23	50	8.78
Open plan office	24	50	9.34
Meeting	25	50	9.92
Artefact	21	50	7.76
Community	25	50	9.92

Table 4. Internal Design Condition (Left: Winter; Right: Summer)

3. Psychometric sketch of each modules – internal & external design conditions

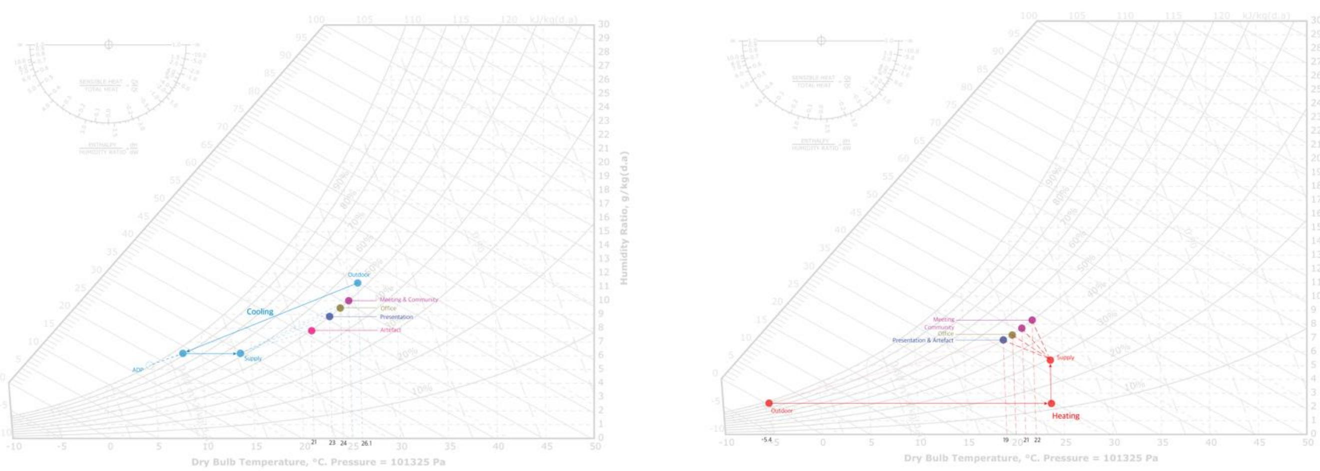


Figure. Rough psychometric process/sketch of design conditions for each module in two seasons (left: summer; right: winter)

-Presentation:

As the presentation module can contain up to 100 occupants, the space may gain a significant amount of heat from occupancy metabolic emission, thus the deadband between winter and summer set point is set to be larger (4 degrees). The module is kept at a lower humidity ratio compare to other modules considering that large occupancy can cause a greater rise in humidity.

-Community:

Similar to the presentation module, the community module can contain more than 100 people, thus a greater deadband between setpoints should be set (5 degrees).

-Open plan office:

Office only contains 10 people, thus metabolic heat gain would be less significant, thus deadband is kept smaller.

-Meeting:

Similar to office, since much less occupancy is allowed, deadband is kept lower.

-Artefact:

This module can potentially contain antiques that can be easily damaged by moisture and sensitive to heat, thus the space is kept cooler, and meet relative ideal for the condition for the majority types of artifacts.

III. DESIGN BUILDER MODEL AND HEATING& COOLING LOADS

1. Design builder model

Design builder is used to assist calculation for heating and cooling loads in all modules and then used to compare with benchmarks. Please see appendix for detailed setting for each module.

2.2 Sensible Heating Load & Latent Load of each module

With the initial construction (as listed in appendix), the values of heating and cooling loads are obtained from Design builder. The simulated heating load is quite close to the benchmark value whereas the simulated cooling load is slighting higher (Table 2.2). This might be caused by modules such as the presentation room which can get overheated easily due to a large amount of occupancy and solar gain.

One solution is to reduce the g-value of glazing or provide shading (mechanical louver control according to occupancy schedule) to lessen solar gain. On the other hand, increasing air movement in the room, such as providing openable windows and increasing the height of the module therefore creating stack effect, can also maintain a better passive internal condition control.

	Winter		Summer	
	Sensible Heating Load (kW)	**Latent Load (kW)**	**Sensible Cooling Load (kW)**	**Latent Load (kW)**
Presentation	3.24	3.92	16.6	3.71
Open plan office	5.73	1.03	8.41	0.77
Meeting	1.67	0.56	3.18	0.53
Artefact	1.59	0.96	1.77	0.93
Community	20.5	9.42	26.22	9.21

Table 2.1 Summary of sensible loads and latent loads of all modules

	Winter Heating Load		Summer Cooling Load	
	Module Average Load (W/m2)	**Benchmark (W/m2)**	**Module Average Load (W/m2)**	**Benchmark (W/m2)**
Office (compare to all other modules)	70.24	70	115.4	87

Table 2.2 Average of all module loads compare to benchmark value **(BSRIA Rules of Thumb)**

POTENTIAL ENVIRONMENTAL SYSTEMS

Having calculated the heating and cooling loads of the building, various HVAC strategies can be evaluated and compared in order to select the most proper system and maintain the conditions of the modules. Figure 3 illustrates the components of the 6 active environmental systems that are assessed in this section.

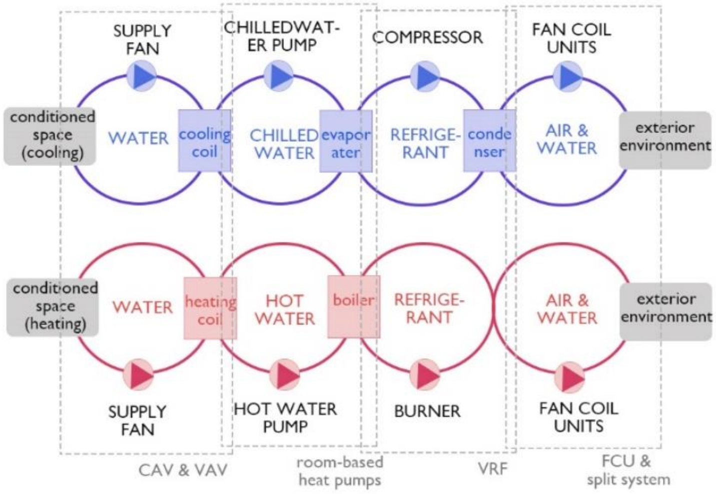


Figure 3. Components and energy circulation of environmental systems

Table 6.

Air-handling unit (AHU) is a typical device of HVAC system equipped to treat the supply air and maintain indoor environment (Gao, 2018). As an all-air system is required for the presentation module, it is potentially more efficient to adopt an all-air system for the whole building which uses a central AHU and a ductwork system to meet the heating/cooling and ventilation requirements of the spaces. Constant air volume (CAV) system is a basic type of AHU in which constant volume of air is supplied and heating/ cooling demands are met by changing the water flow rate inside the cooling/heating coil (ibid). Although variable air volume systems have been more increasingly chosen for their energy efficiency, CAV systems still have the advantages of having simple design, low primary cost,easy maintenance and suitability for small-scale buildings. Therefore, a CAV system is recommended for the project.

III. AIR CONDITIONING SYSTEM FOR PRESENTATION MODULE

I. Supply Air Conditions

An all-air conditioning system is designed to be used in the presentation module. Assuming that the presentation module would allow 5m3/m2h air at 50 Pa, there will be 0.25 ACH due to infiltration (CIBSE guide A, section 4.4, table 4.13). Thus, the latent load could be obtained to calculate how dry the supplied air needs to be. It is assumed that there is an 8-degree temperature difference between supply air and room condition in summer (CIBSE guide B3, Section 3.2); with the same air mass flow, winter would have a 1.56-degree difference. The table below summarizes key values of parameters that describe necessary air conditions. These results are then applied to determine the psychometric process of the air system, then sizing and selection of AHU.

	Latent Load (kW)	Sensible Cooling Load (kW)	Air Mass flow rate (kg/s)	Air Volume flow rate (m^3/s)	temperature difference (supply and room)	Moisture (g/kg)	Supply temperature
Supply air (Summer)	3.7	16.6	2.03	1.7	8	6.1	14
Supply air (Winter)	3.9	3.24	2.03	1.7	1.56	6.06	23.6

Table 7. Summaried design conditions for air system in presentation module

2. Summer – Cooling design

As air enters the air conditioning system, it is first cooled to 7.7 degrees (assuming the cooling coil is 85% efficient), it will then be reheated to supply temperature. The supplied air should be drier than the internal design condition for this allows the conditions to be fulfilled even with a rise in humidity due to occupancy metabolism.
Applying psychometric chart, it is calculated that 76kW of cooling power is needed to reach supply condition. However, the cooling duty is much higher than the cooling load, hence large amount of energy is unused. To optimize the energy efficiency, supply air volume flow and fresh air requirement are compared. Assuming 10L fresh air per person is provided, it is calculated that 59% of supply air need to be fresh air, thus 41% of air can be recirculated from the room. Applying recirculation in the air system, the cooler duty reduced to 67kW, in other words, 12% of energy can be saved compared to the initial design.

	Cooler duty (kW)	(Re)heater duty (kW)	Total (kW)	Compare to cooling load (kW)
Without circulation	63.9	13.	76.9	20.3
With circulation	54.5	12.4	66.9	

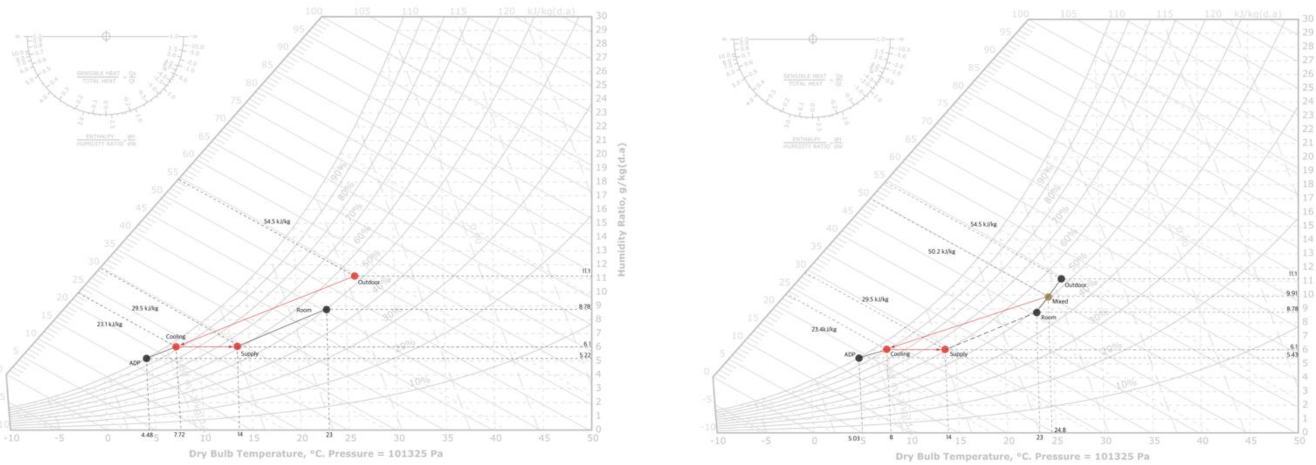


Figure 1. Initial cooling/reheating load psychometric sketch; Cooling with mixed condition – recirculation psychometric sketch

3. Winter – Heating design

In winter, the air is heated so that it is slightly higher than the designed temperature accounting there might be 1.5-degree reduction due to heat loss. Similar to summer cooling process, the use of air circulation could reduce energy consumption for space heating. If 100% fresh air is used, 79.2kW of energy is needed to heat up the presentation module, and 19.7kW is needed to humidify the space to a desirable condition. However, if recirculation and mixed condition is applied (plus, the humidity difference between heated air and supply condition is less than 50% thus humidifier is not necessary), the energy used for heating duty can be reduced to 39.1kW. This can save up to 50% amount of energy.

	Heater duty (kW)	Humidifier (kW)	Total (kW)	Compare to heating load (kW)
Without circulation	59.5	19.7	79.2	7.15
With circulation	39.1	10	49.1	
With circulation (no humidifier)	39.1	0	39.1	

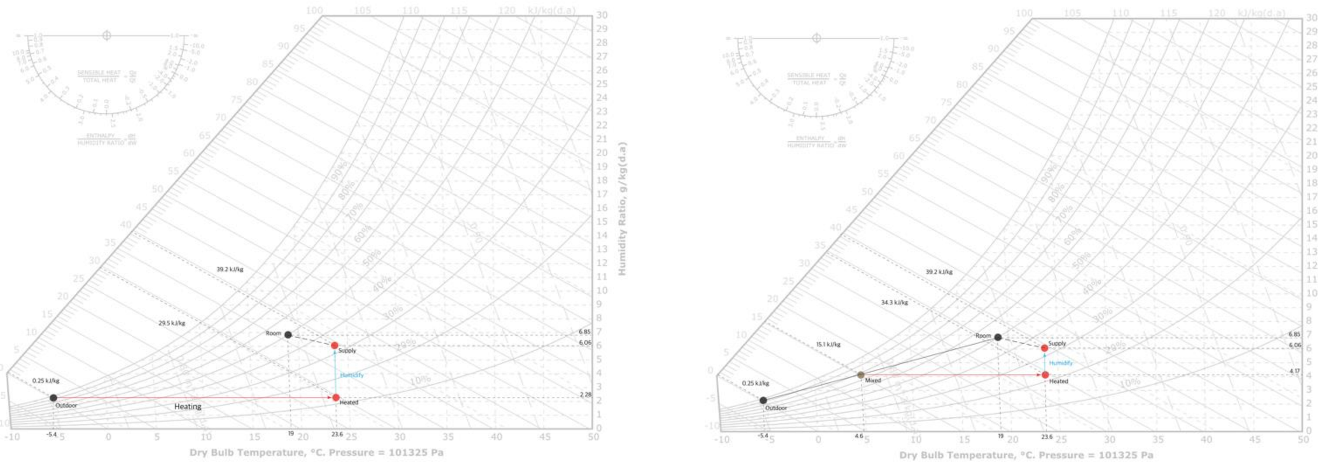


Figure 3. Heating design psychometric sketch; Heating design with recirculation

IV. SUMMARY OF ENERGY PERFORMANCE

Assume all modules are using natural gas single boiler system (<2MW) (non-domestic building compliance guide), with seasonal efficiency is 91%, energy performance is simulated in Design builder (See Appendix Section B for detailed settings). The values obtained from simulation are normalized and compared to benchmarks provide in CIBSE Guide F (table 20.1). The simulated electricity energy is slightly higher than the good practice benchmark but is it within the typical practice value. However, the gas energy consumption is much lower than the benchmark.

This is because the benchmark values are collected and based on existing office building performance, whereas the software and the setting assume the simulated building is brand new and well insulated. However, the software might not be taken account unexpected and random heat loss, such as window opening. To make the simulation closer to a real-life situation, the infiltration is set to be larger accounting users' interaction with the opening. Another simulation is done using the larger infiltration rate, and the energy consumption has raised and got closer to benchmark value. The value is still quite small since it cannot take account of all real-life random heat loss.

V. SYSTEM OUTLINE DESIGN & AIR DISTRIBUTION METHOD

1. AHU and ductwork

An all-air system with constant volume is recommended for this project. Air supply requirements for all modules have been specified in Table 7, based on which the duct sizes can be determined and the AHU product can be selected. The AHU is designed to be put on the roof of the community space, and supply air will be delivered to each module through ducts and air diffusers. The ductwork system is designed according to the sizes and configuration of modules, as shown in Figure 6. The material for the ducts is chosen as galvanised steel, and the shape is designed to be rectangle. As shown in Figure 7, the diverging parts are 90 sweep tees (B,C,D&E in Figure 6), and turning parts are mitred elbows (F in Figure 6).

The detailed process of determining duct lengths, generating corresponding duct diameter and pressure drop (based on CIBSE Guide C Figure 4.2), refining ducts to reasonable sizes (CIBSE Guide C Table 4.16) and calculating duct losses has been shown in the Appendix. The pressure drop in ductwork runs, duckwork fittings, air diffusers and AHU components have all been considered and an index run is carried out. The results in Table 2 indicate that the chosen fans must overcome the 233.1 Pa pressure loss caused by pressure loss (route L-K in Figure 6), and that flow rate at fan operation point is 5.84 m^3/s.

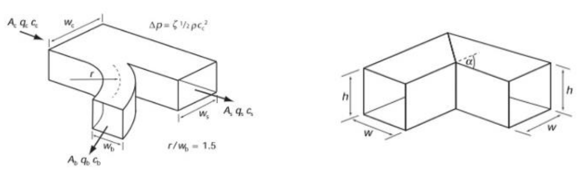


Figure 7. Branches and turning parts
(CIBSE Guide C 4.11.4.4 & 4.11.4.16)

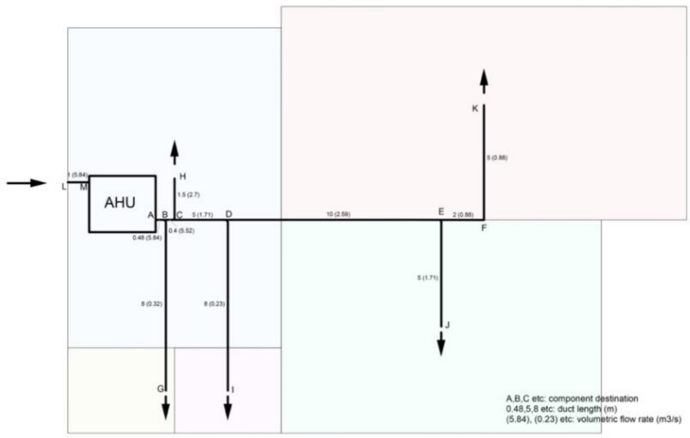


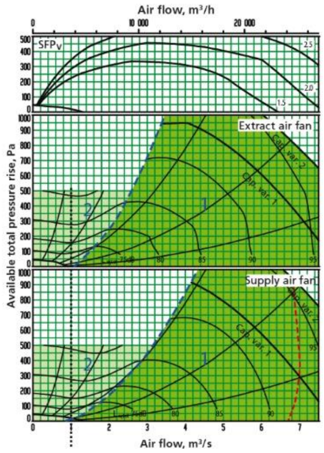
Figure 6. Schematic plan of AHU and ductwork system

AHU		ductwork runs			ductwork fittings		ductwork terminals			
ID	Pressure loss (Pa)	ID	volume flow rate (m3/s)	Duct loss (Pa)	ID	Fitting Loss (Pa)	ID	Fitting Loss (Pa)	Index run (Pa)	
L	82.56	AB	5.84	0.30	B-G	9.60	H	75.70	233.0964	AHU to terminal K
AHU	50	BG	0.32	5.20	B-C	-0.20	G	25.44	175.2044	AHU to terminal J
L-M	0.63	BC	5.52	0.26	C-H	11.43	I	14.31	168.7124	AHU to terminal I
		CH	2.7	1.43	C-D	0.08	J	25.44	173.7324	AHU to terminal G
		CD	2.82	1.25	D-I	16.20	K	57.24	222.10687	AHU to terminal H
		DI	0.23	3.20	D-E	1.87				
		DE	2.59	8.50	E-J	4.51			233.0964	maximum
		EJ	1.71	1.75	E-F	4.32				
		EF	0.88	1.90	F	25.70				
		FK	0.88	4.75						

Table 2. Ductwork sizing and index run (detailed calculation see Appendix)

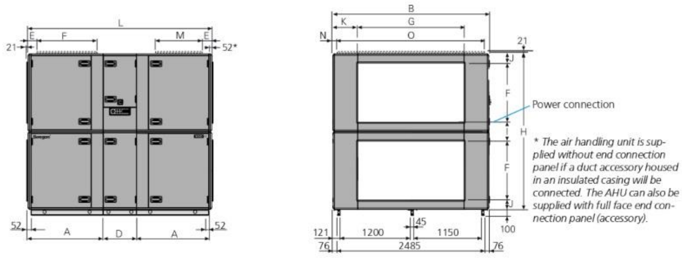
Among the products of Swegon, GOLD RX with its featured rotatory heat exchanger and high energy efficiency is recommended for this module. The pressure rise capacity, component detials and size parameters of are shown in Figure 8. Size 070 is chosen for its pressure rise capacity and maximum flow rate ($7.5m^3/s$) which can meet the requirement for 233.1 Pa pressure rise and $5.84m^3/s$ flow rate (see in Figure 8). The method of extracting and supplying air is shown in Figure 9, and the sizes and positions of AHU and ductwork shown in Figure 10. The AHU is put on the roof of the community space in order to minimise the impact of noises, and the lengths of ducts are designed to maximise delivery efficiency. Considering the sizes of these components, they are all put on roofs so that spaces inside the modules can be saved.

GOLD RX, rotary heat exchanger, size 070



Brand & type	Components	Discription
GOLD RX size 070 *	Casing	flush-mounted cover panels and inspection doors, galvanized sheet steel outer skin, aluminium-zinc plated sheet steel and Magnelis inner skin.
	Fans	GOLD Wing+ type, axial-centrifugal fans, driven by high-efficiency EC motors
	Filters	glass fibre material, bypass leakage Class ePM1 85% (F9), ePM1 50% (F7) filters
	Heat exchangers	rRECOnomic/RECOsorptic rotary heat exchanger with a temperature efficiency of up to 85%
	Duct connections	rectangular duct connections with a securely mounted connection frame for slip-clamp joint connection
	Pressure adjusting plates	control the purging air flow through the heat exchanger
	Electrical & control equipments	integrated into the air handling unit, controls and regulates temperatures, airfl ows and other functions.

* The GOLD RX is a complete air handling unit with rotary heat ex-changer, supply air and extract air fans as well as supply air and ex-tract air filters.



Size	A	B	D	E	F	G	H	I	J	K	L	M	N	O	Weight, kg
070	1273,5	2637	565	162	1000	1800	2640	320	160	418,5	3112	750	118,5	2400	2219-2485

Figure 8. Available pressure drop, component information, configuration and size of Gold RX 070 (https://www.swegon.com/globalassets/_product-documents/air-handling-units/gold-version-f/general/_en/gold_rx_f_dimensioning.pdf)

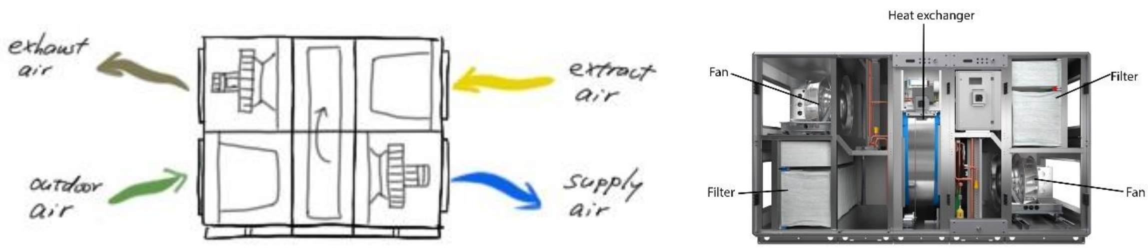


Figure 9. Schematic of air supply & extraction method and picture of components of the AHU (ibid)

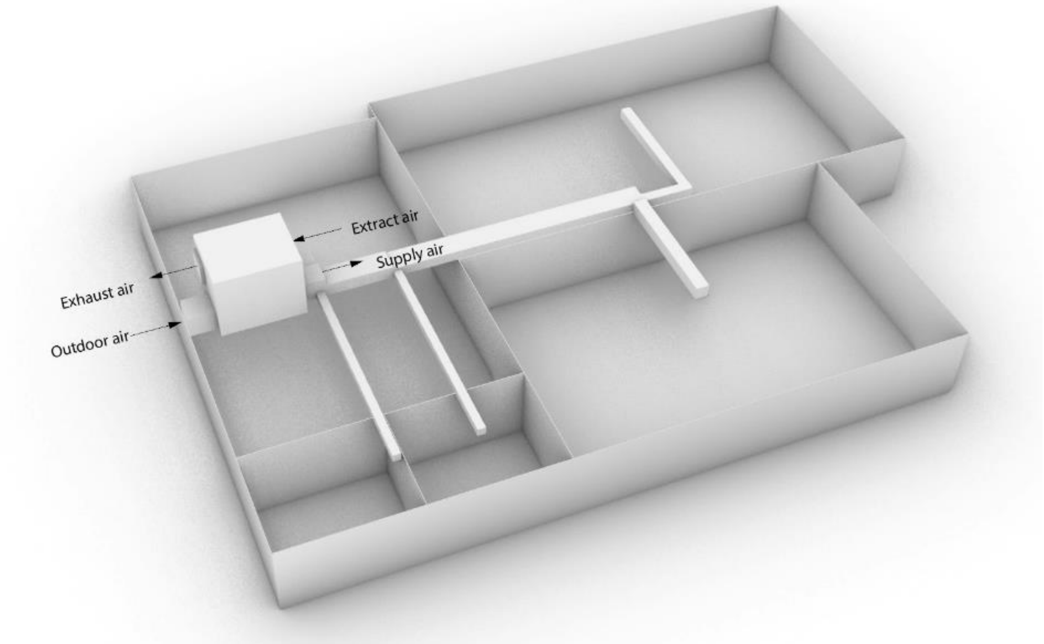


Figure 10. Positions and sizes of AHU and ductwork

VI. LIGHT SCHEME FOR ARTEFACT

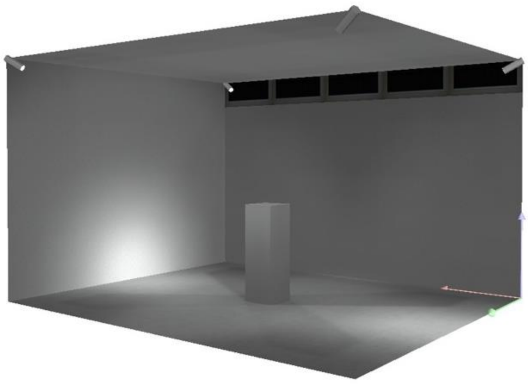


Figure 10. DIALux Simulated model

Adjusting the light intensity is necessary in order to exhibit different types of delicate ancient artifacts in safe conditions. Direct sunlight should generally be excluded due to its high intensity and likelihood of increasing damage risks. Little or no daylight should be allowed into the room, to prevent UV light from damaging artifacts that are highly susceptible to light, such as textiles, handwriting with ink before the 20th century, and natural dyes. (Ajmat, 2011)

Since lights in the artifact module are likely to be retained in use for longer periods than the other modules, the control of light and energy is crucial. Daylight could be used to save energy by allowing it to penetrate through roof-lights and diffuse across the whole space to provide general background lighting. However, there should be a protection layer targeting UV light, such as UV blocking glass and blinds, to minimize light damage to the artifact. Dimming controls can be used along with daylight to give better control of the lighting levels on displays. This allows manual or automatic control (light sensors) over the operation time and the lights can be turned off outside occupancy time thus reducing energy and light damage. Furthermore, LED light could be used since it uses 75% less energy than incandescent lighting.

Spotlights are recommended to be used to light up the artifact but the illuminance on the artifact surface should be less than 200 lux to prevent glare. Direct spotlight might cause too much horizontal light and decrease the lighting contrast on a surface, thus flattens and blurs the form and shape of the artifact. Therefore, it would be ideal to use indirect light that reflects off the walls and light up the room (when daylight is not enough), to allow the ratio of horizontal and cylindrical light stays in the range of 0.3-0.6, which the range where the form of the artifact is more defined. The color rendering index (Ra) of a light source should be greater than 90; Ra below 80 is usually not ideal for exhibiting artifacts (CIBSE LG8, lighting for museums). Additionally, light track-system is also recommended, for it allows spotlights to be moved along the track to various locations and be located at the most suitable position according to the placement of the artifact.

VII. PRESENTATION MODULE ACOUSTIC PERFORMANCE

Reverberation time in the presentation room is a key design parameter which can greatly influence speech intelligibility and acoustic comfort. Spaces with different functions require varied quality of sounds and thus standards of reverberation time. Concert halls, for instance, require richer and warmer sounds and are designed with greater reverberation time. Lecture halls and presentation room on the other hand require better clarity of sounds and thus shorter reverberation time. The layout and materials of the presentation module are illustrated in Figure 11, and the reverberation time is calculated in Table 3 using Sabine's formula. Typical absorptive materials are chosen for the surfaces, and seats are spaced as evenly as possible whereas circulation is not blocked.

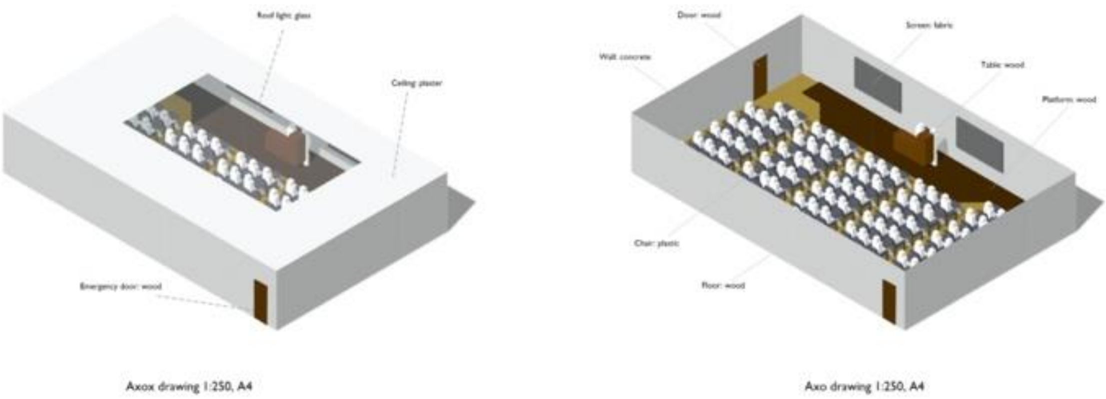


Figure 11. Configuration and material of presentation room

			ABSORPTION COEFFICIENT [1]					
	MATERIAL	AREA (m2)	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
wall	Smooth concrete, painted or glazed	154.4	0.01	0.01	0.01	0.02	0.02	0.02
ceiling	Gypsum plaster tiles, 17% perforated, 22mm	115	0.45	0.7	0.8	0.8	0.65	0.45
floor	Wooden floor on joists	160	0.15	0.11	0.1	0.07	0.06	0.07
door	Wood hollowcore door	3.2	0.3	0.25	0.15	0.1	0.1	0.07
platform	Woodblock on solid floor	22	0.02	0.04	0.05	0.05	0.1	0.05
window	Double glazing, 2-3mm glass, 10mm air gap	45	0.15	0.05	0.03	0.03	0.02	0.02
occupants	Seating, slighty upholstered, occupied	100	0.32	0.62	0.74	0.76	0.81	0.9
		total	117.444	165.574	186.474	185.058	171.858	158.262
		RT60 (s)[2]	0.654	0.464	0.412	0.415	0.447	0.485

1. Source of data: https://www.acoustic.ua/st/web_absorption_data_eng.pdf
2. Sabine's fomula: RT=0.16V/A, where V is the volume of the room and A is the total absoption

Table 3. Calculation of reverberation time.

Recommended reverberation time for classrooms is 0.4-0.5s (Sylvio R. Bistafa & John S. Bradley, 2000). The results of RT60 calculated in Table 3 generally fall within this range, indicating suitable material choices and feasible acoustic designs. Reverberation time is not only influenced by room volume and surface absorption, but also room temperature, seating spacing, audience capacity, etc. Simulations are done in I-SIMPA to evaluate the feasibility of adapting the presentation room to other activities such as music performance (Figure 12). It can be observed from Figure 13 that by putting carpets on the surfaces or replacing the roof window with a regular ceiling, the reverberation time can be increased to a maximum of 3.5s. According to Aretz & Orlowski (2009), the recommended reverberation time for organ music is 2.5s, and for romantic classical music is 1.8-2.2s. Ideal reverberation time can therefore be achieved by carpeting and changing roof light window, and the space can be adapted to hold music performance and potentially a variety of other activities.

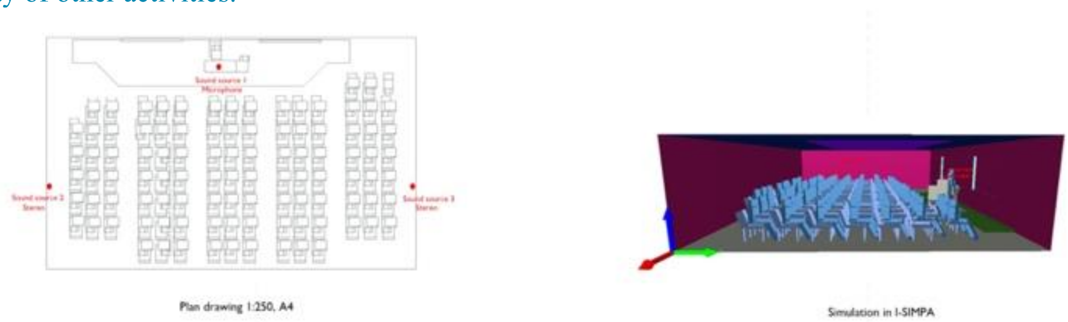


Figure 12. Position of sound sources and simulation in I-SIMPA.

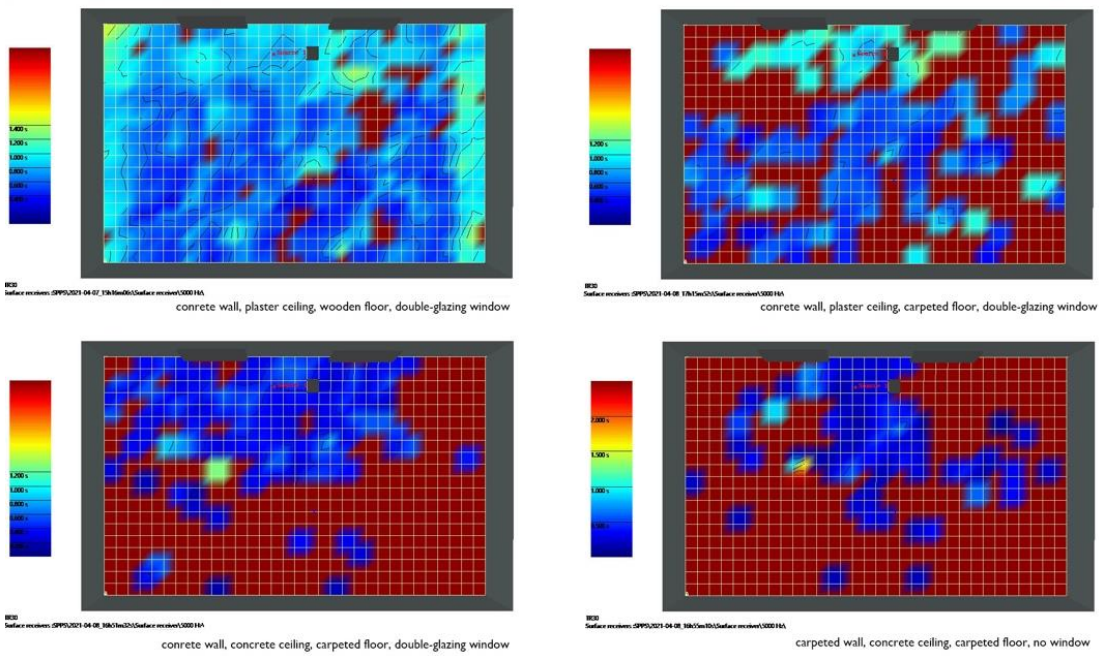


Figure 13. Simulation of reverberation time in the presentation room with different absorptive materials

CONCLUSION

Brief conclusion - critical review of the work undertaken, suggestions for further work, etc

More strategies of environmental systems can be explored in future analysis. Due to the requirement of an all-air system for the presentation module, a CAV system is designed for this project in consideration of installation simplicity and ductwork efficiency. However, it might not have been the best approach to maximising energy efficiency and occupancy comfort. VAV, FCU, heating pumps and VRF systems are also promising, which can be modelled and compared in a more quantitive and detailed manner. During the calculation for the CAV system for this project, the total lengths and costs of the ductwork are not optimised. For further research, the AHU can be put in different positions and various possibilities of ductwork systems can be evaluated.

The reverberation time for the presentation module generally meets the standard. However, only one configuration of occupants and seats has been studied in this report. In the future more possibilities of this regard can be simulated and analyzed.

BIBLIOGRAPHY

Ajmat, R. (2011). *Lighting design in museums: exhibition vs. preservation.* WIT Transactions on The Built Environment.

Jiajia Gao, Xinhua Xu, Xiuming Li, Jili Zhang, Yuan Zhang & Gongda Wei . (2018). odel-based space temperature cascade control for constant air volume air-conditioning system. *Building and Environment*, 308-318.

Marc Aretz & Raf Orlowski. (2009). Sound strength and reverberation time in small concert halls. *Applied Acoustics, 70*(8), 1099-1110.

Sylvio R. Bistafa & John S. Bradley. (2000). Reverberation time and maximum background-noise level for classrooms from a comparative study of speech intelligibility metrics. *The Journal of the Acoustical Society of America, 107*(861). doi:https://doi.org/10.1121/1.428268

APPENDIX

---*Section A*---

Design Builder Activity Setting

	Activity Template (ASHRAE 90.1)	Schedule (ASHRAE 90.1)	Heating (C)	Heating setback (C)	Cooling (C)	Cooling setback (C)	Lighting power density (W/m2)	Equipment power density (W/m2)
Presentation	Educational facilities - Lecture classroom	Occupancy - School	19		23			
Open plan office	Office-Open Plan	Occupancy - Office	21		24			
Meeting	General - Conference/Meeting	Conference /Meeting	22	12	25	28	5	5
Artefact	Public Assembly - Museum/Gallery	Occupancy - Assembly	19		23			
Community	Public Assembly - Lobby	Occupancy - Assembly	20		25			

Table A.1

Design Builder Construction Setting (Project Construction Template)							
	Internal walls adjacency	**Floor Adjacency**	**Floor and Roof U Value (W/m2K)**	**External Walls U Value (W/m2K)**	**Doors U Value (W/m2K)**	**Windows/ Glazing gvalue**	**Infiltration ACH**
Presentation							
Open plan office	Adiabatic	Adjacent to ground	0.25	0.25	1.6	0.6	0.25 Ref: CIBSE guide A, section 4.4, table 4.13
Meeting							
Artefact							
Community							

Table A.2

Design Builder HVAC							
	Template	**Schedule**	**Heat Recovery**	**Fuel**	**Heating System Seasonal CoP**	**DHW**	**Natural Ventilation**
Presentation		Occupancy - School					
Open plan office		Occupancy - Office					
Meeting	CAV Air-cooled chiller	Conference /Meeting	0.7	Natural Gas	0.91 Ref: Non-Domestic building services compliance guide Table 4	Template - Project DHW	/NA
Artefact		Occupancy - Assembly					
Community		Occupancy - Assembly					

Table A.3

---Section B---

			CIBSE GUIDE A 6.3		Latent Load Related to Infiltration						
	Volume (m^3)	**No. Of Occupants**	**Heat Emission (W)**	**Occupant latent load (kW)**	**ACH**	**Air Density kg/m^3**	**m (kg/s)**	**gW (g/kg)**	**hfg (kj/kg)**	**qLW (kW)**	**Total load W (kW)**
Presentation	450	100	35	3.5			0.0375			0.42	**3.92**
Open plan office	570	10	50	0.5			0.0475			0.53	**1.03**
Meeting	60	10	50	0.5	0.25	1.2	0.005	4.57	2450	0.056	**0.56**
Artefact	60	15	60	0.9			0.005			0.056	**0.96**
Community	450	150	60	9			0.0375			0.42	**9.42**

Table B.1

			CIBSE GUIDE A 6.3		Latent Load Related to Infiltration						
	Volume (m^3)	**No. Of Occupants**	**Heat Emission (W)**	**Occupant latent load (kW)**	**ACH**	**Air Density kg/m^3**	**m (kg/s)**	**gS(g/kg)**	**qLS (kW)**	**hfg (kj/kg)**	**Total load S (kW)**

Presentation	450	100	35	3.5			0.0375		0.21		3.71
Open plan office	570	10	50	0.5			0.0475		0.27		0.77
Meeting	60	10	50	0.5	0.25	1.2	0.005	2.84	0.028	2450	0.53
Artefact	60	15	60	0.9			0.005		0.028		0.93
Community	450	150	60	9			0.0375		0.21		9.21

Table B.2

SUMMER (COOLING)

Apparatus Dew Point

assume coil effectiveness is 0.85

0.85(go - gx) = go-gc

g(outdoor) (g/kg)	g(supply) (g/kg)	g(cooling) (g/kg)	gx (g/kg)
11.1	6.104996213	6.104996213	5.223524957

θx	θo	θcooling
4.48	26.1	7.723

Cooling coil load

m (g/kg)	ho (enthalpy) (kj/kg)	hc	cooler duty (kW)
2.034313725	54.5	23.1	**63.87745098**

(Re)heating coil load

m	hs	hc	heater duty (kW)
2.034313725	29.5	23.1	**13.01960784**

Total power needed (kW)	Compare to cooling load (kW)
76.89705882	20.31315

Determine mixed condition (reduced use in power/energy)

occupants	ventilation rate (L/s)	Fresh air requirement (L/s)	m3/s	Total air volume flow rate (m3/s)	% of fresh air	θO	θR	θM (mixed condition)	gM (from psy chart)
100	10	1000	1	1.695261438	0.589879518	26.1	23	24.82862651	9.91
					41.01204819	% can be recycled			

	ADP			Off coil temperature	
gM(mixed) (g/kg)	gc(cooling) (g/kg)	gx (g/kg)	θx (from chart)	θm	θc
9.91	6.104996213	5.433524957	5.03	24.82862651	7.999793976

Cooling coil load

m	hm (enthalpy) (kJ/kg)	hc	cooler duty (kW)
2.034313725	50.2	23.4	**54.51960784**

Reheat load

m	hs	hc	heater duty (kW)
2.034313725	29.5	23.4	**12.40931373**

Total power needed (kW)	Compare to cooling load (kW)
66.92892157	20.31315

Table B.3

WINTER (HEATING/HUMIDIFIER)

NO CIRCULATION

Heater

assume coil effectiveness is 0.85

0.85(go - gx) = go-gc

g(outdoor) (g/kg)	**g(supply) (g/kg)**	at temperature
2.28	**6.06352031**	23.56144578

m (kg/s)	hh (kJ/kg)	hm (kJ/kg)	Heater (kW)
2.034313725	29.5	0.25	**59.50367647**

Humidifier

m (kg/s)	hs (kJ/kg)	hh (kJ/kg)	Humidify (kW)
2.034313725	39.2	29.5	**19.73284314**

Do not really require humidify process

Total power needed (kW)	Compare to cooling load (kW)
79.23651961	7.15986875

WITH CIRCULATION 41% recirculated air (temp) 15.5

59% outdoor air

θo	θR	θh	gM (g/kg)
-5.4	19	4.604	4.17

humidifier is not really needed

m (kg/s)	hh (kJ/kg)	hm (kJ/kg)	Heater (kW)	Total power needed (kW)	Compare to cooling load (kW)

Table B.4

Used to Calculation Values in Tables in Section B

Equations– latent load

$$Occupants\ lantent\ load\ (q_{lo}) = People\ \times\ Heat\ Emission$$

$$Air\ mass\ flow\ (m) = \frac{V \times\ ACH\ \times Air\ density}{3600}$$

$$Infiltration\ latent\ load(q_{li}) = m \times\ g/1000 \times h_{fg}$$

$$Total\ latent\ load\ (q_l) = q_{lo} + q_{li}$$

– Supply air

Summer

$$Supply\ Air\ mass\ flowrate = q_s/(c_p \times \Delta\theta)$$
$$Supply\ Air\ moisture\ content\ (g_s) = q_l/mh_{fg}$$

Winter

$$*\ Supply\ Air\ mass\ flowrate(Summer) =\ Supply\ Air\ mass\ flowrate(Winter)$$
$$\Delta\theta w =\ q_s/(m \times c_p)$$

– Determine values for psychometric sketch

$$Apparatus\ Dew\ Point\ (g_x) = outdoor\ moisture\ content(g_o) - \frac{g_o - g_s}{0.85}$$
$$Cooler\ duty = m(ho - hc)$$
$$Reheat\ duty = m(hs - hc)$$

– Mixed Condition

$$Fresh\ air\ requirement = \frac{10L}{person} \times 100\ occupants = 1000\frac{L}{s} = 1\ m^3/s$$

$$\%\ of\ Fresh\ air = \frac{1}{supplied\ air\ volume\ flow\ rate\ (= 1.69)} = 0.5898 \ldots$$

$$\theta_m = 59\% \times \theta_{outdoor} + 41\% \times \theta_{room} = 24.8$$

$$Off\ coil\ temperature\ (\theta_c) = 0.85\theta_x + 0.15 \times \theta_m = 8$$

	ID	TYPE	volume flow rate (m3/s)	delta P (Pa/m)	Length (m)	Velocity (m/s)(1)	Diameter (m)(1)	closest Rectangular ducts(2)	Refined rectangular ducts w*h(3)	Equivalent diameter (m) (4)	Refined delta P (Pa/m)	Refined velocity (m/s)	Velocity limit(5) (m/s)	Duct Loss (Pa)
ductwork runs	AB	Duct	5.84	1	0.48	9.8	0.87	900*700	900*800	0.934	0.63	8	9	0.30
	BG	Branch	0.32	1	8	4.8	0.29	300*225	300*300	0.33	0.65	4	5.5	5.20
	BC	Duct	5.52	1	0.4	9.5	0.85	800*750	900*800	0.934	0.65	8.1	9	0.26
	CH	Branch	2.7	1	1.5	8	0.65	700*500	600*600	0.661	0.95	6.9	7	1.43
	CD	Duct	2.82	1	2.5	8.1	0.66	650*550	900*500	0.732	0.5	3.7	6	1.25
	DI	Branch	0.23	1	8	4.4	0.26	250*225	300*300	0.33	0.4	3	3.5	3.20
	DE	Duct	2.59	1	10	7.9	0.63	600*550	900*400	0.65	0.85	7.2	7.5	8.50
	EJ	Branch	1.71	1	5	7	0.55	500*500	500*500	0.551	0.35	4	3.5	1.75
	EF	Duct	0.88	1	2	6	0.43	400*400	400*400	0.44	0.95	6	7.5	1.90
	FK	Branch	0.88	1	5	6	0.43	400*400	400*400	0.44	0.95	6	6	4.75

	ID	TYPE	As/Ac	Ab/Ac	qs/qc or qb/qc	Straight /branch factor(6)	Fitting loss (Pa)
ductwork fittings	B-G	90 sweep	1.00	0.12	0.05	1	9.60
	B-C	branch tree			0.95	-0.005	-0.20
	C-H	90 sweep	0.61	0.50	0.49	0.4	11.43
	C-D	branch tree			0.51	0.01	0.08
	D-I	90 sweep	0.79	0.20	0.08	3	16.20
	D-E	branch tree			0.92	0.06	1.87
	E-J	90 sweep	0.46	0.72	0.66	0.47	4.51
	E-F	branch tree			0.34	0.2	4.32
	F	elbow				1.19	25.70

	ID	TYPE	Pressure loss factor(7)	Velocity (m/s)	Pressure loss (Pa)
ductwork terminals	H	air diffuser	2.65	6.9	75.6999
	G	air diffuser	2.65	4	25.44
	I	air diffuser	2.65	3	14.31
	J	air diffuser	2.65	4	25.44
	K	air diffuser	2.65	6	57.24

		Pressure loss factor(7)	Velocity (m/s)	length (m)	Pressure loss (Pa)
AHU	air entry	2.15	8		82.560
	AHU components				50(8)
	intake duct			1	0.63

Index run (Pa)	
233.096	AHU to terminal K
175.204	AHU to terminal J
168.712	AHU to terminal I
173.732	AHU to terminal G
222.107	AHU to terminal H
233.096	maximum

1. CIBSE Guide C Figure 4.2
2. CIBSE Guide C Table 4.16
3. Refine the size based on maximum pressure drop of 1 Pa/m, and maximum velocity doesn't exceed limits for each space
4. CIBSE Guide C Table 4.16
5. CIBSE Guide B2 (2016) Table 3.2
6. CIBSE Guide C Table 4.124 & 4.125
7. CIBSE Guide C Table 4.103
8. Provided by brand (see Figure 6)

WORK PLAN

I. Main Tasks Summary and Divide to smaller Tasks

1) Determine appropriate dimensions for the modules

Summarise known details about the modules
Find or determine missing details, such as occupants estimation
Reference CIBSE or ASHRAE guides for occupancy density
Conclude module size
Take in account of orientation and community module and arrange the adjacency of modules
Sketch in Rhino

2) Tabulated performance specification for the 4 modules

Summarise known details about the modules
List out potentional parameters and elements that affect internal conditions in both winter and summer (such as activites, occupants, metabolic gain, solar gain etc.)

3) Psychrometric sketch(es) of the internal and external design conditions

Reference CIBSE or ASHRAE guides for external and internal design conditions (temperature and humidity)
Determine sensible deadband between setpoints
Rough cooling and heating process oh pyschometric chart

4) Develop DesignBuilder model and simulation

Set location information with known details from external design conditions
Construct blocks and adiabatic adjacency
Construct openings such as windows and doors
Adjust activity template, construction, lighting, HVAC to suitable values and conditions for our project

5) Heating load and cooling load, compare against appropriate 'benchmarks'.

Simulate heating and cooling loads in Design Builder
Find CIBSE benchmarks
Compare and state significant difference and reason that might cause it

6) Provide an executive comparison of the types of active environmental systems

Simulate heating and cooling loads in Design Builder
Find CIBSE benchmarks
Compare and state significant difference and reason that might cause it

7) Assess projected energy performance of the building

Compare different potential envrionmental systems
Simulate energy use in Design Builder
Find CIBSE benchmarks
Compare and state significant difference and reason that might cause it

8) Design ducted 'all air' system with identification of suitable component parts and approximate sizes for a system to serve the presentation module.

Determine latent load and sensible load
Use heating and cooling load from before to determine supply air mass flow and humidity
Explore energy saving methods, such as mixed condition in air conditioning system and see if it makes a big difference
Calculate duct sizing based on air flow rates, pressure drop, etc. Refine the ducts based on reasonable assumptions. Determine the most proper AHU brand, type and components.

9) Provide a justified recommendation for the lighting types/schemes that could be adopted in the artefact module.

List out potential lighting requirement needed and parameters for exhibition spaces, referencing CIBSE guide (horizontal to cylindrical, illuminance level, rendering etc.)

Determine if natural light can be used

Dimming control

Dialux simulation with different lighting products and see the effect

10) Acoustic & Reverberation time in the presentation module assessment

Determine surface materials, room configurations, occupancy capacity, seat distancing, etc.

II. Tasks Allocation and Cooridination

Together:

Determine appropriate dimensions for the modules

Tabulated performance specification for the 4 modules

Separate:

Person A doing…	**Meanwhile Person B doing…**
Psychrometric sketch(es) of the internal and external design conditions	Provide an executive comparison of the types of active environmental systems
Develop DesignBuilder model and simulation	Acoustic & Reverberation time in the presentation module assessment
Heating load and cooling load, compare against appropriate 'benchmarks'	
Assess projected energy performance of the building	
Sensible and load to determine air mass flow and supply air humidity, Psychrometric sketch(es) air system	AHU Selection and Calculation
Lighting design	
Last tweak and report check, work plan, appendix writing	

III. Task time estimation v.s. Actual completion & time taken

Month	Task	Planned time (hr)	Used time(hr)
Feburary	Decide on configuration and sizes of modules, prepare writing documents/report on word	2hr	2.5 hr
March	Make module models on DB and Rhino, tabulating basic information, start making models on i-simpa	3-4 hr	5.5hr
March	Determine internal and external design conditions, comparison of the types of active environmental systems	4hr	5hr
March	Heating load and cooling load, compare against appropriate benchmarks, comparison of the types of active environmental systems, i-simpa development and sound simulation	5hr	3hr

March	Psychrometric sketch, Energy performance assessment on Design Builder	6hr	5hr
March	Energy performance assessment on Design Builder, fresh air requirement calculation, model confirmation, acoustic model development	6hr	8hr
March	Light scheme planning, lighting scheme draft writing	3-4 hr	4hr
March	Air flow calculation, apparaturs dew point, cooling load, heating load	4hr	5hr
March	Mixed condition calculation, AHU choosing and sizing, lighting research and writing	6hr	6.5hr
April	Report writing, AHU development, psychometric sketches, lighting writing and DIALux model try out	6hr	7hr
April	First draft hand in	/	/
April	Check and improve writing, (grammar and shorten writing) according feed back	3.5hr	4hr
April	Adjust false calculation and fill in things missed during previous process	5hr	8hr
April	Final calculation check, develop Appendix for detailed calculations, finish writing work book	4hr	2.5hr

IV. Reflection