MSc SBDE Title Page

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Module Title: Building Systems Development and Operation

Coursework Title: Building Systems Evaluation and Development

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1. Analysis for the whole building (both activity and heritage area)

New activity area has light weight construction. In group phase it was concluded that having setback temperature during not occupied hours is an energy efficient strategy for both areas. To use this strategy efficiently systems that have high response time in minutes and not in hours are required. For example, air systems are very dynamic, but underfloor heating system are not.

Both spaces need to be designed for high occupancy [Appendix B] with peak occupancy in activity 80 people and heritage 120 people, which means that both spaces need to have high fresh air rates.

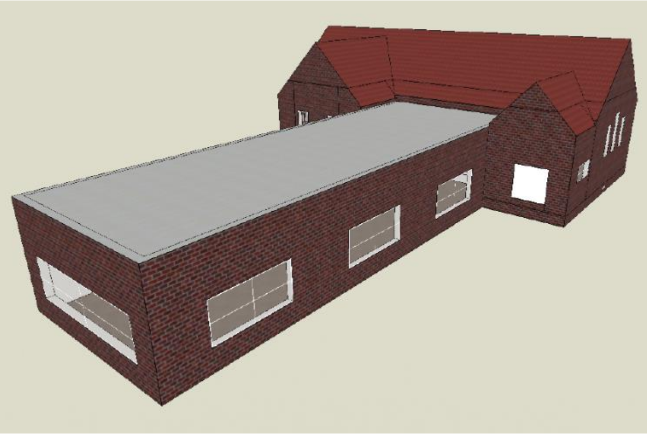


Figure 1 - 3D visualisation of building from DesignBuilder

To understand local climate simple coefficients HDD (heating design days) and CDD (cooling design days) were compared to understand if air would be mainly heated or cooled.

$$HDD\ 18.3 = 3193 > CDD18.3 = 18$$

(2017 ASHRAE Handbook - Fundamentals (SI) for AUGHTON, United Kingdom)

Simple CAV system was proposed as a baseline for both areas as both have high demand for fresh air.

To control temperature and humidity with levels specified in the group coursework (temperature 19-25, relative humidity 40-60%) heating coil, cooling coil and humidifier were added. As it is primarily heat requiring climate heat exchangers were added. Two separate AHU units are proposed as it easier to fit two smaller AHU units than one big one and separate exhaust air from heritage area that goes through under crawl space. It was assumed that with these heat losses it will be possible to supply air without big temperature difference so that heating coil could work with low temperature sources such as the one from the heat pump to work efficiently in order to create nearly zero energy building.

In VAV system fans would use less electricity and not run on 100% capacity for the whole year during occupied hours. However, this would add complexity and air distribution of the air would be harder to control.

Further analysis showed that the fans and ducts were sized for the maximum fresh air rate without the need to size them to higher air rates. CAV air system with variable supply temperature was chosen as a simple and easy to maintain solution.

a) Psychrometric sketches peak load and part load

Basic sketches were developed on A4 paper with psychrometric chart (Appendix A). These were created as a rough approximation for winter and summer peak load and part load to have a general idea. Simplified psychrometric chart is presented below. [Figure 1] Only single psychrometric chart is presented as both areas have the same systems, the only difference is heat exchanger efficiency, but the concept is the same.

		Heritage (132 m2)		Activity (131 m2)	
		Peak Load	Part Load*	Peak Load	Part Load*
With ventilation	$Q_{heating}$ [kW]	47,6	23,8	33,5	16,8
	$Q_{cooling}$ [kW]	13,7	6,8	9,8	3,6
Without ventilation	$Q_{heating}$ [kW]	9,0	4,5	6,0	3,0
	$Q_{cooling}$ [kW]	12,8+3,6	6,4+1,8	9,8+2,4	4,9+1,2

Table 1 - Loads with and without ventilation

*Part Load is 50% of peak load and 50% occupancy

One of the outputs from group coursework were $Q_{heating}$ and $Q_{cooling}$ peak and part loads. These values included ventilation load and were not be used for system sizing. Loads without ventilation were used [Appendix C and D].

$Q_{heating}$ is equal to enthalpy difference between points 3-R times maximum fresh air mass flowrate. For sizing heating coil points 1-2 were used, humidifier 2-3, cooling coil 5-4.

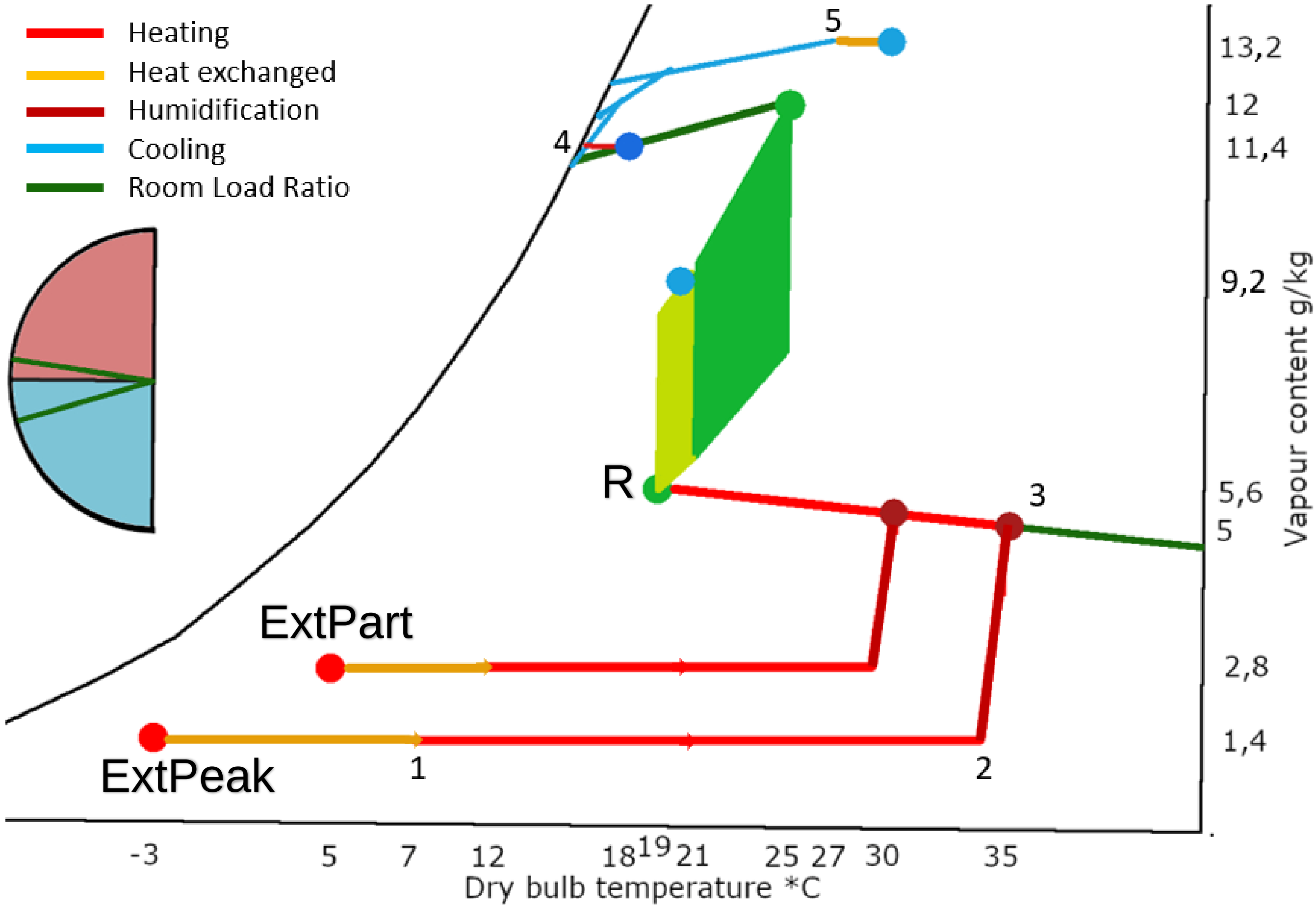


Figure 2 - Simplified psychrometric chart

b) Sizing equipment and manufacturer data

For sizing heating coil, cooling coil and humidifier enthalpies from 5 points were taken from psychometric chart. [Figure 1]

Two separate air handling units (AHU) for each area of the building are proposed to enable efficient control of each zone separately with possibility to place both on the attic as they are smaller than one AHU would be.

AHU components Sizing	Activity Area (AHU 1)	Heritage Area (AHU 2)
Fans	Supply 2880 m^3/s 300 Pa Extract 2880 m^3/s 250 Pa	Supply 4320 m^3/s 300 Pa Extract 4320 m^3/s 250 Pa
Cooling coil	DX coil 15.4 kW	DX coil 24.5 kW
Heating Coil	Hot water coil 15.4 kW	Hot water coil 30.2 kW
Humidifier	Evaporative 3.8 kW	Evaporative 5.8 kW
Heat exchanger	Rotary heat exchanger 85% efficiency	Crossflow Plate Heat Exchanger 65% efficiency

Table 2 - Sized components based on psychrometric chart

AHU components Manufacturer data	Activity Area (AHU 1)	Heritage Area (AHU 2)
Fans	Supply 2880 m^3/s 416 Pa Extract 2880 m^3/s 266 Pa	Supply 4320 m^3/s 338 Pa Extract 4320 m^3/s 224 Pa
Cooling coil Qc Tev	DX coil 25.8 kW 6*C	DX coil 39.2 kW 6*C
Heating Coil Qh Ts/Tr	Hot water coil 14.8 kW 45/40 °C	Hot water coil 28.6 kW 45/40 °C
Humidifier	Evaporative 19.2 kg/h	Evaporative 33.6 kg/h
Heat exchanger	Rotary heat exchanger 82% efficiency	Crossflow Plate Heat Exchanger 56% efficiency

Table 3 - Equipment sizes based on manufacturers data

c) Method of supplying and extracting air clearly explained and shown

Brief specifies that system for the activity area should be all air system. Activity area has 80 people and minimum fresh air of 0,8 m^3/s which is a quite substantial amount of air changes around 5,5 ach. This flow will be used to supply peak load for heating and cooling with temperatures at 17*C and 32*C.

Similarly, for heritage area with 120 people fresh air flow is around 1,2 m^3/s (8,3 ach). Maximum airflow will stay constant and CAV system will be our baseline for the analysis for both areas. That means that the ducts will be sized based on max fresh air flow: activity area 0,8 m^3/s, heritage area 1,2 m^3/s. Once duct size is calculated it will be fixed and won't be reinvestigated in further system analysis.

When choosing air distribution, it is important to focus on temperature gradient and ventilation efficiency. Ventilation efficiency is describing how well air distribution system can remove contaminants created internally in the space. Temperature gradient in that case is the difference between supply air temperature and space temperature. [1]

To high temperature gradient can lead to discomfort, it is especially critical when air is supplied straight to the occupied zone. For example: if air would be supplied at the floor level, then the temperature difference should not exceed 3K. [1]

Knowing all this I chose 2nd air distribution with supply on top and return on bottom.

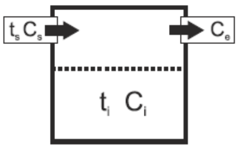
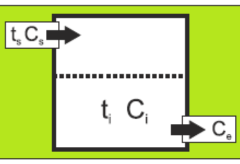
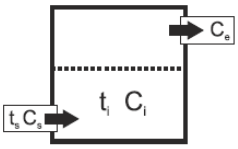
Air distribution	**Temperature difference** $T_S - t_i$, [K]	**Ventilation efficiency**
	< 0	0,9 ÷ 1,0
	0 ÷ 2	0,9
	2 ÷ 5	0,8
	> 5	0,4 ÷ 0,7
	< -5	0,9
	-5 ÷ 0	0,9 ÷ 1,0
	> 0	1,0
	> 2	0,2 ÷ 0,7
	0 ÷ 2	0,7 ÷ 0,9
	< 0	1,2 ÷ 1,4

Table 4 - Typical values for ventilation efficiencies in relation to air distribution and temperatures of supply air t_i and space t_S. [1]

To exhaust air from the space grilles would be places on the floor and ducts would be placed below floor level. It was assumed that under floor of heritage area exists 50 cm high under crawl space in which round 350 mm flexible duct insulated with 5cm of wool could be placed. Two and not one for the easier mounting.

Or whole under crawl space could be a duct, further analysis is needed. New activity area would not have under crawl space and would need duct 450 mm round duct or rectangular equivalent.

To place ahu in the attic it is proposed to move ceiling insulation just below the roof and use more efficient and thinner insulation for example 4 cm vacuum insulated panels (VIP) that have equivalent R-value to 22 cm of expanded polystyrene (EPS).

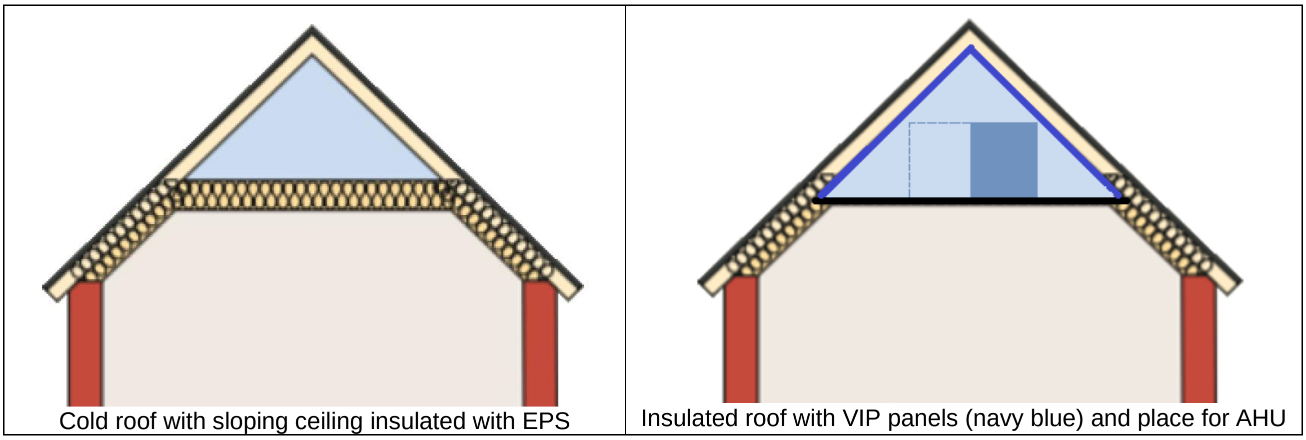


Figure 5 - Comparison of thickness and space on attic with two different insulation solutions

I. Schematic drawing for zones and equipment

Schematic drawing of AHU for sanctuary, same configuration for activity area (except for different heat exchanger type). Equipment specification and manufacturers data already presented in subchapter 1.b.

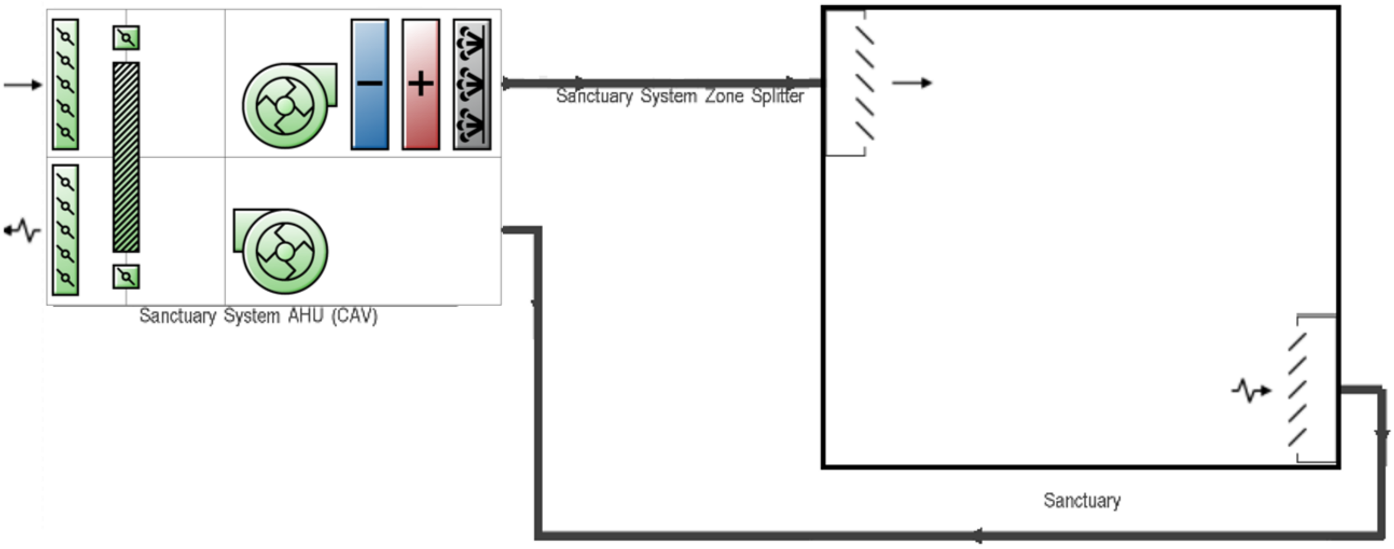


Figure 3 - Schematic drawing for system with components and zone

II. Floor plan with equipment and duct layout design.

Both areas are conditioned with air handling units. In sanctuary area air is supplied with 8 slot diffusers and exhausted through the under-crawl space to the round duct and back to AHU. In activity area air is also distributed at the top but with the 4 long horizontal grilles.

First design had air extracted from the activity area through 4 extract grilles located on the floor and connected into single insulated duct located below the slab. Inlet and outlet ducts are located on the facade with at least 3 m distance between each other.

Second design accounted for the fact that activity area is 20 m long, the gradient of the temperatures inside might be too great during peak demands if supplied only from one side with grilles. Activity area supply air distribution was redesigned with textile ducts with directional micro perforation to evenly supply air and coolth to the space. Additionally, meeting acoustics target and low maintenance target as textile ducts are much better in meeting these targets compared to metal ducts.

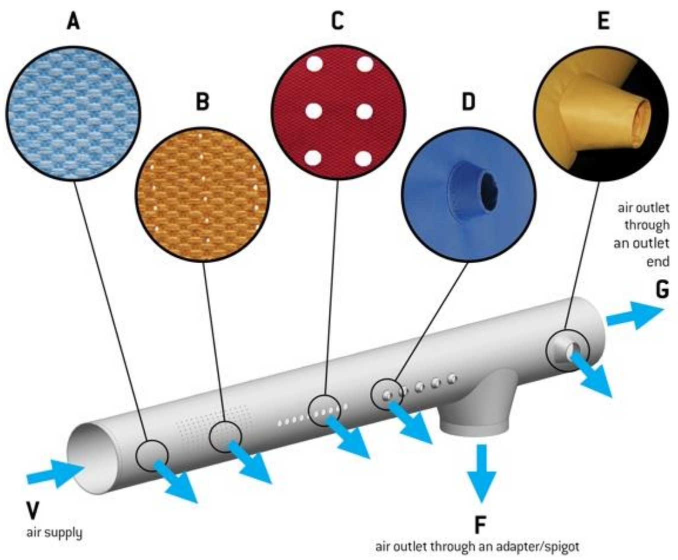


Figure 5 - Textile duct perforation types

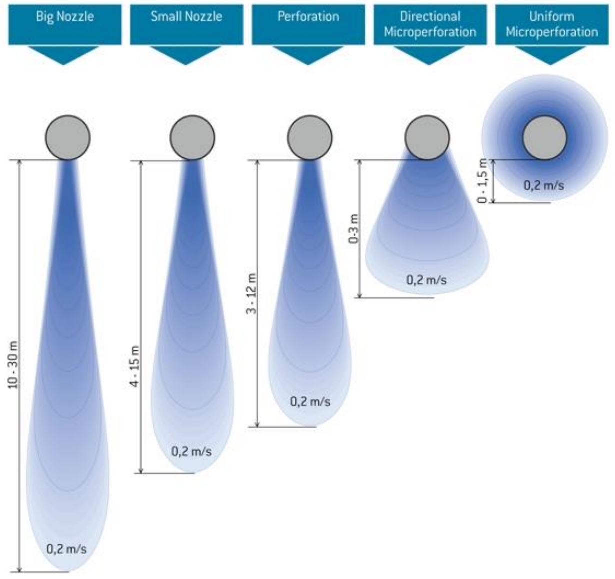


Figure 4 - Vertical throw for 0.2 m/s for different type of perforations on textile ducts

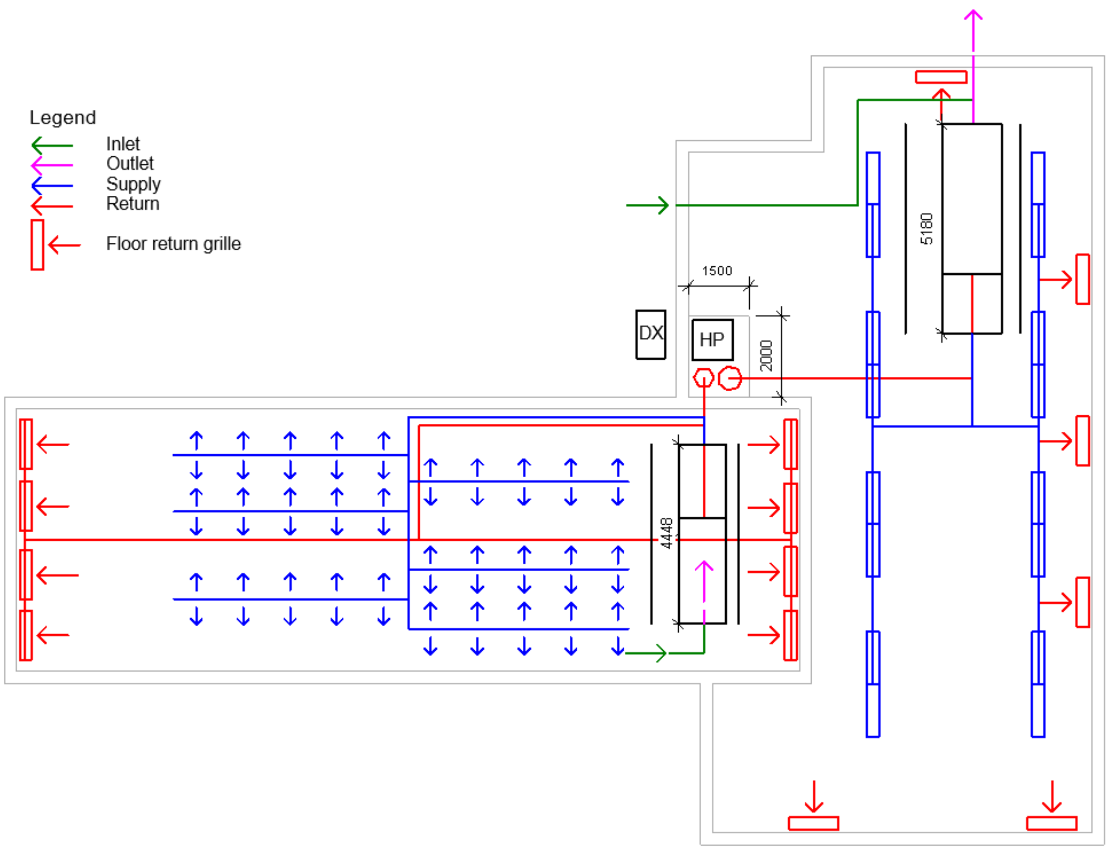


Figure 5 - Floor plan with concept design

Part of heritage area was used as a technical room with place for two return ducts and space for ground source heat pump with hot water tank. Technical room is fitted in the corner in a cabinet 2m x 1,5m x 3m. Outside of that wall is an external unit for direct expansion (DX) system that has compressor, condenser and thermal expansion valve. Technical room was placed in this location as it is more less in the centre of whole building and an area which is not the most representative area.

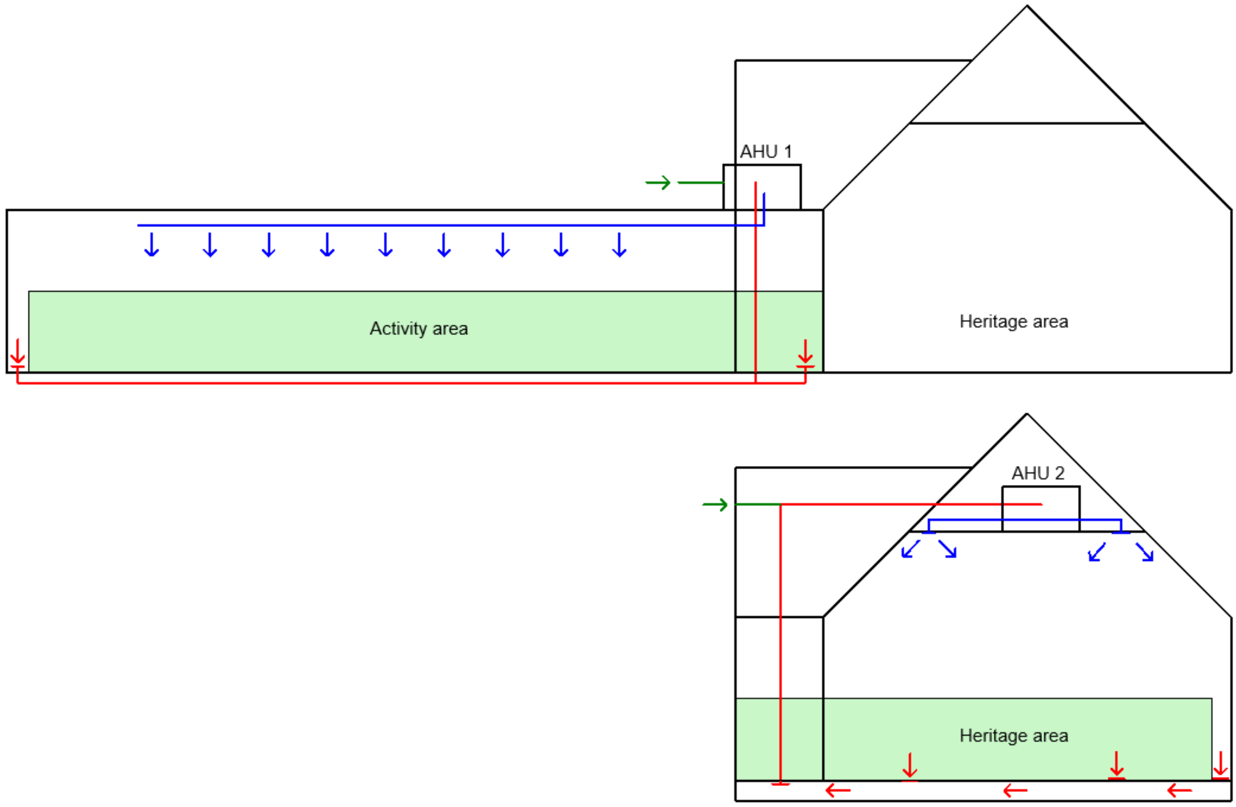


Figure 6 - Sections for activity and heritage area with visible air distribution

2. Adjusted Building Benchmark for the whole building

Building type: Entertainment - social clubs
Gross floor area: 290 m^2
Location: 7 West Pennines
Climate: 2037 HDD (reference value 2021 HDD), 1% difference
Hours of occupancy: 12*365 = 4380

Emission factors used to calculate CO_2 benchmarks for electricity: 0.55 kgCO2/kWh was taken from TM46: 2008 Table 3. No fossil-fuel is used designed system.

According to CIBSE Guide F [2] social clubs typical practice benchmark for electricity is 110 and good practice is 60 kWh/m^2*year. Designed building EPC is calculated to be around 103 kWh/m^2*year, which is just above typical practice.TM 46 did not have good building category that would reflect coursework community centre with that high occupancy counts. Note: calculations do not have energy use for humidification and pumps.

Values for table 6 were simulated in DesignBuilder 6.9 with detailed HVAC for one year.

	Electricity used [kWh]	Energy produced [kWh]	Carbon emission [kgCO_2]
Heating	20072	80288	11040
Cooling	653	1959	359
Fans	789	789	434
DHW	8352	25056	4594
Total	29866	108092	16426
W/m^2	103	373	57

Table 6 - Electricity used, energy produced and carbon emission for each system component for the whole building.

Above data in table could be used to create Energy Performance Certificate (EPC) and would show energy consumption for heating cooling, air conditioning systems and domestic how water (DHW).

Additionally, it should have fixed lighting, it is not added as it was not in the main scope of the analysis. The difference between EPC and Display Energy Certificate (DEC) is that EPC is taken calculated with the help of simulation tool and data used is standardized average or median value for specific building type and use, but DEC is real data measured and aggregated for example after 1 year to show what that building really used.

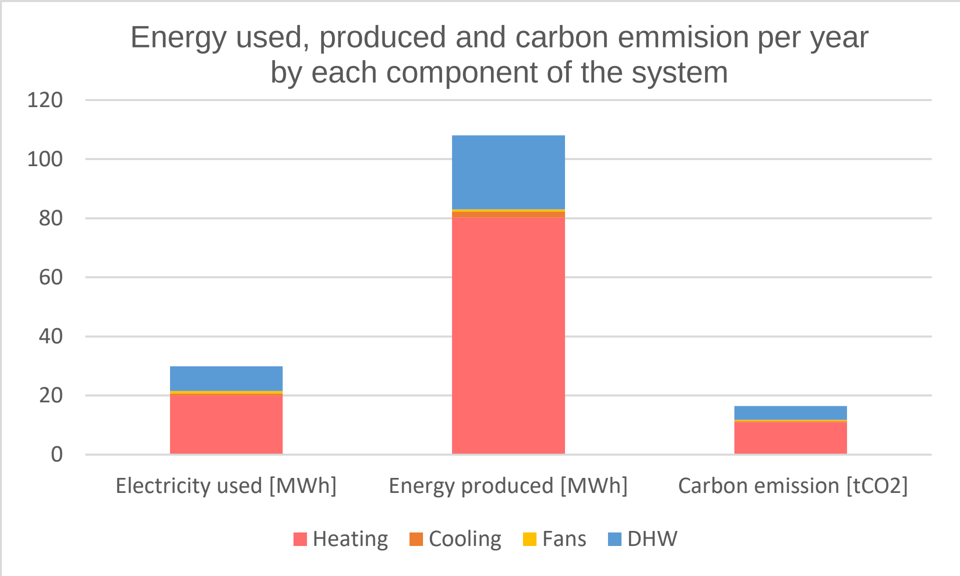


Figure 7 - Electricity used, energy produced and carbon emission for each system component for the whole building.

3. Lessons learned from visiting experts

During this module we had lecturers with expert practitioners such as:

Frank Mills - *Designing for net-zero.* Understanding climate change and its implications. Open question that designer should design for future climate and if so, should it be also standardized? Solutions in building sector that help in designing smallest possible life cycle carbon footprint buildings.

David Arnold - *Moving 20th-century building HVAC into sustainable operation for the 21st-century.* Simulate systems and whole building if possible, to check how it will behave without the need to build it.

Nishesh Jain - *DesignBuilder workshop* – Learning how to model in DesignBuilder which was used to simulate buildings heat gains, heat losses and systems.

Ant Wilson - *The evolution of computer tools for robust integrated building services solutions.*

Sung-Min Hong - *Benchmarking the Operational Energy Efficiency of Non-domestic Buildings*. Methodology for benchmarking and understanding the differences between EPC and DEC.

Phil Jones – *How can we decarbonise heat in the UK?* with good applications of heat pumps. Ground source heat pump was used in the coursework.

Phil King - which gave good insight into designing building as a whole and not only optimizing single system. Understanding BIM methodology which could have been applied when talking with architects or other engineers.

Kevin Mitchell – about *Large scale project delivery* project management, communication, bidding where focus is on different issues than in small scale projects.

4. Establishing and monitoring personal work plan

The basis of the work plan is to create work breakdown structure (WSB) to know exactly what needs to be done without the need to structure it in a chronological order.

1. BSDO Individual CW
    a. Psychrometric charts
        i. For peak and part load
            1. DesignBuilder heating design
            2. DesignBuilder cooling design
            3. Draw processes for heating and cooling
    b. Produce effective and efficient all air system for activity area
        i. Possible solutions
        ii. Component sizing
        iii. Specify manufacturer components
    c. Produce effective and efficient system for heritage area
    d. Floor plan with duct layout and equipment
    e. Schematic drawing of system
    f. Adjusted building energy benchmark
        i. Simulate energy use with manufacturers data
            1. DesignBuilder annual simulation
        ii. Building type
        iii. Location
        iv. Occupancy
    g. Reflect on knowledge of visiting practitioners
    h. Personal work plan
    i. Produce report

d) Original plan

Within first week WBS was not prepared, there was only a single target to meet – finish coursework one week before original deadline – 30th of March to have more time for other projects.

e) Monitored work

As the situation changed due to unpredictable reason, focus was on other aspects. There was almost no measurable progress in the first three weeks of march. Report was finished on 8th of April.

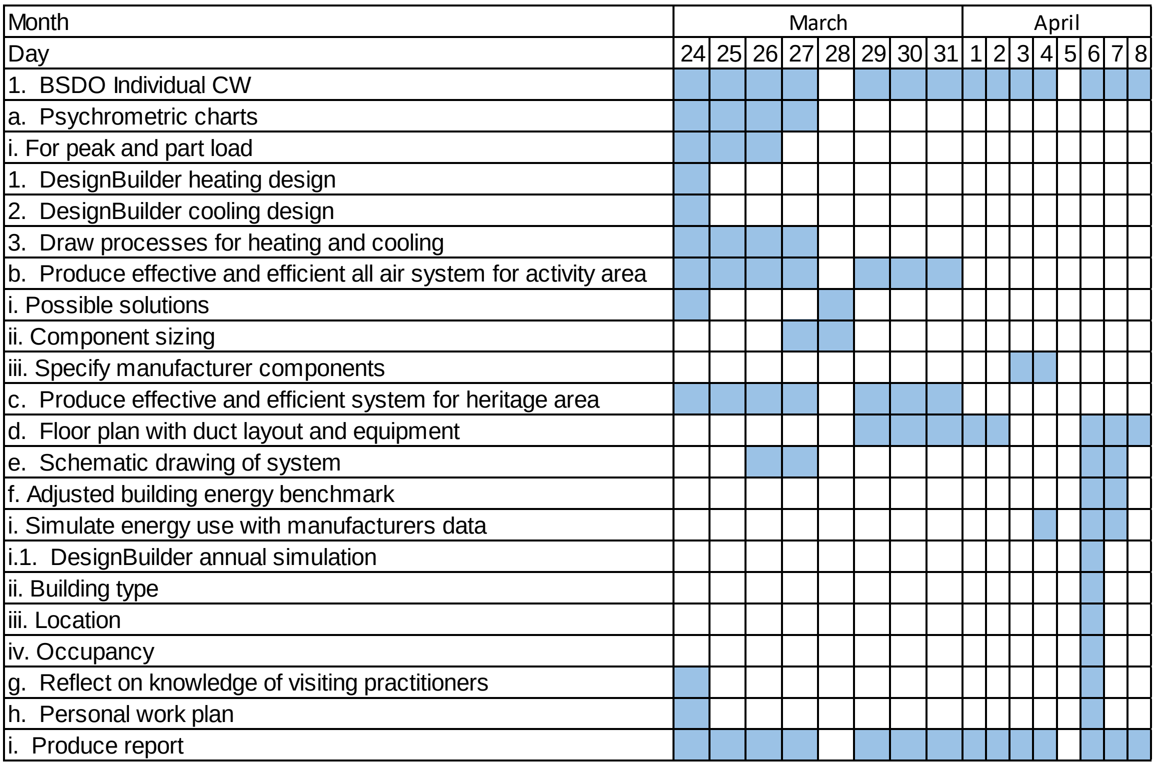


Figure 8 - Gant chart for monitored work

5. References

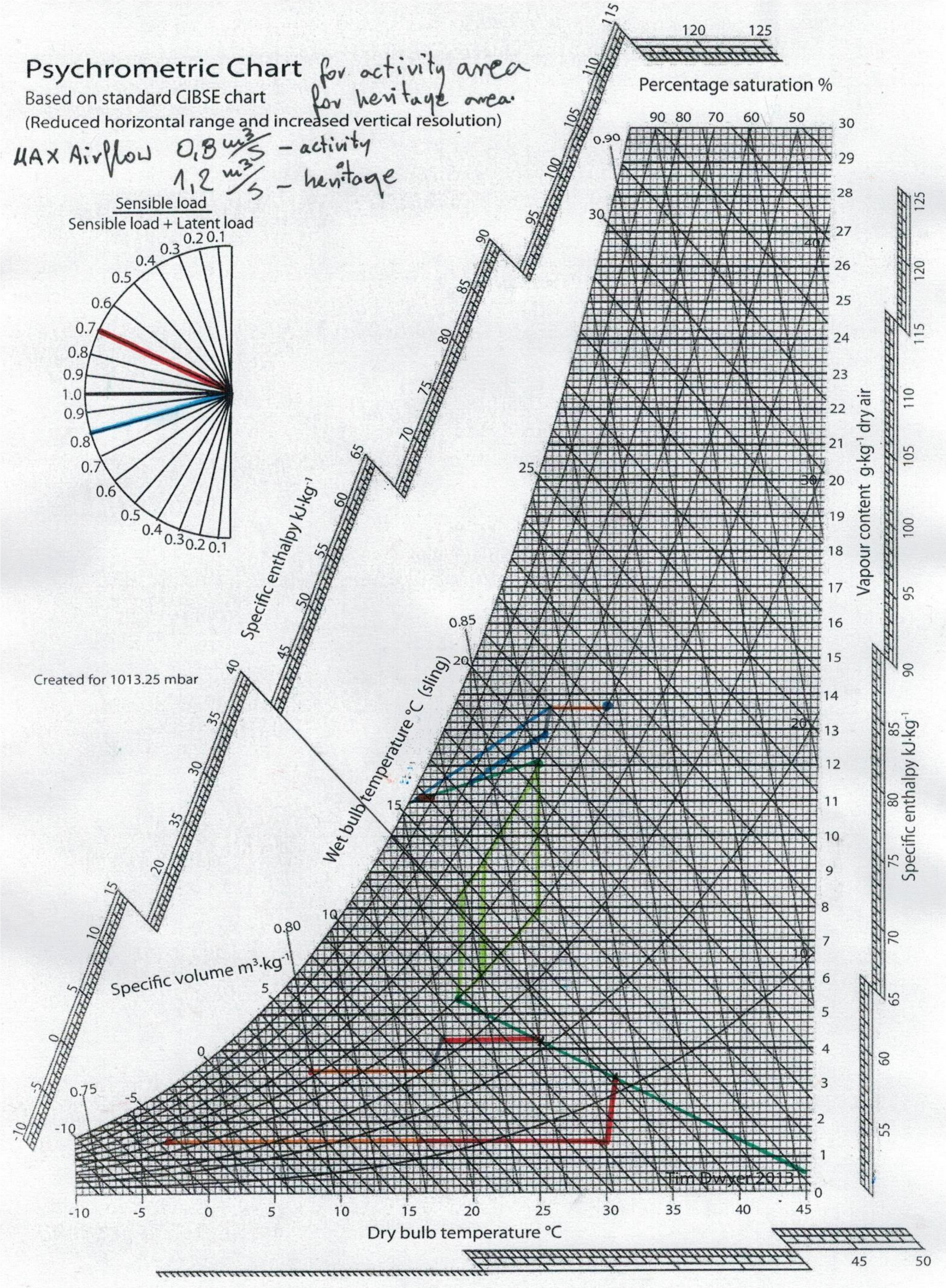
1. J. Hendiger, P. Ziętek, M. Chludzińska, Venture Industries, (2014), Wentylacja i Klimatyzacja – Materiały pomocnicze do projektowania

2. CIBSE, (2012), Guide F

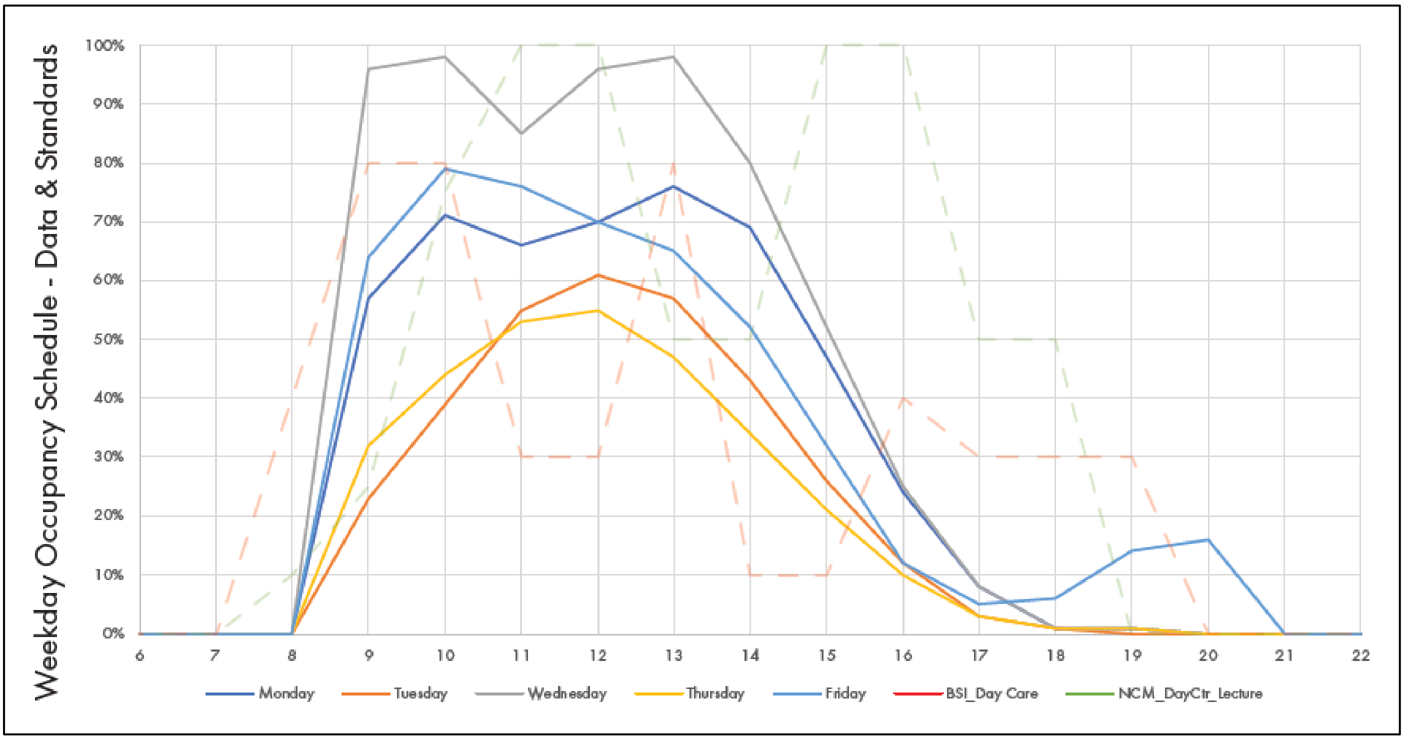
3. CIBSE, (2008), TM 46: 2008 – Energy benchmarks

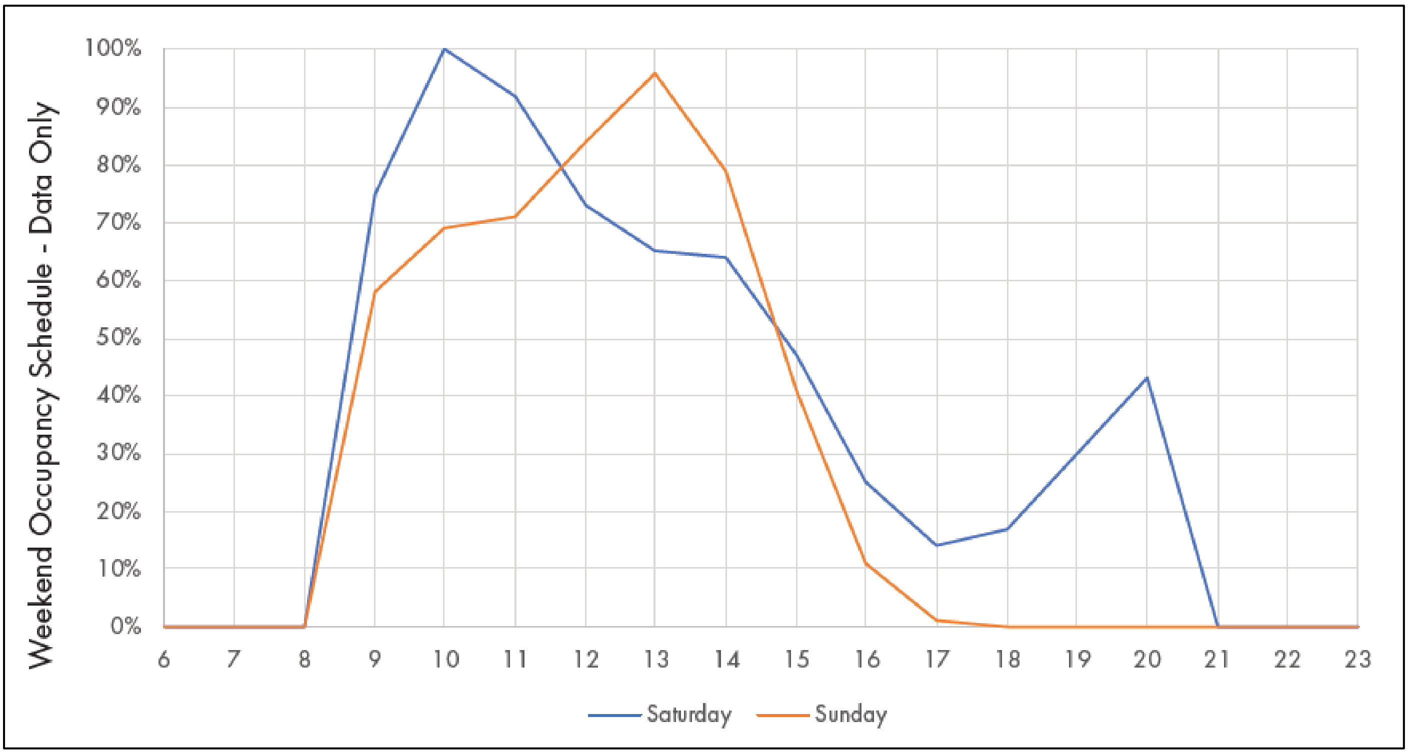
4. D. Oughton, A. Wilson, AECOM, (2015), Faber & Kell's Heating and Air-conditioning of Buildings 11th ed.

Appendix A – Psychrometric Chart



Appendix B - Occupancy Schedules





Appendix C – Heating design - DesignBuilder 6.9

BSDO_Aughton, Mossack Park Golf Club, Building 1, Activity Space

Steady-state | Summary

Temperature and Heat Loss

EnergyPlus Output

Student

Air Temperature (°C)	22,63
Radiant Temperature (°C)	19,37
Operative Temperature (°C)	21,00
Outside Dry-Bulb Temperature (°C)	-2,90
Glazing (kW)	-1,52
Walls (kW)	-0,72
Ground Floors (kW)	-0,06
Partitions (int) (kW)	0,00
Roofs (kW)	-0,81
External Infiltration (kW)	-3,42
External Vent. (kW)	-23,01
Zone Sensible Heating (kW)	29,54

BSDO_Aughton, Mossack Park Golf Club, Building 1, Heritage Building

Steady-state | Summary

Temperature and Heat Loss

EnergyPlus Output

Student

Air Temperature (°C)	22,29
Radiant Temperature (°C)	19,71
Operative Temperature (°C)	21,00
Outside Dry-Bulb Temperature (°C)	-2,90
Glazing (kW)	-0,65
Walls (kW)	-2,31
Ceilings (int) (kW)	-0,00
Floors (int) (kW)	0,01
Partitions (int) (kW)	-0,00
Roofs (kW)	-0,22
Floors (ext) (kW)	-0,02
External Infiltration (kW)	-5,90
External Vent. (kW)	-34,51
Zone Sensible Heating (kW)	43,62

Appendix D – Cooling design – DesignBuilder 6.9

BSDO_Aughton, Mossack Park Golf Club, Building 1, Activity Space

Analysis | Summary

Temperature and Heat Gains - Activity Space

EnergyPlus Output — 15 Aug, Sub-hourly — Student

Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Air Temperature (°C)	25,13	24,47	24,08	22,46	22,54	22,85	22,60	22,00	27,46	27,82	26,76
Radiant Temperature (°C)	26,13	25,46	25,92	27,65	27,43	27,11	27,47	28,07	28,92	28,52	27,67
Operative Temperature (°C)	25,63	24,97	25,00	25,06	24,99	24,98	25,04	25,03	28,19	28,17	27,22
Outside Dry-Bulb Temperature (°C)	19,59	19,00	19,00	21,37	24,94	27,41	28,70	28,11	26,32	23,75	21,97
Glazing (kW)	-0,50	-0,49	0,32	1,12	0,92	0,57	1,04	1,46	0,83	-0,43	-0,46
Walls (kW)	0,45	0,38	-0,15	-0,24	0,06	0,09	0,06	0,14	-0,88	0,36	0,48
Ground Floors (kW)	0,35	0,51	-0,76	-1,24	-0,25	0,04	-0,61	-1,08	-2,12	-0,28	-0,07
Partitions (int) (kW)	0,01	0,04	-0,19	-0,33	-0,13	-0,11	-0,16	-0,17	-0,68	-0,21	-0,09
Roofs (kW)	0,16	0,05	-0,66	-0,90	-0,19	0,26	0,49	0,69	-0,23	0,67	0,48
External Infiltration (kW)	-0,69	-0,68	-0,63	-0,13	0,29	0,55	0,73	0,74	-0,14	-0,50	-0,59
External Vent. (kW)	0,00	0,00	0,00	0,00	2,06	4,46	3,03	0,47	0,00	0,00	0,00
General Lighting (kW)	0,00	0,00	0,00	0,10	0,10	0,10	0,10	0,10	0,00	0,00	0,00
Occupancy (kW)	0,00	0,00	0,00	5,88	5,28	5,96	3,17	0,51	0,04	0,00	0,00
Solar Gains Exterior Windows (kW)	0,00	0,00	2,78	5,30	3,42	1,74	3,05	5,40	4,12	0,00	0,00
Zone Sensible Cooling (kW)	0,00	0,00	-0,73	-9,69	-9,07	-8,83	-8,04	-7,93	-0,01	0,00	0,00
Sensible Cooling (kW)	0,00	0,00	-0,73	-8,46	-11,10	-13,26	-11,05	-8,40	0,00	0,00	0,00
Total Cooling (kW)	0,00	0,00	-0,73	-8,55	-11,38	-13,26	-11,86	-8,82	0,00	0,00	0,00
Relative Humidity (%)	46,69	48,56	49,70	63,32	61,66	61,74	59,84	57,37	41,09	39,96	42,41
Mech Vent + Nat Vent + Infiltration (ac/h)	0,71	0,71	0,71	6,07	5,43	6,17	3,59	1,13	0,76	0,71	0,71

BSDO_Aughton, Mossack Park Golf Club, Building 1, Heritage Building

Analysis | Summary

Temperature and Heat Gains - Heritage Building

EnergyPlus Output — 15 Aug, Sub-hourly — Student

Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Air Temperature (°C)	24,85	24,53	24,22	23,70	23,33	23,05	23,10	23,40	26,13	26,10	25,62
Radiant Temperature (°C)	26,13	25,87	25,67	26,34	26,69	26,99	26,89	26,59	26,79	26,74	26,59
Operative Temperature (°C)	25,49	25,20	24,95	25,02	25,01	25,02	25,00	24,99	26,46	26,42	26,11
Outside Dry-Bulb Temperature (°C)	19,59	19,00	19,00	21,37	24,94	27,41	28,70	28,11	26,32	23,75	21,97
Glazing (kW)	-0,20	-0,20	0,02	0,38	0,65	0,75	0,91	0,75	0,31	-0,13	-0,16
Walls (kW)	1,06	1,08	0,85	-0,19	-0,11	-0,17	0,25	0,71	-0,27	0,40	0,74
Ceilings (int) (kW)	0,02	0,03	0,02	-0,09	-0,08	-0,08	-0,04	0,00	-0,07	-0,03	-0,01
Floors (int) (kW)	0,13	0,21	0,06	-0,58	-0,54	-0,61	-0,42	-0,12	-0,80	-0,16	-0,08
Partitions (int) (kW)	0,10	0,07	0,01	-0,08	0,03	0,02	0,06	0,11	-0,17	0,14	0,16
Roofs (kW)	-0,08	-0,09	-0,13	-0,13	0,04	0,17	0,27	0,30	0,12	0,12	0,01
Floors (ext) (kW)	-0,00	-0,00	-0,01	-0,01	0,00	0,01	0,01	0,01	-0,00	0,00	-0,00
External Infiltration (kW)	-1,14	-1,20	-1,14	-0,50	0,34	0,92	1,18	0,99	0,04	-0,50	-0,79
External Vent. (kW)	0,00	0,00	0,00	0,00	2,15	6,53	4,44	0,57	0,00	0,00	0,00
Occupancy (kW)	0,00	0,00	0,00	8,22	7,54	8,88	4,71	0,71	0,07	0,00	0,00
Solar Gains Exterior Windows (kW)	0,00	0,00	0,59	1,29	1,73	1,98	2,16	1,91	1,17	0,00	0,00
Zone Sensible Cooling (kW)	0,00	0,00	-0,32	-8,46	-9,66	-11,96	-9,07	-5,26	-0,00	0,00	0,00
Sensible Cooling (kW)	0,00	0,00	-0,32	-5,05	-11,78	-18,44	-13,48	-5,84	0,00	0,00	0,00
Total Cooling (kW)	0,00	0,00	-0,33	-5,06	-11,81	-18,47	-13,65	-6,25	0,00	0,00	0,00
Relative Humidity (%)	47,49	48,40	49,22	58,45	58,73	59,58	58,45	53,28	44,34	44,17	45,35
Mech Vent + Nat Vent + Infiltration (ac/h)	1,02	1,02	1,02	7,62	6,81	7,72	4,55	1,53	1,07	1,01	1,01