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Individual Assignment Cover Sheet

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Course code: MECH4880 **Course name:** Refrigeration and Air Conditioni

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Student number: z5038392 **Course Convenor name:** ____________

Assignment: Assignment 1

Assignment due date: 18/09/2016 **Date submitted:** 18/09/2016

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Contents

1. Introduction

1.1 Design Task

The aim of this assignment is to design the HVAC system for a building with a basement carpark. The assignment is divided into two parts. The first part is to calculate the heat load. The second part is to perform preliminary duct design as well as unit selection for this building.

1.2 Design Requirement

The design requirement is listed below in Table 1

Table 1 Outside design conditions

Latitude	30° South
Summer	33.8°C DB / 22.9°C WB
Winter	2.1°C DB / 80% RH

Definition of building north is 30°C clockwise from true north.
Minimum supply air temperature is 12°C
Cooling coil effectiveness is 0.85
Outside air temperature is 10L/s per person

1.3 Assumptions

(1) Room 212 and room 213 have the most people at 3 pm.
(2) There is no sun light on 21st June at 7 am.
(3) Carpet should be installed on carpet underlay due to underlay can support carpet and make it quieter. (http://www.carpetcourt.com.au/faqs)
(4) False ceiling is made of gypsum plaster (sand) as room 212 and room 213's ceiling/roof material.(http://www.british-gypsum.com/product-range/plaster-products/10-things-you-should-know-about-plaster)
(5) According to Table 25 on DA09[2], we choose brick veneer with 90mm brick, 150mm air gap and a plaster-board 12mm. U-values for this brick veneer combined with plaster are 2.03W/m^2°C in summer and 2.09W/m^2°C in winter.
(6) The thickness of marble, I assume a thickness of 20mm due to its availability in Sydney. http://www.marable.com.au/marble/.
(7) We use steel sash window: k_1 = 1.17
(8) No haze in Australia, so haze correction factor: k_2 = 100%
(9) This building is right on sea level. Altitude correction factor: $k_3 = 101.4\%$

(10) Dew point correction factor: $k_4 = 102.1\%$

(11) There are 35 people sitting and the rest 45 people are standing at peak time in 212.

(12) We assume the opening hours is from 9am from 9pm the same as Westfield in Sydney https://www.google.com/search?q=google&rct=j#q=westfield+opening+hours

(13) It is fluorescent lights suspended ceiling or exposed incandescent lights due to that we have a suspended ceiling in room 212 and 213.

(14) Windows are all gasketed.

(15) This shopping mall located in Temperate Town opens between from 9am to 9pm

2. Design Day Selection and Specification Comprehension

2.1 Design Day Selection

2.1.1 Definition of Design Days and the Significance to Heat Load Calculation

Design days are days that have the most extreme working conditions (highest cool load and heat load). If HAVC designed can work effectively on design days, then it can cope with the rest days whose working conditions are not as harsh as design days' working conditions. Working conditions for HAVC contain two aspects: external loads and internal loads. For the hottest design day, compared with ordinary days it must have the highest external and internal loads. For the coldest design day, it should have the lowest external loads and internal loads.

2.1.2 Summer and Winter Design Days Selection

For external sunlight part, the latitude of our target shopping mall is 30^{o} South from design constraints part in assignment 1. In southern hemisphere, summer is between December and February, and winter is between June and August. Correspondingly, the hottest day theoretically occurs on summer solstice 21st June and the coldest day happens on winter solstice 22nd December. On summer solstice southern hemisphere including Australia receives the longest sunlight hours and of course the strongest sun radiation leading to the hottest day. On the contrary, on winter solstice southern hemisphere receives the shortest sunlight hours and weakest sun radiation resulting in the coldest external condition.

After design days are determined, design hours in winter and summer should be determined as well. According to CAMEL, daily and yearly range is shown below in Figure 1.

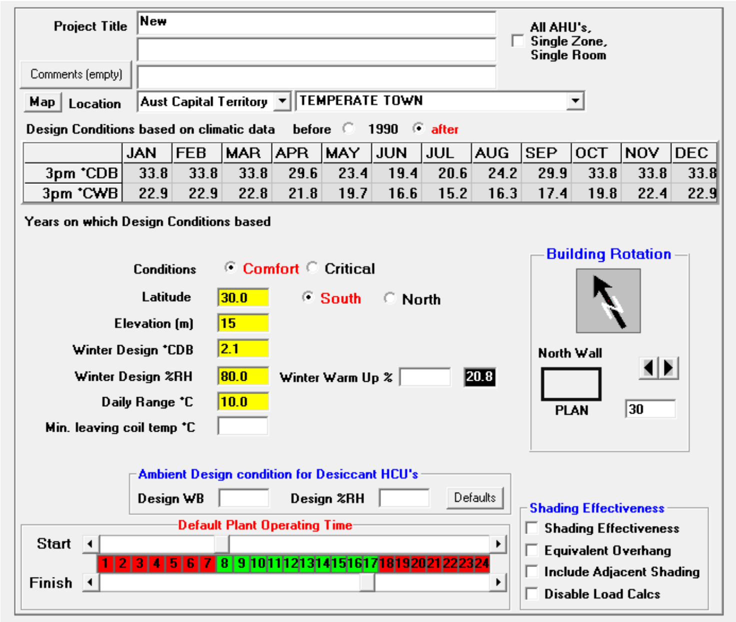


Figure 1 Daily and yearly temperature range from CAMEL

Yearly range is 33.8-2.1=31.7°C and daily range is 10°C. According to Table 2 in DA09[2], the correction temperature with a daily range of 20 °C is highest at 3pm, which is 0°C. Also, based on our assumption that there are most people at 3pm, so design hour in summer is 3pm, 22nd December. According to Table 2c OCCUPANCY AND OPERATION PROFILES OF A CLASS 6 SHOP OR SHOPPING CENTRE in NCC 2016[3], there is no people at 7am, which brings the least internal loads. Based on our assumption that there is no sunlight at 7pm on 21st June, external and internal heat is the lowest. So deign hour is 7 am on 21st June.

2.2 Specification comprehension

2.2.1Design Conditions (Internal and External)

According to Assignment 1 – Project Specifications[6], external conditions and internal external conditions are listed in Table 2 and Table 3 below:

Table 2 External Conditions

External Conditions	
Summer	33.8°C DB / 22.9°C WB
Winter	2.1°C BD / 80% RH
External Glazing and Skylights	Food court fa çade: U = 5.48 SHGC=0.435 Skylights: U = 5.26 SHGC = 0.574 All other glazing: U=5.62 SHGC = 0.611
External Walls, Floors and Roofing	External walls: R = 2.6 Floors: R = 1.5

	Roofing: R = 3.2 Absorbance = 0.5 (light colour) Values are as above unless the surface does not compliance with NCC2016 Section J then raise to minimum value as specified by Section J
Storage Mass	Can be assumed as 420 kg/m^2

Table 3 External Conditions

Internal Conditions	
Outside Air Requirement	10L/s.person
Internal Walls	Internal Walls and Partitions: R = 1 Internal Floors and Ceilings: See External Values are as above unless the surface does not compliance with NCC2016 Section J then raise to minimum value as specified by Section J
Internal Glazing	6mm plate glass as defined in DA09

2.2.2 Ceiling Height and True Floor Height

Ceiling height is the distance from one floor's slab to its ceiling. True floor height is the distance from one floor's slab to upper floor's slab. Actually there is space above ceiling and below slab. According to south west view in elevational view in Figure 2, true floor height is 6000mm and ceiling height is 4500mm (this is because false ceiling space is 1.5m high based on Assignment 1 – Project Specifications)[6].

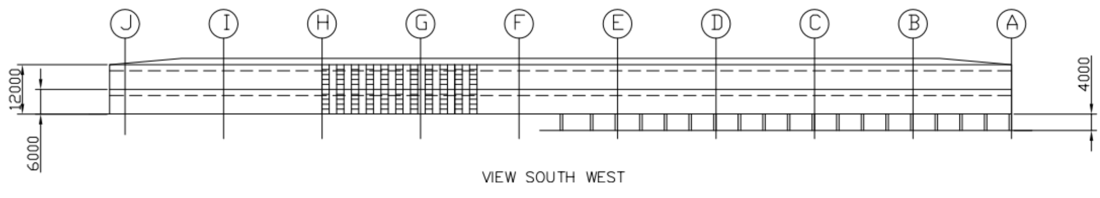


Figure 2 South west view in elevation view

2.2.3 Definition of Glazing, Partition, Infiltration, AHU

Glazing: glass part of walls and windows
Partition: division walls between inner rooms
Infiltration: it is sometimes called air leakage. Due to wind and pressure difference, outside and inside air transfer through cracks in rooms.
AHU: air handling unit as a device as part of HVAC system is utilized to regulate and circulate air.

2.2.4 Daily and Yearly Temperature Ranges

As Figure 1 Daily and yearly temperature range from CAMEL shows, daily range is 10°C and yearly range is 33.8-2.1=31.7 °C as the following figure 3 shows.

3. Wall Specifications

3.1 Difference Between U-Value and R-Value

Both U-value and R-value (thermal resistance) are parameters measuring energy efficiency. R-value, on the hand, is a property value of materials. It measures resistance to heat transfer. U-value calculates the rate at which heat transfers through 1 square meter of material. It also measures how well materials can keep heat inside. In calculation $\mathrm{U} = 1/\mathrm{R}$.

3.2 U-Value Calculation Made from a Series of Layers of Differing Materials.

When calculate R-value and U-value for compounded wall, R-value should be calculated first based on the parameters of each layer's materials. After R-value of all components of a wall is determined, R-value in total is the sum of each sub-R-value $R_{total} = R_1 + R_2 + R_3 + \cdots + R_n$. Then U-Value can be calculated by using this formula $\mathrm{U} = 1/\mathrm{R}$.

3.2.1 Layers in Series.

As shown in the following Figure 3, three layers of different materials are combined together. Each layer has its own thickness (h_1, h_2 and h_3 respectively, SI Units) and thermal resistance (R_1, R_2 and R_3 respectively, SI Units).

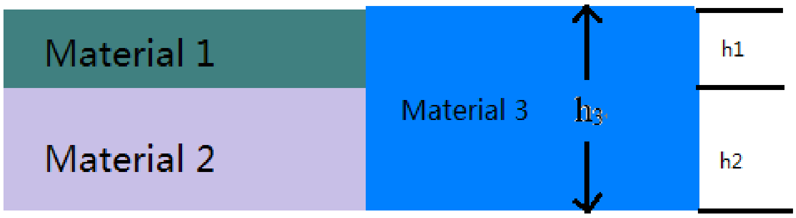
$$R_{total} = R_1 * h_1 + R_2 * h_2 + R_3 * h_3$$

$$U = \frac{1}{R_{total}} = \frac{1}{R_1 * h_1 + R_2 * h_2 + R_3 * h_3}$$

Figure 3 R-value calculation of layers in series

3.2.2 Layers in Parallel

As shown in the following Figure 4, layer 1, layer 2 and layer 3 have three different materials. At the mean time layer 1 and layer 2 are in series, these two layers together are in parallel to layer 3. Their thicknesses are h_1, h_2, h_3 respectively.



$$R_{total} = \frac{1}{\frac{1}{R_1 + R_2} + \frac{1}{R_3}} = \frac{R_3(R_1 + R_2)}{R_1 + R_2 + R_3}$$

$$U = \frac{1}{R_{total}} = \frac{R_1 + R_2 + R_3}{R_3(R_1 + R_2)}$$

Figure 4 R-value calculation of layers in parallel

3.3 Different Values in Winter and Summer

External conditions such as wind speed as well as position of air film/space impact U-values by affecting R-values of air film or air space.

3.4 U-Values Calculations for All Surfaces in Shops 212 and 213

3.4.1 Floor (212 & 213)

Room 212 and room 213 share the same floor structure. According to Assignment 1 (2016) – Project Specifications[6], floor between ground level and first level has 150mm concrete slab covered with carpet above. Also, there is a 1.5m false ceiling space below floor. We need to note that carpet should be installed on carpet underlay due to underlay can support carpet and make it quieter. Another factor needs to be considered is that there are internal air films (still air) on both sides of floor and on both sides of false ceiling. Before calculation of U-value of floor, The structure of floor is shown in the following Figure 6.

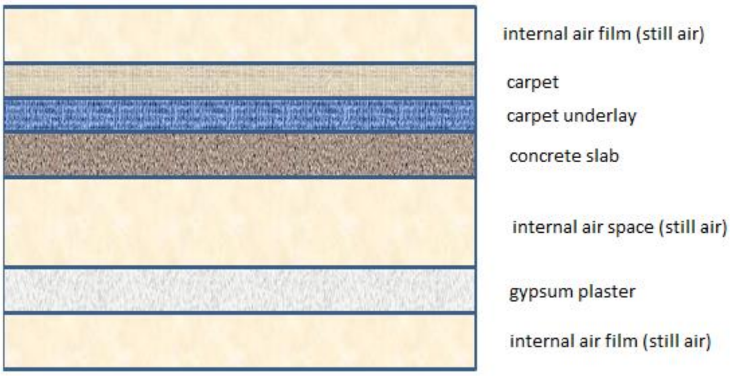


Figure 6 Floor structure

According to Table 37 Thermal Resistance R-Building and insulating Materials (Cont.) in DA09[2], materials' resistivity and its corresponding thickness (some values of thickness are required and thickness with signal # is assumed) can be found in the following Table 4:

Table 4 Properties of each component of floor

Component	Thickness mm	Resistivity (1/k) m°C/W	R-values m^2°C/W
air space (still air)	1500	1.5	3.255
air film (still air)	/		0.162
carpet	6#	17.5	0.105
carpet underlay	15#	21.4	0.321
crushed rock, 1:2:4	150	0.69	0.104
gypsum plaster (sand)	8#	1.54	0.012

When choosing R-values of air space and air film, considerations should be taken into direction of heat flow. Due to the fact that M02 is below room 212 and room213, summer set point and winter set point of M02 are 22^{o}C Dry Bulb and 20^{o}C Dry Bulb respectively which are lower than those of 212 and 213's, which are 24^{o}C Dry Bulb and 21^{o}C Dry Bulb respectively according to Assignment 1 – Project Specifications[6]. So heat flow direction is down. Air space between concrete and false ceiling is in the same situation. R-value of carpet should vary from 0.119-0.09m^2°C/W and R-value of carpet underlay should fluctuate between 0.400-0.242m^2°C/W.

R-value of floor: $R_{floor(212\&213)} = 2 * R_{air\ film} + R_{carpet} + R_{carpet\ underlay} + R_{crushed\ rock} + R_{air\ space} + R_{gypsum\ plaster} = 4.121\text{m}^2\text{°C/W}$

U-value of floor: $U_{floor(212\&213)} = \frac{1}{R_{floor(212\&213)}} = 0.243\text{W/m}^2\text{°C}$

3.4.2 Ceiling and Roof

According to the Project Specifications and Elevational Views[4], the structure of ceiling and roof is shown below in Figure 7.

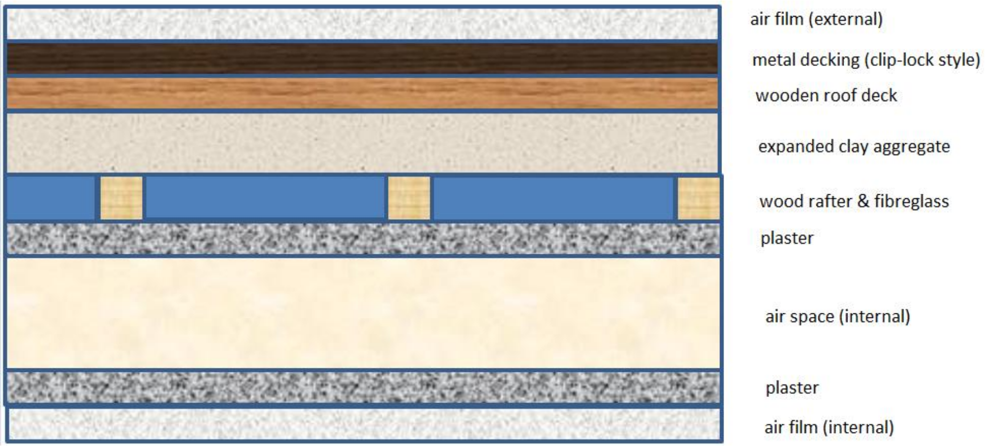
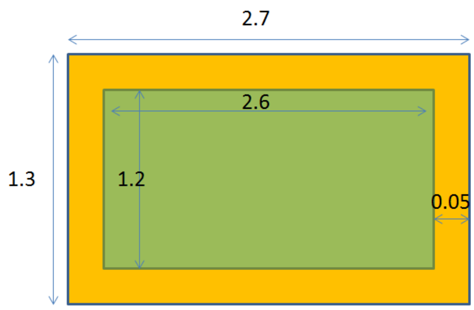


Figure 7 Structure of ceiling and roof

For structure of wood rafter and fibreglass, the structure is shown below in Figure 8



Figuire 8 structrue of wood rafter with fibreglass

Area of insulation A_1 is 3.12m^2, area of timer A_2 is 0.39m^2 and total area of unit A_{total} is 3.51m^2. Resivity of each material can be found in Table 37 DA09[2]. The thickness of each component is 0.1m.

$$\frac{1}{R_a} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{3.12}{0.1 * 31.52} + \frac{0.39}{0.1 * 6.25} = 1.414W/°\mathrm{C}$$

So $R_a = \frac{1}{1.414} = 0.42°\mathrm{C}/W$ and $R = R_a * A_{total} = 0.42 * 3.51 = 2.17m^2°\mathrm{C}/W$

Density of each component can be found in Table37 DA09[2]: $\rho_1 = 104kg/m^3$ $\rho_2 = 769m^3$

$$m_1 + m_2 = m_{total}$$

$$\rho_1 V_1 + \rho_2 V_2 = \rho_{total} V_{total}$$

$$104 * 3.12 * 0.1 + 769 * 0.39 * 0.1 = \rho_{total} * 0.1 * 3.51$$

So $\rho_{total} = 177.89kg/m^3$

Materials' resistivity and its corresponding thickness (some values of thickness are required and thickness with signal # is assumed) can be found in the following Table 5:

Table 5 Properties of each layer of ceiling and roof

Component	Thickness mm	Resistivity (1/k) m°C/W	R-values (m^2°C/W)
air film (external)*	/		Winter 0.030
	/		Summer 0.044
metal decking (clip-lock style). Density 78.5 kg/m^3	30#	13.6	0.408
Expanded clay aggregate	150	2.89	0.434
wooden roof deck. Density 106 kg/m^3	25#	22.37	0.559
wood rafter & fibreglass	100	/	2.17
plaster (gypsum)	8#	2.7	0.022
air space (internal)*	1500	1.5	Winter 2.25 (up)
		2.17	Summer 3.255 (down)
plaster (gypsum)	8#	2.7	0.022
air film (internal)*	/	/	Winter 0.107(up)
			Summer 0.162 (down)

For R-value of air space and air film with signal *, direction of heat flow should be determined first. Due to the fact that external temperatures is 33.8℃ DB in summer and 2.1℃ DB in winter are lower than temperatures of room 212 and 213, which are 24℃ DB in summer and 21℃ DB respectively, so direction of heat flow is up.

Total R-value of ceiling and floor in winter: $R_{W(ceiling\,\&\,roof)} = R_{W(air\ film-external)} + R_{metal\ decking} + R_{wooden\ roof\ deck} + R_{wood\ raft\ er\,\&\,fibreglass} + 2 * R_{plaster} + R_{W(air\ space)} + R_{W(air\ film-internal)} = 6.002m^2$°C/W

Total R-value of ceiling and floor in summer: $R_{S(ceiling\,\&\,roof)} = R_{S(air\ film-external)} + R_{metal\ decking} + R_{wooden\ roof\ deck} + R_{wood\ raft\ er\,\&\,fibreglass} + 2 * R_{plaster} + R_{S(air\ space)} + R_{S(air\ film-internal)} = 7.076m^2$°C/W

So U-value of ceiling and floor in winter: $U_{W(ceiling\,\&\,roof)} = \frac{1}{R_{W(ceiling\,\&\,roof)}} = 0.167W/m^2$°C

U-value of ceiling and floor in winter: $U_{W(ceiling\,\&\,roof)} = \frac{1}{R_{W(ceiling\,\&\,roof)}} = 0.141W/m^2$°C

3.4.3 Eest Wall (212 & 213)

Both east walls of 212 and 213 are the same in that they are all brick veneer, plastered outside and thin marble inside as we can see in the following Figure 9:

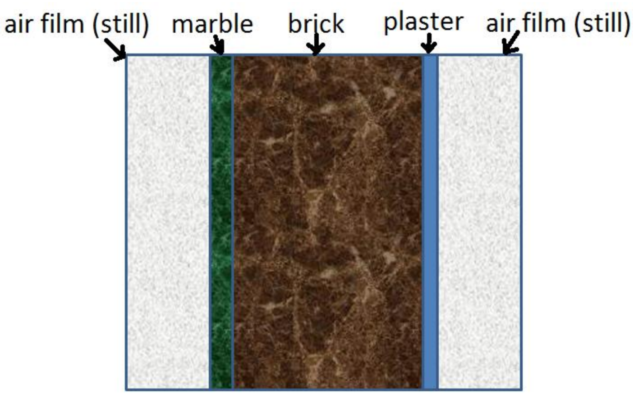


Figure 9 Structure of east wall

Materials' resistivity and its corresponding thickness can be found in the following Table 7:

Table 7 Resistivity and thickness of brick venner

Component	Thickness mm	U-values (W/m^2°C)
Brick Veneer with 12mm plaster	90 (brick) + 150 (air gap)+ 12 plaster = 252	winter 2.09
		summer 2.03

Note that the U-value difference of brick veneer is caused by different external wind speed. Air film on one side of brick veneer is still. On the other side of brick veneer, air film flows at different speed in summer and winter as Table 8 shows.

Table 8 Properties of each layer

Component	Thickness mm	Resistivity (1/k) m°C/W	R-values (m^2°C/W)
marble (various samples)	20#	0.7 (0.77-0.6)	0.014
air film (still air)	/	/	0.12
air film (7 m/s in winter)	/	/	0.03
air film (3.5 m/s in summer)	/	/	0.044

R-value of brick veneer with plaster board in winter: $R_{W(BV\&PB)} = \frac{1}{U_{W(BV\&PB)}} = \frac{1}{2.09} = 0.478\mathrm{m}^2{}^\circ\mathrm{C/W}$

R-value of brick veneer with plaster board in summer: $R_{S(BV\&PB)} = \frac{1}{U_{S(BV\&PB)}} = \frac{1}{2.03} = 0.492\mathrm{m}^2{}^\circ\mathrm{C/W}$

R-value of combination of brick, plaster board, inside air film (still) in winter and summer:
$R_{W-S(E-comb)} = R_{S(BV\&PB)} - R_{S(air\ film-external)} = R_{W(BV\&PB)} - R_{W(air\ film-external)} = 0.448$

R-value of East Wall of 212 and 213: $R_{E-212\&213} = R_{W-S(E-comb)} + R_{marble} + R_{air\ film\ (still)} = 0.582\mathrm{m}^2{}^\circ\mathrm{C/W}$

U-value of East Wall of 212 and 213: $U_{E-212\&213} = \frac{1}{R_{E-212\&213}} = 1.718W/\mathrm{m}^2{}^\circ\mathrm{C}$

3.4.4 West Wall (212)

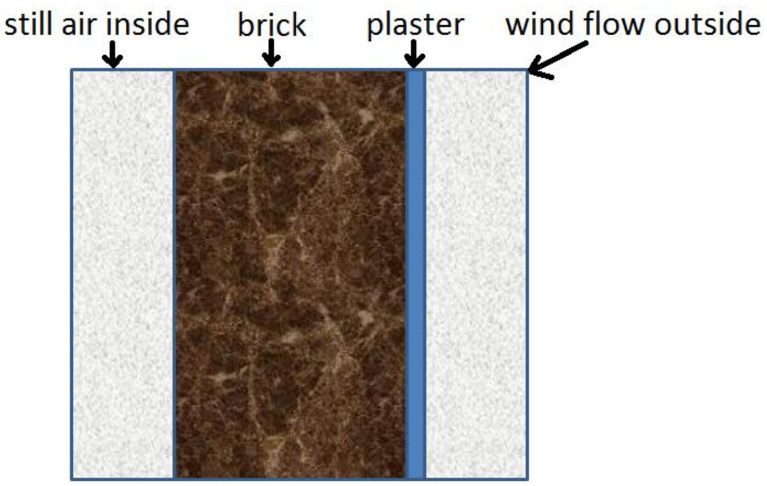
West wall of 212 consists of floor to ceiling glazing. According to external conditions listed in Assignment 1 – Project Specifications[6], all other glazing except food court has a U-value of 5.62 $U_{W(W-212)} = U_{S(W-212)} = 5.62\mathrm{W/m^2°C}$

3.4.5 West Wall (213)

West Wall for Room 213 is divided into two parts by the west wall of Room 214. The first part is defined as being between 213 and courtyard. For this part, U-value is the same as U-value of west wall of 212, $U_{W(W-213-1)} = U_{S(W-213-1)} = 5.62\mathrm{W/m^2°C}$.

As for the second part of 213 west wall, it is defined as being between Room 213 and Room 214. For this part, the material is brick veneer. However, according to Table 25 Transmission Coefficient U-Veneer Walls in DA09[2], the 12mm plaster board veneer chosen is measured in the situation of still air inside and wind flow outside (7m/s during winter and 3.5m/s during summer). Under such circumstance, U-value for part 2 of west wall (213) should be recalculated considering the situation that both two sides of plaster board veneer are still air.

As shown in Figure, U-value of original plaster board veneer is $2.09\mathrm{W/m^2°C}$ during winter and $2.03\mathrm{W/m^2°C}$ in summer. We need to calculate R-value of combination of still air inside, brick and plaster first, then add R-value of still air outside so that we can obtain U-value of part 2 of west wall (213) like Figure 10 show.



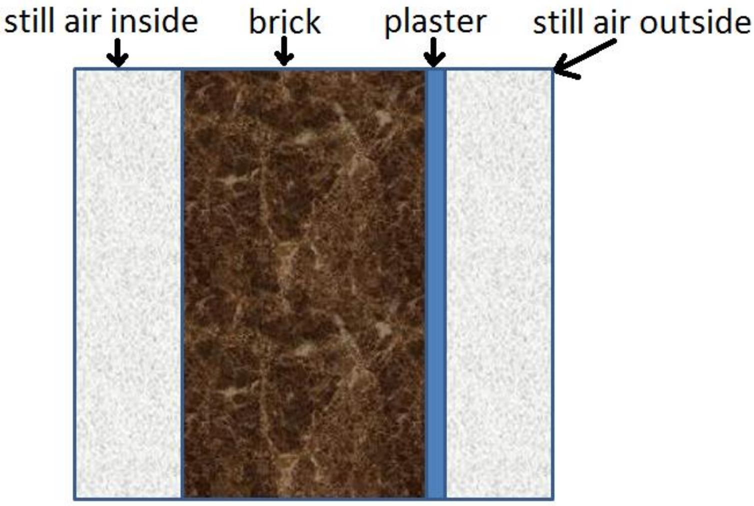


Figure 10 Structure of west wall

Materials' resistivity and its corresponding thickness (some values of thickness are required and thickness with signal # is assumed) can be found in the following Table 10 and 11:

Table 10 U-value and thickness of brick veneer with 12mm plaster

Component	Thickness mm	U-values (W/m^2°C)
Brick Veneer with 12mm plaster	90(brick)+150(air gap)+12 plaster=252	winter 2.09
		summer 2.03

Table 11 Properties of each component of west wall 213

Component	Thickness mm	Resistivity (1/k) m°C/W	R-values (m^2°C/W)
air film (still air)	/	/	0.12
air film (7 m/s in winter)	/	/	0.03
air film (3.5 m/s in summer)	/	/	0.044

R-value of plaster board brick veneer with still air inside and wind flow outside in winter:

$R_{W-original(W-213-2)} = \frac{1}{U_{W(BV\&PB)}} = \frac{1}{2.09} = 0.478\mathrm{m}^2\mathrm{°C/W}$

R-value of the combination of still air inside, brick and plater board in winter: $R_{W(comb)} = R_{W-original(W-213-2)} - R_{7m/s\,wind} = 0.448\mathrm{m}^2\mathrm{°C/W}$

R-value of part 2 of west wall (213) in winter: $R_{W(w-213-2)} = R_{W(comb)} + R_{still\ air} = 0.568\mathrm{m}^2\mathrm{°C/W}$

U-value of part 2 of west wall (213) in winter: $U_{W(W-213-2)} = \frac{1}{R_{W(w-213-2)}} = \frac{1}{0.568} = 1.761W/\mathrm{m}^2\mathrm{°C}$

R-value of plaster board brick veneer with still air inside and wind flow outside in summer:

$R_{S-original(W-213-2)} = \frac{1}{U_{S(BV\&PB)}} = \frac{1}{2.03} = 0.493\mathrm{m}^2\mathrm{°C/W}$

R-value of the combination of still air inside, brick and plater board: $R_{S(comb)} = R_{S-original(W-213-2)} - R_{3.5m/s\,wind} = 0.448\mathrm{m}^2{}^\circ\mathrm{C/W}$

R-value of part 2 of west wall (213) in summer: $R_{S(w-213-2)} = R_{S(comb)} + R_{still\ air} = 0.568\mathrm{m}^2{}^\circ\mathrm{C/W}$

U-value of part 2 of west wall (213) in winter: $R_{S(W-213-2)} = \frac{1}{R_{S(w-213-2)}} = \frac{1}{0.568} = 1.761W/\mathrm{m}^2{}^\circ\mathrm{C}$

3.4.6 South Wall (213)

South Wall of Room 213 is made of 100mm-thick crushed rock aggregate with two sides of plasters. However, according to Table 24 Transmission Coefficient U-Masonry Walls[2], there is only one layer of 15mm gypsum plaster sticked to100mm-thick crushed rock aggregate like the following Figure shows. Under such circumstance, another layer of plaster should be added on the other side of crushed rock aggregate. The structure of south wall is shown in the following Figure 11.

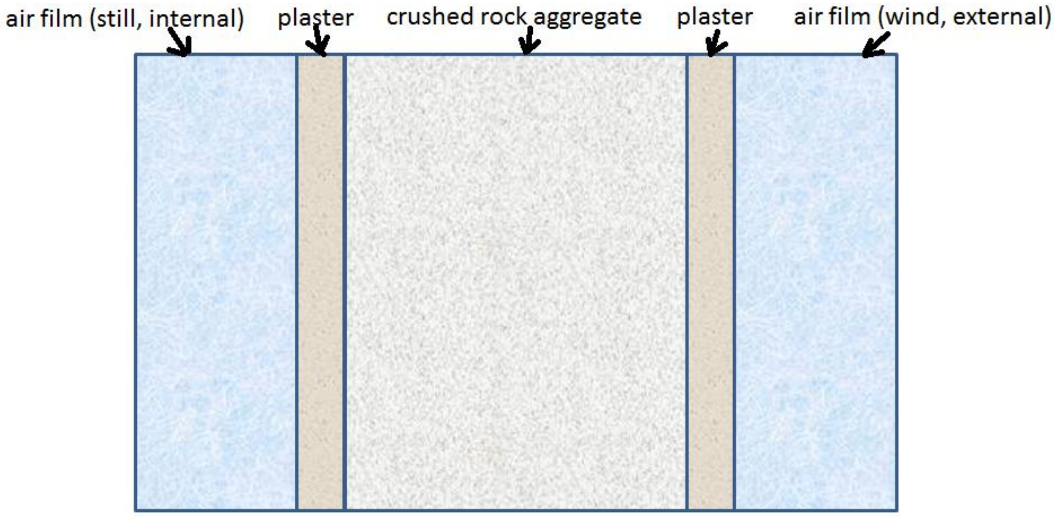


Figure 11 Structure of south wall 213

Materials' resistivity and its corresponding thickness (some values of thickness are required and thickness with signal # is assumed) can be found in the following Table 12 and 13:

Table 12 R-value and thickness of crushed rock aggregeate

Component	Thickness mm	R-values (m^2°C/W)
crushed rock aggregate	100	winter 4.59
		summer 4.29

Table 13 Properties of each component of south wall

Component	Thickness mm	Resistivity (1/k) m°C/W	R-values (m^2°C/W)

plaster (gypsum)	11#	2.7	0.03
air film (still air)	/	/	0.12
air film (7 m/s in winter)	/	/	0.03
air film (3.5 m/s in summer)	/	/	0.044

R-value of crushed rock aggregate with one air film inside and one air film outside in winter:

$R_{W(CRA\,\&\,air\,film\,inside\,\&\,air\,film\,outside)} = \frac{1}{U_{W(CRA)}} = 0.218\text{m}^2\text{°C/W}$

So R-value of crushed rock aggregate with two-side plaster, air film inside and air film outside in winter: $R_{W(S-213)} = R_{W(CRA\,\&\,air\,film\,inside\,\&\,air\,film\,outside)} + 2 * R_{plaster(gypsum)} = 0.278\text{m}^2\text{°C/W}$

So U-value of south wall 213 in winter: $R_{W(S-213)} = \frac{1}{R_{W(S-213)}} = 3.597\text{m}^2\text{°C/W}$

R-value of crushed rock aggregate with one air film inside and one air film outside in summer:

$R_{S(CRA\,\&\,air\,film\,inside\,\&\,air\,film\,outside)} = \frac{1}{U_{S(CRA)}} = 0.233\text{m}^2\text{°C/W}$

R-value of crushed rock aggregate with two-side plaster, air film inside and air film outside in summer: $R_{S(S-213)} = R_{S(CRA\,\&\,air\,film\,inside\,\&\,air\,film\,outside)} + 2 * R_{plaster(gypsum)} = 0.293\text{m}^2\text{°C/W}$

So U-value of south wall 213 in summer: $R_{S(S-213)} = \frac{1}{R_{S(S-213)}} = 3.413\text{m}^2\text{°C/W}$

3.4.7 North Wall (213)

North wall of Room 213 is made of double brick with two-side plaster as Figure 12 shows.

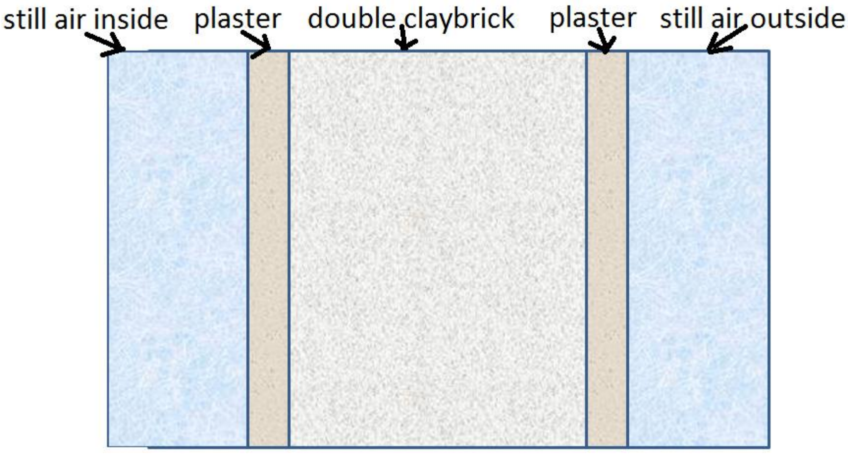


Figure 12 Structure of north wall 213

Materials' resistivity and its corresponding thickness (some values of thickness are required and thickness with signal # is assumed) can be found in the following Table 15 and 16:

Table 14 R-values and thickness of double heat brick

Component	Thickness mm	R-values (m^2°C/W)
double heat brick	240	winter 2.12
		summer 2.11

Table 15 Properties of each component of north wall 213

Component	Thickness mm	Resistivity (1/k) m°C/W	R-values (m^2°C/W)
plaster (gypsum)	11#	2.7	0.03
air film (still air)	/	/	0.12
air film (7 m/s in winter)	/	/	0.03
air film (3.5 m/s in summer)	/	/	0.044

R-value of original double claybrick with one air film (internal) and one air film (external, wind) in winter: $R_{W(originial)} = \frac{1}{U_{W(DHB)}} = 0.472\mathrm{m}^2°\mathrm{C/W}$

R-value of original double claybrick with one air film (internal) and one air film (external, wind) in summer: $R_{S(originial)} = \frac{1}{U_{S(DHB)}} = 0.474\mathrm{m}^2°\mathrm{C/W}$

R-value of north wall of 213 in winter: $R_{W(N-213)} = R_{W(originial)} - R_{W(air\ film-external)} + R_{air\ film} + 2 * R_{plaster} = 0.622\mathrm{m}^2°\mathrm{C/W}$

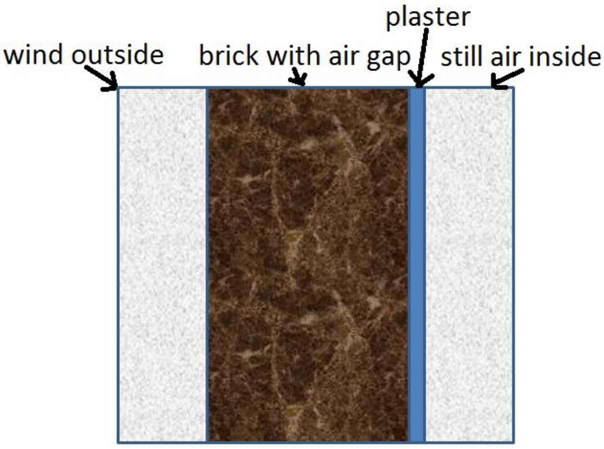
R-value of north wall of 213 in summer $R_{S(N-213)} = R_{S(originial)} - R_{S(air\ film-external)} + R_{air\ film} + 2 * R_{plaster}$ $=0.61\mathrm{m}^2°\mathrm{C/W}$

So U-values of north wall 213 in winter: $R_{W(N-213)} = \frac{1}{R_{W(N-213)}} = 1.608\mathrm{W/m}^2°\mathrm{C}$

So U-values of north wall 213 in summer: $R_{S(N-213)} = \frac{1}{R_{S(N-213)}} = 1.639\mathrm{W/m}^2°\mathrm{C}$

3.4.8 North Wall (212)

The north wall of room 212 is made of brick veneer with plaster board inside. According to Table 25[2], the structure of brick veneer (90mm brick and 150mm air gap) with a layer of plaster is shown in Figure. $R_{W(BV\,\&\,PB)} = 2.09$ in winter and $R_{S(BV\,\&\,PB)} = 2.03$ in summer. However, north wall of room 212 is internal wall with still air on both sides. Under such circumstance, wind outside should be replaced with still air inside. Structure of north wall 213 is shown below in figure 11



Materials' resistivity and its corresponding thickness (some values of thickness are required and thickness with signal # is assumed) can be found in the following Table 16 and 17:

Table 16 U-value and thickness of brick veneer with 12mm plaster

Component	Thickness mm	U-values (W/m^2℃)
Brick Veneer with 12mm plaster	90(brick)+150(air gap)+12 plaster=252	winter 2.09
		summer 2.03

Table 17 Properties of each component of north wall 212

Component	Thickness mm	Resistivity (1/k) m℃/W	R-values (m^2℃/W)
air film (still air)	/	/	0.12
air film (7 m/s in winter)	/	/	0.03
air film (3.5 m/s in summer)	/	/	0.044

R-value of original brick veneer in winter: $R_{W(BV\,\&\,PB)} = \frac{1}{U_{W(BV\,\&\,PB)}} = 0.478\text{m}^2\text{°C/W}$

R-value of original brick veneer in summer: $R_{S(BV\,\&\,PB)} = \frac{1}{U_{S(BV\,\&\,PB)}} = 0.493\text{m}^2\text{°C/W}$

R-value of north wall (212) in winter: $R_{W(N-212)} = R_{W(BV\,\&\,PB)} - R_{7m/s\,wind} + R_{still\,air} = 0.568\text{m}^2\text{°C/W}$

And R-value of north wall (212) in summer: $R_{S(N-212)} = R_{S(BV\,\&\,PB)} - R_{3.5m/s\,wind} + R_{still\,air} = 0.569\text{m}^2\text{°C/W}$

Finally U-value of north wall (212) in winter: $U_{W(N-212)} = \frac{1}{R_{W(N-212)}} = 1.761\mathrm{W/m^2°C}$

And U-value of north wall (212) in summer: $U_{S(N-212)} = \frac{1}{R_{S(N-212)}} = 1.757\mathrm{W/m^2°C}$

3.4.9 Summary of All Surfaces

R-values and U-values of each surface is listed in the following Table 18:

Table18 R-values and U-values of all surfaces

Surfaces	R-values (m^2°C/W)	U-values (W/m^2°C)
Floor	4.121	0.243
Ceiling and Roof	W 6.002	W 0.18
	S 7.076	S 0.151
East Wall (212 & 213)	0.582	1.718
West Wall (212)	/	5.62
West Wall (213) - part 1	/	5.62
West Wall (213) - part 2	W 0.568	W 1.761
South Wall (213)	W 0.278	W 3.597
	S 0.293	S 3.413
North Wall (213)	W 0.622	W 1.608
	S 0.61	S 1.639
North Wall (212)	W 0.568	W 1.761
	S 0.569	S 1.757

3.5 Minimum R-values for All Surfaces

The minimum requirement of ceiling/roof in zone 6 is 3.2 m^2°C/W as figure 13 shows according to Table J1.3a Roofs and Ceilings – Minimum Total R-value for Each Climate Zone in NCC 2016 Volume one[3].

Climate zone	1, 2, 3, 4 and 5	6	7	8
Direction of heat flow	Downwards		Upwards	
Minimum *Total R-Value* for a roof or ceiling with a roof upper surface solar absorptance value of not more than 0.4	3.2	3.2	3.7	4.8
Minimum *Total R-Value* for a roof or ceiling with a roof upper surface solar absorptance value of more than 0.4 but not more than 0.6	3.7	3.2	3.7	4.8
Minimum *Total R-Value* for a roof or ceiling with a roof upper surface solar absorptance value of more than 0.6	4.2	3.2	3.7	4.8

(b) For compliance with **Table J1.3a**, roof and ceiling construction is deemed to have the thermal properties listed in **Specification J1.3**.

(c) Where, for operational or safety reasons associated with exhaust fans, flues or recessed downlights, the area of *required* ceiling insulation is reduced, the loss of insulation must be compensated for by increasing the *R-Value* of the insulation in the remainder of the ceiling in accordance with **Table J1.3b**.

Figure 13 NCC minimum requirement of ceiling/roof

Based on calculation in Chapter 3, R-value of ceiling and roof is 5.568 m^2°C/W in winter and 6.642 m^2°C/W in summer, which is bigger than the minimum requirement.

According to Table J1.6 Floors – Minimum Total R-Value[3], the minimum R-value requirement of floor is 1.25 m^2°C/W in zone 6 as figure 14 shows, which is smaller than R-value of floor 4.121 m^2°C/W.

Location	*Climate zone*							
	1	2	3	4	5	6	7	8
Direction of heat flow	Upwards	Downwards and upwards		Downwards				
(c) A suspended floor with an in-slab or in-screed heating or cooling system where the non-*conditioned space* is— (i) enclosed; and (ii) where mechanically ventilated by not more than 1.5 air changes per hour	1.25	1.25	1.25	1.25	1.25	1.25	1.75	2.75
(d) For other than (a), (b) or (c)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.5
Note: A subfloor space with not more than 150% of the *required* subfloor ventilation is considered enclosed.								

Figure 14 NCC minimum requirement of floor

According to Table J1.5a Options for Each Part of an External Wall That is Part of an Envelope[3] as figure 15 shows, we need to calculate the density, orientation first. For density, it mostly depends on the brick structure, brick veneer (240*0.1 = 24kg/m^3) and double claybrick (346*0.24 = 83.04 kg/m^3) are the materials for walls. Density of both bricks is far less than 240kg/m^3. So minimum requirement of R-value for east wall is 2.8 m^2°C/W. Minimum requirement of south wall's R-value is 2.3 m^2°C/W. All internal walls' minimum R-value (north wall of 212 and 213) is 1 m^2°C/W according to project specification[6].

4, 5 and 6	(a) (i) Achieve a minimum *Total R-Value* of 2.8. (ii) The minimum *Total R-Value* in (i) is reduced— (A) for a wall with a surface density of not less than 220 kg/m^2, by 0.5; and (B) for a wall that is— (aa) facing the south orientation as described in **Figure J2.3**, by 0.5; or (bb) shaded with a projection shade angle in accordance with **Figure J1.5** of— (AA) 30 degrees to not more than 60 degrees, by 0.5; or (BB) more than 60 degrees, by 1.0.
	(b) Where the only space for insulation is provided by a furring channel, top hat section, batten or the like— (i) achieve a minimum *Total R-Value* of 1.4; and (ii) satisfy *glazing* energy index Option B of **Table J2.4a**.

Figure 15 NCC minimum requirement of external walls

3.6 Correction for Surfaces

We use N to demonstrate number of increments of R = 0.5 insulation.

1. Floor and roof/ceiling's R-values satisfy the minimum requirement. No needs for correction.

2. East wall (212 & 213) N=$\left\lceil\frac{2.8-0.582}{0.5}\right\rceil = 5$

3. West wall of 212 and part 1 of 213 is made of glazing and does not necessarily need to be corrected.

4. 2nd part of west wall 213: $N_W = \left\lceil\frac{1-0.568}{0.5}\right\rceil = 1$

5. South wall (213) $N_W = \left\lceil\frac{2.3-0.278}{0.5}\right\rceil = 5 \quad N_S = \left\lceil\frac{2.3-0.293}{0.5}\right\rceil = 5$

   Therefore, no matter in winter or summer, five layers of insulation are needed.

6. North wall (213) $N_W = \frac{1-0.622}{0.5} = 1 \quad N_S = \frac{1-0.61}{0.5} = 1$

7. North wall (212) $N_W = \frac{1-0.568}{0.5} = 1 \quad N_S = \frac{1-0.569}{0.5} = 1$

R-values and U-values after correction are listed in the following Table 19:

Table 19 R-values and U-values after correction.

Surfaces	R-values (m2°C/W)	Increments in R-values (m2°C/W)	Corrcted R-values (m2°C/W)	Corrected U-values (W/m2°C)
Floor	4.121	0	4.121	0.243
Ceiling and Roof	W 6.002	0	W 6.002	W 0.167

	S 7.076	0	S 7.076	S 0.141
East Wall (212 & 213)	0.582	2.5	3.082	0.324
West Wall (212)	/	0	/	5.62
West Wall (213) - part 1	/	0	/	5.62
West Wall (213) - part 2	0.568	0.5	1.068	0.936
South Wall (213)	W 0.278	2.5	W 2.778	W 0.36
	S 0.293	2.5	S 2.793	S 0.358
North Wall (213)	W 0.622	0.5	W 1.122	W 0.891
	S 0.61	0.5	S 1.11	S 0.9
North Wall (212)	W 0.568	0.5	W 1.068	W 0.936
	S 0.569	0.5	S 1.069	S 935

3.7 Storage Mass and its Influence on Heat Load Calculations

Storage mass is the resistance of one sort of material to temperature change. Storage mass influences storage load factor (SF) in calculating glass radiation and influences calculations of internal loads of people and lights.

3.8 Calculation of Storage Mass

3.8.1 Storage Mass of Room 212

Density, thickness and mass of all surfaces in room 212 are shown in the below Tables . We need to mention that west wall (212) is made of glass and there is no need to calculate its storage mass.

Table 20 Total mass of roof/ceiling

Roof/Ceiling (212)					
Component	Thickness mm	Density kg/m3	Mass per unit area kg/m2	Area m2	Mass kg
Metal decking (clip-lock style)	30	78.5	/	390	918.5
Wooden roof deck	25	106	/	390	1033.5
Expanded clay aggregate	150	1121	/	390	65578.5
Wood rafter & fibreglass	100	177.89	/	390	6937.7
plaster (gypsum)	8*2=16	1217	/	390	7594.1
Total mass kg					82062.3

Table 21 Total mass of floor

Floor

Component	Thickness mm	Density kg/m3	Mass per unit area kg/m2	Area m2	Mass kg
Carpet (Nylatron MC901)	6	1150	/	390	2691
Carpet underlay	15	30.4	/	390	177.84
Expanded clay aggregate	150	1121	/	390	65578.5
Gypsum plaster (sand)	8	1410	/	390	4399.2
Total mass kg					72846.5

Table 22 Total mass of north wall 212

North Wall (212)					
Component	Thickness mm	Density kg/m3	Mass per unit area kg/m2	Area m2	Mass kg
Brick veneer	240	/	184	90	16560
Batts*1	75	32	/	90	216
Total mass kg					16776

Table 23 Total mass of south wall 212

South Wall (212)					
Component	Thickness mm	Density kg/m3	Mass per unit area kg/m2	Area m2	Mass kg
Double heat brick with plaster	240	/	346	90	31140
Batts*1	75	32	/	90	216
Total mass kg					31356

Table 24 Total mass of east wall 212

East Wall (212)					
Component	Thickness mm	Density kg/m3	Mass per unit area kg/m2	Area m2	Mass kg
Brick veneer with plaster	240	/	184	104	19136
Marble (various samples)	20	2700	/	104	5616
Batts*5	75*5=375	32	/	104	1248
Total mass kg					26000

According to Table 6 – Storage Load Factors, Solar Heat Gain Through Glass in DA09, Room on building exterior $= \frac{(Mass\ of\ outside\ walls,kg)+0.5(Mass\ of\ partitions,floor\ and\ ceiling,kg)}{floor\ area\ in\ room\ m^2} =$

$$\frac{82062.3+26000+0.5*(31356+16776+72846.5)}{390} = 432.2kg/m^2$$

3.8.2 Storage Mass of Room 213

Density, thickness and mass of all surfaces in room 213 are shown in the below Tables . We need to mention that part 1 of west wall (213) is made of glass and there is no need to calculate its storage mass.

Table 25 Total mass of roof/ceiling

Roof/Ceiling (213)					
Component	Thickness mm	Density kg/m3	Mass per unit area kg/m2	Area m2	Mass kg
Metal decking (clip-lock style)	30	78.5	/	436	1026.8
Wooden roof deck	25	106	/	436	1155.4
Wood rafter & fibreglass	100	177.89	/	436	7756
Expanded clay aggregate	150	1121	/	436	73313.4
Total mass kg					83251.6

Table 26 Total mass of floor

Floor					
Component	Thickness mm	Density kg/m3	Mass per unit area kg/m2	Area m2	Mass kg
Carpet (Nylatron MC901)	6	1150	/	436	3308.4
Carpet underlay	15	30.4	/	436	198.8
Expanded clay aggregate	150	1121	/	436	73313.4
Gypsum plaster (sand)	8	1410	/	436	4918.1
Total mass kg					81738.7

Table 27 Total mass of west wall 213

Part 2 of West Wall 213					
Component	Thickness mm	Density kg/m3	Mass per unit area kg/m2	Area m2	Mass kg
Brick veneer with plaster	240	/	184	90	3974.4
Batts*1	75	32	/	90	216
Total mass kg					4190.4

Table 28 Total mass of east wall 213

East Wall 213					
Component	Thickness mm	Density kg/m3	Mass per unit area kg/m2	Area m2	Mass kg
Brick veneer with plaster	240	/	184	120	5299.2
Marble (various	20	2700	/	120	6480

samples)					
Batts*5	75*5=375	32	/	120	1440
Total mass kg					13219.2

Table 29 Total mass of south wall 213

South Wall 213					
Component	Thickness mm	Density kg/m3	Mass per unit area kg/m2	Area m2	Mass kg
Crushed rock aggregate	100	2400	/	60	14400
Plaster*2	11	1217	/	60	803.22
Batts*5	75*5=375	32	/	60	720
Total mass kg					15923.2

Table 30 Total mass of north wall 213

North Wall 213					
Component	Thickness mm	Density kg/m3	Mass per unit area kg/m2	Area m2	Mass kg
Double heat brick with plaster	240	/	346	90	31140
Batts*1	75	32	/	90	216
Total mass kg					31356

According to Table 6 – Storage Load Factors, Solar Heat Gain Through Glass in DA09, Room on building exterior $= \frac{(Mass\ of\ outside\ walls, kg)+0.5(Mass\ of\ partitions, floor\ and\ ceiling, kg)}{floor\ area\ in\ room\ m^2} =$

$\frac{83251.6+13219.2+15923.2+0.5*(81738.7+4190.4+31356)}{436} = 392.3kg/m^2$

4. External Loads – Solar Transmission

4.1 Surfaces Experiencing Solar Transmission Loads

Solar transmission happens when surfaces are exposed to sunlight. Under such circumstance, east wall and roof of room 212 and south wall, east wall and roof of room 213 will experience solar transmission loads.

4.2 Modified Temperature Difference

When we calculate the heat load of surfaces external to this building, we use a modified temperature difference. This is because such surfaces experience solar radiation as well as conduction. Modified temperature difference covers the combination of solar radiation and conduction in calculation. If modified temperature difference is not used, the heat load, then, will decrease correspondingly.

4.3 Formulas Used in Calculating Heat Loads of External Glazing

When heat loads of external glazing are calculated, conduction and solar radiation should be considered. Heat loads for external glazing = conduction + solar radiation. For conduction part, the formula is $Q\ [W] = U * A * \Delta T$, where U is U-value of glazing, A is area of glazing and ΔT is temperature difference between internal and external conditions. For solar radiation, $Q\ [W] = Peak\ solar\ heat\ gain\ \left[\frac{W}{m^2}\right] * A\ [m^2] * SF * k_1 * k_2 * k_3 * k_4 * k_5$, where peak solar heat gain can be found in Table 14, A is area of glazing, SF is storage load factor found in Table 6-10, k1 is sash correction factor, k2 is haze correction factor, k3 is altitude correction factor, k4 is dew point correction factor and k5 is glass factor.

4.4 Calculation of Heat Load

Summer outside design dry-bulb in Temperate Town =33.8°C DB from CAMEL
Winter outside design dry-bulb in Temperate Town = 2.1°C DB from CAMEL
Yearly range: 33.8 - 2.1 = 31.7 °C
Correction in outdoor design temperature for December and a yearly range of 31.7°C =0 approximately (Table 3 in DA09[2] interpolated)
Outside design temperature in December at 3 p.m. = 33.48– 0 =33.8 °C
With a 24 °C DB room design, the outdoor to indoor difference is 33.8 – 24 = 9.8 °C.
Average daily design in Temperate Town = 10 °C from CAMEL
The difference between outdoor design for December at 3 p.m. and room temperature of 9.8 °C and the daily range of 10 °C results in - 0.2 addition to the equivalent temperature difference, by interpolation in Table 23 DA09[2].

4.4.1 Conduction/Radiation (External Walls)

4.4.1.1 East Wall 212

(1) For east wall 212 except window part

1) In winter, there is only conduction. $Q_{W-c(EW-212)} = U.A.\Delta t = 0.324 * 104 * (21 - 2.1) = 636.9W$

2) In summer, equivalent temperature difference for east wall 212 (Mass of wall per unit area 250kg/m^3; Table 24) for 3 p.m. December at 30ºC South latitude:

(a) Δt_{em} for east wall in sun = 9.4 (Table 21[2] interpolated) – 0.2 = 9.2ºC

(b) Δt_{es} for east wall in shade = 7.3 (Table 21[2] interpolated) – 0.2 = 7.1ºC

The correction for light solar intensity is $\Delta t_e = 0.55\frac{\sigma_s}{\sigma_m}\Delta t_{em} + (1 - 0.55\frac{\sigma_s}{\sigma_m})\,\Delta t_{es}$, where $\sigma_s = 540W/m^2$ sash area (Table 14[2] for 30ºC South, December, east wall) and $\sigma_m = 550W/m^2$ sash area (Table 14[2], 40 º South, January, east wall). So $\Delta t_e = 8.2$°C

$$Q_{S-r\&c(EW-212)} = U.A.\Delta t_e = 0.324 * 104 * 8.2 = 276.3W$$

(2) For windows on east wall 212

1) In winter, there is only conduction $Q_{W-c(EW-121-win)} = UA\Delta t = 5.62 * 52 * (21 - 2.1) = 5523.4W$

2) In summer, heat load through glass comes from conduction and radiation.

For conduction: $Q_{S-c(EW-121-win)} = UA\Delta t = 5.62 * 52 * (33.8 - 24) = 2864W$

For radiation: $Q_{S-r(EW-121-win)} = Solar\ Heat\ Gain * A * SF * k_1 * k_2 * k_3 * k_4 * k_5$

Solar heat gain = 47W/m^2 (east wall, 3 p.m. Dec, 30º south, Table 14)

Area = 52 m^2

SF = 0.236 (Mass per unit area of floor 432.2kg/m^2, east wall, Table 9[2], interpolated)

Sash correction factor: k_1 = 1.17

Haze correction factor: k_2 = 100%

Altitude correction factor: $k_3 = 101.4\%$

Dew point correction factor: $k_4 = 102.1\%$

Glass factor $k_5 = 0.94$ (Table 15)

So $Q_{S-r(EW-121-win)} = 47 * 52 * 0.236 * 1.17 * 100\% * 101.4\% * 102.1\% * 0.94 = 656.8W$

Total heat gained through East Wall 212 in winter: $Q_{W(EW-212)} = Q_{W-c(EW-212)} + Q_{W-c(EW-121-win)} = 6160.3W$

In summer: $Q_{S(EW-212)} = Q_{S-r\&c(EW-212)} + Q_{S-r(EW-121-win)} = 993.1W$

4.4.1.2 East Wall 213

(1) For east wall 213 except window part

1) In winter, there is only conduction. $Q_{W-c(EW-213)} = U.A.\Delta t = 0.324 * 116 * (21 - 2.1) = 710.3W$

2) In summer, heat load through glass comes from conduction and radiation. Equivalent temperature difference for east wall 213 (Mass of wall per unit area 250kg/m^3; Table 24[2]) for 3 p.m. December at 30ºC South latitude:

(a) Δt_{em} for east wall in sun = 9.4 (Table 21[2] interpolated) – 0.2 = 9.2ºC

(b) Δt_{es} for east wall in shade = 7.3 (Table 21[2] interpolated) – 0.2 = 7.1°C

The correction for light solar intensity is $\Delta t_e = 0.55\frac{\sigma_s}{\sigma_m}\Delta t_{em} + (1 - 0.55\frac{\sigma_s}{\sigma_m})\,\Delta t_{es}$, where $\sigma_s = 540W/m^2$ sash area (Table 14[2] for 30°C South, December, east wall) and $\sigma_m = 550W/m^2$ sash area (Table 14[2], 40 ° South, January, east wall). So $\Delta t_e = 8.2$°C

$$Q_{S-r\&c(EW-213)} = U.A.\Delta t_e = 0.324 * 116 * 8.2 = 308.2W$$

(2) For windows on east wall 213

1) In winter, there is only conduction $Q_{W-c(EW-213-win)} = UA\Delta t = 5.62 * 58 * (21 - 2.1) = 6160.6W$

2) In summer, heat load through glass comes from conduction and radiation.

For conduction: $Q_{S-c(EW-213-win)} = UA\Delta t = 5.62 * 58 * (33.8 - 24) = 3194.4W$

For radiation: $Q_{S-r(EW-213-win)} = Solar\ Heat\ Gain * A * SF * k_1 * k_2 * k_3 * k_4 * k_5$

Solar heat gain = 47W/m^2 (east wall, 3 p.m. Dec, 30° south, Table 14[2])

Area = 58 m^2

SF = 0.236 (Mass per unit area of floor 186.8kg/m^2, east wall, Table 9[2], interpolated)

Sash correction factor: k_1 = 1.17

Haze correction factor: k_2 = 95%

Altitude correction factor: $k_3 = 101.4\%$

Dew point correction factor: $k_4 = 102.1\%$

Glass factor $k_5 = 0.94$ (Table 15)

So $Q_{S-r(EW-213-win)} = 47 * 58 * 0.236 * 1.17 * 100\% * 101.4\% * 102.1\% * 0.94 = 732.5W$

Total heat gained through East Wall 213 in winter: $Q_{W(EW-213)} = Q_{W-c(EW-213)} + Q_{W-c(EW-213-win)} = 6870.9W$

In summer: $Q_{S(EW-213)} = Q_{S-r\&c(EW-213)} + Q_{S-r(EW-213-win)} = 1040.7W$

4.4.1.3 South Wall 213

(1) For south wall 213 except window part

1) In winter, there is only conduction. $Q_{W-c(SW-213)} = U.A.\Delta t = 0.36 * 60 * (21 - 2.1) = 408.2W$

2) In summer, heat load through glass comes from conduction and radiation. Equivalent temperature difference for south wall 213 (Mass of wall per unit area 265kg/m^3; Table 24[2]) for 3 p.m. December at 30°C South latitude:

(a) Δt_{es} for south wall in shade = 7.1 (Table 21[2] interpolated) – 0.2 = 6.9°C

(b) Due to the fact that south wall is always in shade, so $\Delta t_{em} = \Delta t_{es} = 6.9$°C

The correction for light solar intensity is $\Delta t_e = 0.55\frac{\sigma_s}{\sigma_m}\Delta t_{em} + (1 - 0.55\frac{\sigma_s}{\sigma_m})\,\Delta t_{es}$, where $\sigma_s = 110W/m^2$ sash area (Table 14[2] for 30°C South, December, south wall) and $\sigma_m = 80W/m^2$ sash area (Table 14[2], 40 ° South, January, south wall). So $\Delta t_e = 6.9$°C

Heat Gain though south wall 213 in summer $Q_{S-r\&c(SW-213)} = U.A.\Delta t_e = 0.358 * 60 * 6.9 = 148.2W$

(2) For windows on south wall 213

1) In winter, there is only conduction $Q_{W-c(SW-213-win)} = UA\Delta t = 5.62 * 30 * (21 - 2.1) = 3186.5W$

2) In summer, heat load through glass comes from conduction and radiation.

For conduction: $Q_{S-c(SW-213-win)} = UA\Delta t = 5.62 * 30 * (33.8 - 24) = 1652.3W$

For radiation: $Q_{S-r(SW-213-win)} = Solar\ Heat\ Gain * A * SF * k_1 * k_2 * k_3 * k_4 * k_5$

Solar heat gain = 47W/m^2 (south wall, 3 p.m. Dec, 30^o south, Table 14[2])

Area = 30 m^2

SF = 0.846 (Mass per unit area of floor 392.3kg/m^2, east wall, Table 9[2], interpolated)

Sash correction factor: k_1 = 1.17

Haze correction factor: k_2 = 100%

Altitude correction factor: $k_3 = 101.4\%$

Dew point correction factor: $k_4 = 102.1\%$

Glass factor $k_5 = 0.94$ (Table 15[2])

So $Q_{S-r(SW-213-win)} = 47 * 30 * 0.846 * 1.17 * 100\% * 101.4\% * 102.1\% * 0.94 = 1358.2W$

Total heat gained through South Wall 213 in winter: $Q_{W(SW-213)} = Q_{W(SW-213)} + Q_{W-c(SW-213-win)} = 3594.7W$

In summer: $W_{S(SW-213)} = Q_{S-r\&c(SW-213)} + Q_{S-r(SW-213-win)} = 1506.4W$

4.4.1.4 Roof and Ceiling 212

(1) In winter, there is only conduction $Q_{W-c(roof\&ceiling-212)} = UA\Delta t = 0.167 * 390 * (21 - 2.1) = 1231W$

(2) In summer, there should be conduction and radiation, equivalent temperature difference for roof and ceiling 212 (Mass per unit area of floor 191kg/m^3; Table 24[2]) for 3 p.m. December at 30^{o}C South latitude:

(a) Δt_{em} for roof and ceiling in sun = 22.3 (Table 22[2] interpolated) – 0.2 = 22.1^{o}C

(b) Due to the fact that roof are always under sunshine without a shade so $\Delta t_{es} = \Delta t_{em} = 22.1℃$

The correction for light solar intensity is $\Delta t_e = 0.55 \frac{\sigma_s}{\sigma_m} \Delta t_{em} + (1 - 0.55 \frac{\sigma_s}{\sigma_m}) \Delta t_{es}$, where $\sigma_s = 840W/m^2$ sash area (Table 14[2] for 30^{o}C South, December, horizontal) and $\sigma_m = 790W/m^2$ sash area (Table 14[2], 40^o South, January, horizontal). So $\Delta t_e = 22.1℃$

$$Q_{S(R\&C-212)} = U.A.\Delta t_e = 0.141 * 390 * 22.1 = 1215.3W$$

4.4.1.5 Roof and Ceiling 213

(1) In winter, there is only conduction $Q_{W-c(roof\&ceiling-213)} = UA\Delta t = 0.167 * 436 * (21 - 2.1) = 1376.1W$

(2) In summer, there should be both conduction and radiation, equivalent temperature difference for roof and ceiling 213 (191kg/m^3; Table 24) for 3 p.m. December at 30^{o}C South latitude:

(a) Δt_{em} for roof and ceiling in sun = 22.3 (Table 22[2] interpolated) – 0.2 = 22.1^{o}C

(b) Due to the fact that roof are always under sunshine without a shade so $\Delta t_{es} = \Delta t_{em} = 22.1℃$

The correction for light solar intensity is $\Delta t_e = \Delta t_{es} + \frac{\sigma_s}{\sigma_m}(\Delta t_{em} - \Delta t_{es})$, where $\sigma_s = 840W/m^2$ sash area (Table 14[2] for 30ºC South, December, horizontal) and $\sigma_m = 790W/m^2$ sash area (Table 14[2], 40 º South, January, horizontal). So $\Delta t_e = 22.1$℃

$$Q_{S(R\&C-213)} = U.A.\Delta t_e = 0.141 * 436 * 22.1 = 1358.6W$$

4.4.1.6 West Wall 212

In both summer and winter, west wall of room 212 is shaded, which means there is no sun radiation. So only conduction needs to be considered. Also, there should be wall above 4.5m high ceiling and blow 6m roof. We assume this wall area is made of the same materials as partition part of west wall 213. $U = 0.936W/m^2$℃

For wall part,

(1) In winter, $Q_{W-c(WWall-212)} = UA\Delta t = 0.936 * 26 * 1.5 * (21 - 2.1) = 690W$

(2) In summer, $Q_{S-c(WWall-212)} = UA\Delta t = 0.936 * 26 * 1.5 * (33.8 - 24) = 357.7W$

For glazing part,

(1) In winter, $Q_{W-c(WW-212)} = UA\Delta t = 5.62 * 26 * 4.5 * (21 - 2.1) = 12427.5W$

(2) In summer, $Q_{S-c(WW-212)} = UA\Delta t = 5.62 * 26 * 4.5 * (33.8 - 24) = 6443.9W$

Total heat gained through South Wall 213 in winter: $Q_{W(WW-212)} = Q_{W-c(WWall-212)} + Q_{W-c(WW-212)} = 13117.5W$

In summer: $W_{S(SW-213)} = Q_{S-c(WWall-212)} + Q_{S-c(WW-212)} = 6801.6W$

4.4.1.7 West Wall 213

In both summer and winter, west wall of room 213 is shaded, which means there is no sun radiation. So only conduction needs to be considered. Also, there should be wall above 4.5m high ceiling and blow 6m roof. We assume this wall area is made of the same materials as partition part of west wall 213. $U = 0.936W/m^2$℃

For wall part,

(1) In winter, $Q_{W-c(WWall-212)} = UA\Delta t = 0.936 * 14 * 1.5 * (21 - 2.1) = 371.5W$

(2) In summer, $Q_{S-c(WWall-212)} = UA\Delta t = 0.936 * 14 * 1.5 * (33.8 - 24) = 192.6W$

For glazing part,

(3) In winter, $Q_{W-c(WW-213)} = UA\Delta t = 5.62 * 14 * 4.5 * (21 - 2.1) = 6691.7W$

(4) In summer, $Q_{S-c(WW-213)} = UA\Delta t = 5.62 * 14 * 4.5 * (33.8 - 24) = 3469.8W$

Total heat gained through west wall 213 in winter: $Q_{W(WW-213)} = Q_{W-c(WWall-212)} + Q_{W-c(WW-213)} = 7063.2W$

In summer: $W_{S(WW-213)} = Q_{S-c(WWall-212)} + Q_{S-c(WW-213)} = 3662.4W$

4.4.2 Summary of Heat Gain through Walls of 212 and 213

Note that all heat transferred through walls are sensible heat without changing the moisture content. Heat gain through exposed walls of 212 and 213 are listed in the following Tables 31 and 32.

Table 31 Heat gain through exposed wall of 212

Heat Gain Through Exposed Walls of 212		
Wall	winter (W)	summer (W)
East Wall	6160.3	993.1
Roof & Ceiling	1231	1215.3
West Wall	13117.5	6801.6
Total	**20508.8**	**9010**

Table 32 Heat gain through exposed wall of 213

Heat Gain Through Exposed Walls of 213		
Wall	winter (W)	Summer(W)
East Wall	6870.9	1040.7
South Wall	3594.7	1506.4
Roof & Ceiling	1376.1	1358.6
West Wall	7063.2	3662.4
Total	**18904.9**	**7568.1**

5 External Loads – Partitions

5.1 Calculation Difference Between Partitions and External Surfaces

Partition is defined as common area between rooms. External surfaces are exposed to outside environment. In such situations, partition obtains heat gain only though conduction. As for external surfaces, they receive sun radiation in addition.

In calculation, partition conduction uses formula $Q[W] = UA\Delta t$. External surfaces use $[W] = UA\Delta t_e$ to calculate both conduction and radiation.

5.2 Calculation and Report of the Heat Load for All Partitions

Partitions of room 212 and 213 contain south wall of 212, north wall 212, west wall 213 part 2, floor of 212 and floor of 213.

For south wall of 212, it is between room 212 and room 213. Temperatures between these two rooms are the same (24°C in summer, 21°C in winter). So there is no heat load for south wall 212.

For north wall of 212, it is between room 212 and room 211. Temperatures between these two rooms are the same (24°C in summer, 21°C in winter). So there is no heat load for north wall 212.

For west wall of 213 part 2, it is between room 213 and room 214. Temperatures between these two rooms are the same (24°C in summer, 21°C in winter). So there is no heat load for north wall 213.

For floor of 212 and 213, the overlap is shown below in figure 16. Temperature of M02 is 22°C in summer and 20°C in winter. Temperature of MM15 is 24°C in summer and 21°C in winter. Heat transfer between floor of 212 and 213 is conduction only.

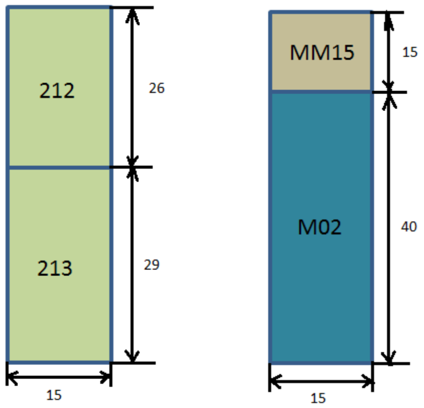


Figure 16 overlap between 212&213 and their correspoinding area on ground floor

Conduction of 212 floor in winter is $Q_{W-c(floor-212)} = QA\Delta t = 0.243 * 15 * 15 * (21 - 21) + 0.243 * 15 * 11 * (21 - 20) = 40.1W$

Conduction of 212 floor in summer is $Q_{S-c(floor-212)} = QA\Delta t = 0.243 * 15 * 15 * (24 - 24) + 0.243 * 15 * 11 * (24 - 21) = 120.3W$

Conduction of 213 floor in winter is: $Q_{W-c(floor-212)} = QA\Delta t = 0.243 * 436 * (21 - 20) = 106W$

Conduction of 213 floor in summer is: $Q_{S-c(floor-212)} = QA\Delta t = 0.243 * 436 * (24 - 21) = 317.8W$

Note that all heat transferred through walls are sensible heat without changing the moisture content. Heat gain through partitions is listed in the following Table 33.

Table 33 Heat gain through partitions

Heat Gain through Partitions (Floor)		
Room	Winter (W)	Summer(W)
212	40.1	120.3
213	106	317.8

6 External Loads – Winter

6.1 Three Key Differences Between Calculating External Loads for Cooling and Heating.

(1) Air film in calculating U-values. R-value (U-value) of external air film is different in summer and winter. Wind speed is different in summer (3.5m/s) and winter (7m/s). Also for horizontal air film, direction of heat flow influences too. Different direction of heat flow results in various air film R-value.

(2) Solar radiation. When calculating cooling loads in summer, heat load comes from conduction and radiation. But when calculating heating loads in winter, heat load comes only from conduction.

(3) Temperature difference. External temperature is 33.8ºC in summer and 2.1ºC in winter. Internal design temperature of 212 and 213 is 24ºC in summer and 21ºC in winter. Temperature difference in summer is $33.8 - 24 = 9.8℃$ and $21 - 2.1 = 18.9℃$ in winter.

6.2 Calculation and Report of External Loads under Winter Condition

As calculated in 4.4.1 Conduction/Radiation (external walls), external loads under winter conditions are listed below in Table 34:

Table 34 External loads through external walls under winter condition

Component	External load (W)
East wall 212	636.9 + 5523.4 = 6160.3
East wall 213	710.3 + 6160.6 = 6870.9
South wall 213	408.2 + 3186.5 = 3594.7
Roof and ceiling 212	1231

Roof and ceiling 213	1376.1
West wall 212	690 + 12427.5 = 13117.5
West wall 213	371.5 + 6691.7 = 7063.2

7 Internal Loads – Summer

7.1 Three Main Forms of Internal Loads Excluding Infiltration

These three main sources of internal loads are equipment, lights and people inside. Lights can only offer sensible heat. However, people and equipment inside can provide both sensible and latent heat to rooms.

7.2 Calculation and Report of All Internal Loads and Infiltration Loads in Summer

7.2.1 Internal Loads of Room 212 and Infiltration

7.2.1.1 Internal Loads Caused by People

Occupancy of 212 is maximum of 80 people (35 which seated) according to Project Specifications[6]. Considering the fact that 212 is a bookshop/internet café. We assume there are 35 people sitting and the rest 45 people are standing at peak time. Heat gain from people can be calculated from (DA9 Table 45[2]) as shown in Table 35 below.

Table 35 Heat gain from people

Degree of activity	Typical Application	ROOM DRY-BULB TEMPERATURE							
		24°C		22°C		21°C		20°C	
		Watts		Watts		Watts		Watts	
		Sens.	Lat.	Sens.	Lat.	Sens.	Lat.	Sens.	Lat.
Seated, very light work	High school	70	50	78	42	81#	39#	84	36
Seated, standing	Office, hotels	70	60	78	52	82#	48#	86	44

# These 4 value is estimated combine the value of 20°C and 22°C calculation as follow:
82 = (78+86)/2; 48 = (52+44)/2; 82=(78+86); 48=(52+44)/2

And based on Table 11 in DA09[2], storage factor is 0. 938 (interpolated). Diversity factor is 0.95 (middle value of department store) according to Table 13 in DA09[2].

So sensible heat gain from people in summer (24oC) is: $Q_{Sens-people-212} = (35 * 70 + 45 * 70) * 0.938 * 0.95 = 5600W$

Latent heat gain from people in summer (24°C) is: $Q_{Lat-people-212} = (35 * 50 + 45 * 60) * 0.938 * 0.95 = 4450W$

7.2.1.2 Internal Loads Caused by Equipment

According to Project Specifications[6], Equipment in Shop 212 contains the followings:

(1) 20*desktop computers (2.3GHz processor, 3GB RAM)
According to Table 8 in 2009 ASHRAE Handbook – Fundamentals[1], sensible heat load for desktops is $Q_{sens} = 20 * 97 = 1940W$

(2) 15*Laptop computers (2.3GHz processor, 3GB RAM)
According to Table 8 in 2009 ASHRAE Handbook – Fundamentals[1], sensible heat load for laptops is $Q_{sens} = 15 * 36 = 540W$

(3) 1*colour A3 laser printers (speed: 24 pages per minute)
According to Table 9 in 2009 ASHRAE Handbook – Fundamentals[1], sensible heat load for a color laser printer is $Q_{sens} = 1 * 130 = 130W$

(4) 1*larger plotter
According to Table 9 in 2009 ASHRAE Handbook – Fundamentals[1], sensible heat load for a color laser printer is $Q_{sens} = 1 * 250 = 250W$

(5) 1*small steam kettle (35L)
According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[1], sensible and latent heat load for 1*small steam kettle: $Q_{sens} = 35 * 21 = 735W$ $Q_{lat} = 35 * 14 = 490W$

(6) 2*Toaster (small pop-up) – 4 slice
According to Table 5A in 2009 ASHRAE Handbook – Fundamentals[1], sensible and latent heat load for 2*Toaster(small pop-up): $Q_{sens} = 2 * 1600 = 3200W$ $Q_{lat} = 2 * 1000 = 2000W$

(7) 2*Freezer (small) - 0.5m^3
According to Table 5A in 2009 ASHRAE Handbook – Fundamentals[1], sensible heat for 2*freezer (small): $Q_{sens} = 2 * 1100 = 2200W$

(8) 2*Coffee maker, 10 cups
According to Table 5A in 2009 ASHRAE Handbook – Fundamentals[1], sensible and latent heat for 2*coffee maker: $Q_{sens} = 2 * 1050 = 2100W$ $Q_{lat} = 2 * 450 = 900W$

(9) According to Table 5A in 2009 ASHRAE Handbook – Fundamentals[1], sensible and latent heat load for 2*freezer (small): $Q_{sens} = 2 * 1050 = 2100W$ $Q_{lat} = 2 * 1540 * 0.293 = 902.4W$

In summary, internal heat loads of 212 caused by equipment in summer are demonstrated in Table 36 below:

Table 36 internal heat loads of 212 caused by equipment in summer

Item	Sensible heat (W)	Latent heat (W)	Total(W)

20*desttop computers(2.3GHz processor,3GB RAM)	1940		1940
15*laptop computers (2.3GHz processer, 3GB RAM)	540		540
1*color A3 laser printers (speed: 24 pages per minute)	130		130
1* large plotter	250		250
1* small steam kettle(35L)	735	490	1225
2*toaster (small pop-up) - 4 slices	3200	2000	5200
1* microwave oven (residential type) - 30L	2200		2200
2* freezer (small) - 0.5m3	2200		2200
2* coffee maker, 10 cups	2100	900	3000
TOTAL	13295	3390	16685

7.2.1.3 Internal Loads Caused by Lights

Internal loads of lights contain only sensible heat. It should be calculated using this formula: $Q_{lights} = Heat\ Gain\ [W] * Storage\ Factor * Diversity\ Factor$. According to Project Specifications[6], the lighting power is 30W/m^2. And based on Table 11 in DA09[2], storage factor is 0. 938 (interpolated). Diversity factor is 0.95 (middle value of department store) according to Table 13 in DA09[2]. So the internal loads caused by lights: $Q_{lights} = 30 * 390 * 0.938 * 0.95 = 10425.9W$

7.2.1.4 Internal Loads Caused by Infiltration

Usually infiltration happens where there are windows or doors in a room. This is mainly due to the pressure difference between inside and outside. $Q_{sens} = 1.2\forall_{zone}AC_{hour}\Delta t$ $Q_{lat} = 2.9\forall_{zone}AC_{hour}\Delta w$

(1) Through windows

From Table 44 in DA09[2], AC_{hour} is determined by exposure, construction, location of window, type of window, degree of fenestration and partitioning.

Exposure: $Ch_1 = +0.5$h

Construction: $Ch_2 = +0.5$h

Location of windows: $Ch_3 = 0$

Type of windows: Ch= 0

Degree of fenestration: $Ch_5 =$ +0.25h (interpolated)

$$\text{Openable window area per wall area} = \frac{2}{6} = 33.3\%$$

Partitioning: $Ch_6 = 0$

Total $Ch = Ch_1 + Ch_2 + Ch_3 + Ch_4 + Ch_5 + Ch_6 = 1.25h$

So sensible heat of infiltration of room 212: $Q_{sens} = 1.2\forall_{zone}AC_{hour}\Delta t = 1.2 * (390 * 4.5) * 1.25 * (33.8 - 24) * \frac{1000}{3600} = 7166.3W$

On Psychrometric Table, moisture content of summer set point of 212 and 213 is 12.2g/kg, and moisture content of external summer condition is 13.4g/kg

So latent heat of infiltration of room 212: $Q_{slat} = 2.9\forall_{zone}AC_{hour}\Delta w = 2.9 * (390 * 4.5) * 1.25 * (13.4 - 10.2) * \frac{1000}{3600} = 5655W$

(2) Through door

In General Details from Project Specifications, any external entrance to a shop is 200L/s. So sensitive heat through door: $Q_{sens} = 1.2 * \dot{v} * \Delta t = 1.2 * 200 * (33.8 - 24) = 2352W$ $Q_{lat} = 2.9 * \dot{v} * \Delta w = 2.9 * 200 * (13.4 - 10.2) = 1856W$

Summer's sensible and latent heat gained from windows and door in total are listed in Table 37 below:

Table 37 sensible and latent heat gained from windows and door in summer

Item	Through windows	Through door	Total
Sensible heat (W)	7166.3	2352	9518.3
Latent heat (W)	5655	1856	7511

7.2.2 Internal Loads of Room 213 and Infiltration

7.2.1.1 Internal Loads Caused by People

Occupancy as listed on Project Specifications is between 60 and 90 during peak times. For the sake of calculating the maximum of heat load for summer condition, we consider the biggest internal heat loads. Under such circumstance, there are 90 people at peak time.

So first we can get the sensible heat and latent heat of people from Manual DA09[2], as shown in table 38.

Table 38 sensible and latent heat gained from people

Degree of activity	Typical Application	ROOM DRY-BULB TEMPERATURE							
		24°C		22°C		21°C		20°C	
		Watts		Watts		Watts		Watts	
		Sens.	Lat.	Sens.	Lat.	Sens.	Lat.	Sens.	Lat.
Sedentary work	Restaurant	80	80	90	70	94#	66#	98	62

#These 4 value is estimated combine the value of 20°C and 22°C calculation as follow:
94 = (98+90)/2; 48 = (70+62)/2

And based on Table 11 in DA09[2], storage factor is 0.942 (interpolated). Diversity factor is 0.95 (middle value of department store) according to Table 13 in DA09[2].

So sensible heat gain from people in summer (24°C) is: $Q_{Sen-people-213} = 90 * 80 * 0.942 * 0.95 = 7200W$

And latent heat gain from people in summer (24ºC) is: $Q_{Sen-people-213} = 90 * 80 * 0.942 * 0.95 = 7200W$

7.2.1.2 Internal Loads Caused by Equipment

According to Project Specifications, Equipment in Shop 212 contains the followings:

(1) 6*Barbeque (pit), 50kg of food capacity

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible and latent heat load for 6*Barbeque (pit), 50kg of food capacity: $Q_{sens} = 6 * 50 * 57 = 17100W$ $Q_{lat} = 6 * 50 * 31 = 9300W$

(2) 2*Blender - 2L

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible and latent heat load for 2*Blender - 2L: $Q_{sens} = 2 * 2 * 310 = 1240W$ $Q_{lat} = 2 * 2 * 160 = 640W$

(3) 1*Coffee heater, 2 burners (boiling burner)

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible and latent heat load for 1*Coffee heater, 2 burners (boiling burner): $Q_{sens} = 440W$ $Q_{lat} = 230W$

(4) 1*Dishwasher (hood type, chemical sanitizing) -1000 dishes/hour

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible and latent heat load for 1*Dishwasher (hood type, chemical sanitizing): $Q_{sens} = \frac{1000}{100} * 50 = 500W$

$Q_{lat} = \frac{1000}{100} * 110 = 1100W$

(5) 2*Display case (refrigerated), 1.5 m3

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible heat load for 2*Display case (refrigerated), 1.5 m3: $Q_{sens} = 2 * 1.5 * 640 = 1920W$

(6) 8*Food warmer (shelf type), 1 m3

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible and latent heat load for 8*Food warmer (shelf type), 1 m3: $Q_{sens} = 8 * 2330 = 18640W$ $Q_{lat} = 8 * 600 = 4800W$

(7) 4*Griddle/grill (large), 0.5 m2

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible and latent heat load for 4*Griddle/grill (large), 0.5 m2: $Q_{sens} = 4 * 0.5 * 1940 = 3880W$ $Q_{lat} = 4 * 0.5 * 1080 = 2160W$

(8) 2*Ice maker (large) - 100kg/day

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible heat load for 2*Ice maker (large) - 100kg/day: $Q_{sens} = 2 * 2730 = 5460W$

(9) 1*Microwave oven (heavy duty, commercial) - 20L

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible heat load for 1*Microwave oven (heavy duty, commercial) - 20L : $Q_{sens} = 2730W$

(10) 1*Mixer (large) - 77L

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible heat load for 1*Mixer (large) - 77L: $Q_{sens} = 77 * 29 = 2233W$

(11) 1*Steam kettle (large) - 200L

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible heat and latent load for 1*Steam kettle (large) - 200L: $Q_{sens} = 200 * 7 = 1400W$ $Q_{lat} = 200 * 5 = 1000W$

(12)2*Waffle iron - 0.05m2

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible heat and latent load for 2*Waffle iron - 0.05m2: $Q_{sens} = 2 * 700 = 1400W$ $Q_{lat} = 2 * 940 = 1880W$

(13)1*Broiler (conveyor infrared) - 2 m2

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible heat load for 1*Broiler (conveyor infrared) - 2 m2: $Q_{sens} = 2 * 12100 = 24200W$

(14)2*Fryer (pressurized) - 6kg

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible heat load for 2*Fryer (pressurized) - 6kg: $Q_{sens} = 6 * 38 = 228W$

(15)4*Oven (pizza) - 1 m2

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible and latent heat load for 4*Oven (pizza) - 1 m2: $Q_{sens} = 4 * 1970 = 7880W$ $Q_{lat} = 4 * 690 = 2760W$

(16)4*Freezer (large) - 2 m3

According to Table 5 in 2009 ASHRAE Handbook – Fundamentals[6], sensible heat load for 4*Freezer (large) - 2 m3: $Q_{sens} = 4 * 540 = 2160W$

(17)2*Water cooler, 30L/h

According to Table 10 in 2009 ASHRAE Handbook – Fundamentals[6], sensible heat load for 2*Water cooler, 30L/h: $Q_{sens} = 2 * 350 = 700W$

(18)1*Hot water urn (large) - 50L

According to Table 10 in 2009 ASHRAE Handbook – Fundamentals[6], sensible and latent heat load for 1*Hot water urn (large) – 50L: $Q_{sens} = 50 * 50 = 2500W$ $Q_{lat} = 50 * 16 = 800W$

In summary, internal heat loads of 213 caused by equipment in summer are demonstrated in the following table 39:

Table 39 internal heat loads of 213 caused by equipment

Item	Sensible heat (W)	Latent heat (W)	Total(W)
6*Barbeque (pit) , 50kg of food capacity	17100	9300	26400
2*Blender - 2L	1240	640	1880
1*Coffee heater, 2 burners	440	230	670
1*Dishwasher (hood type, chemical sanitizing) -1000 dishes/hour	500	1100	1600
2*Display case (refrigerated), 1.5 m3	1920		1920
8*Food warmer (shelf type), 1 m3	18640	4800	23440
4*Griddle/grill (large), 0.5 m2	3880	2160	6040
2*Ice maker (large) - 100kg/day	5460		5460
1*Microwave oven (heavy duty, commercial) - 20L	2730		2730

1*Mixer (large) - 77L	2233		2233
1*Steam kettle (large) - 200L	1400	1000	2400
2*Waffle iron - 0.05m2	1400	1880	3280
1*Broiler (conveyor infrared) - 2 m2	24200		24200
2*Fryer (pressurized) - 6kg	228		228
4*Oven (pizza) - 1 m2	7880	2760	10640
4*Freezer (large) - 2 m3	2160		2160
2*Water cooler, 30L/h	700		700
1*Hot water urn (large) - 50L	800		800
TOTAL	92911	23870	116781

7.2.1.3 Internal Loads Caused by Lights

Internal loads of lights contain only sensible heat. It should be calculated using this formula: $Q_{lights} = Heat\ Gain\ [W] * Storage\ Factor * Diversity\ Factor$. According to Project Specifications, the lighting power is 30W/m^2. And based on Table 11 in DA09[2], storage factor is 0.942 (interpolated). Diversity factor is 0.95 (middle value of department store) according to Table 13 in DA09[2]. So the internal loads caused by lights: $Q_{lights} = 30 * 436 * 0.942 * 0.95 = 11705.3W$

7.2.1.4 Internal Loads Caused by Infiltration

Usually infiltration happens where there are windows or doors in a room. This is mainly due to the pressure difference between inside and outside. $Q_{sens} = 1.2\forall_{zone} AC_{hour} \Delta t$ $Q_{lat} = 2.9\forall_{zone} AC_{hour} \Delta w$

(1) Through windows

From Table 44 in DA09[2], AC_{hour} consists of considerations of exposure, construction, location of window, type of window, degree of fenestration and partitioning.

Exposure: $Ch_1 = +0.5$h

Construction: $Ch_2 = +0.5$h

Location of windows: $Ch_3 = 0$

Type of windows: Ch= 0

Degree of fenestration: $Ch_5 =$ +0.25h (interpolated)

$$\text{Openable window area per wall area} = \frac{2}{6} = 33.3\%$$

Partitioning: $Ch_6 = 0$

Total $Ch = Ch_1 + Ch_2 + Ch_3 + Ch_4 + Ch_5 + Ch_6 = 1.25h$

So sensible heat of infiltration of room 212: $Q_{sens} = 1.2\forall_{zone} AC_{hour} \Delta t = 1.2 * (346 * 4.5) * 1.25 * (33.8 - 24) * \frac{1000}{3600} = 6357.8W$

On Psychrometric Chart, moisture content of summer set point of 212 and 213 is 12.2g/kg, and moisture content of external summer condition is 13.4g/kg

So latent heat of infiltration of room 213: $Q_{lat} = 2.9\forall_{zone} AC_{hour} \Delta w = 2.9 * (346 * 4.5) * 1.25 * (13.4 - 10.2) * \frac{1000}{3600} = 5017W$

(2) Through door

In General Details from Project Specifications, any external entrance to a shop is 200L/s. So sensitive heat through door: $Q_{sens} = 1.2 * \dot{v} * \Delta t = 1.2 * 200 * (33.8 - 24) = 2352W$ $Q_{lat} = 2.9 * \dot{v} * \Delta w = 2.9 * 200 * (13.4 - 10.2) = 1856W$

Summer sensible and latent gained from windows and door in total are listed in the following table 40:

Table 40 summer sensible and latent gained from windows and door

Item	Through windows	Through door	Total
Sensible heat (W)	6357.8	2352	8709.8
Latent heat (W)	5017	1856	6873

7.2.3 Summary of Internal Loads of 212 and 213

Note that all heat transferred through walls are sensible heat without changing the moisture content. Internal loads in summer are listed in the following table 41.

Table 41 Internal loads in summer

Internal Loads in Summer					
Room	People (W)	Equipment (W)	Lights (W)	Infiltration (W)	Total (W)
212-Sensible	5600	13295	10425.9	9518.3	38839.1
212-Latent	4450	3390	0	7511	15351
213-Sensible	7200	92911	11705.3	8709.8	120526.1
213-Latent	7200	23870	0	6873	37943

8. Internal Loads – Winter

8.1 Three Key Differences Between Calculating Internal Loads for Cooling (Summer) and Heating (Winter)

Internal loads vary in summer and winter in that internal loads such as equipment, lights and people inside vary too.

8.2 Calculation and Report of All Internal Loads and Infiltration Loads in Winter

8.2.1 Internal Loads of Room 212 and Infiltration

8.2.1.1 Internal Loads Caused by People

Based on the assumption that this shopping mall located in Temperate Town opens between from 9am to 9pm, there should be no people in room 212 and room 213 at 7am. In this situation, internal loads caused by people are 0.

8.2.1.2 Internal Loads Caused by Equipment

Most equipment should be switched off between 9pm and 9am except 2*freezer (small) – 0.5m3. There two freezers need to run all day long and they only produce sensible heat. So $Q_{sens} = 2200W$

8.2.1.3 Internal Loads Caused by Lights

In order to save money and protect the environment, there should be no lights at 7 am.

8.2.1.4 Internal Loads Caused by Infiltration

Usually infiltration happens where there are windows or doors in a room. This is mainly due to the pressure difference between inside and outside. $Q_{sens} = 1.2\forall_{zone}AC_{hour}\Delta t$ $Q_{lat} = 2.9\forall_{zone}AC_{hour}\Delta w$

(1) Through windows

From Table 44 in DA09, AC_{hour} consists of considerations of exposure, construction, location of window, type of window, degree of fenestration and partitioning.

Exposure: $Ch_1 = +0.5\text{h}$

Construction: $Ch_2 = +0.5\text{h}$

Location of windows: $Ch_3 = 0$

Type of windows: Ch= 0

Degree of fenestration: $Ch_5 =$ +0.25h (interpolated)

$$\text{Openable window area per wall area} = \frac{2}{6} = 33.3\%$$

Partitioning: $Ch_6 = 0$

Total $Ch = Ch_1 + Ch_2 + Ch_3 + Ch_4 + Ch_5 + Ch_6 = 1.25h$

So sensible heat of infiltration of room 212: $Q_{sens} = 1.2\forall_{zone}AC_{hour}\Delta t = 1.2 * (390 * 4.5) * 1.25 * (21 - 2.1) * \frac{1000}{3600} = 13820.6W$

On Psychrometric Chart, moisture content of winter set point of 212 and 213 is 12.5g/kg, and moisture content of external summer condition is 3.6g/kg

So latent heat of infiltration of room 212: $Q_{slat} = 2.9\forall_{zone}AC_{hour}\Delta w = 2.9 * (390 * 4.5) * 1.25 * (12.5 - 3.6) * \frac{1000}{3600} = 15728W$

(2) Through door

Since the door is closed at 7am in winter. So there is theoretically no infiltration through door. Summer sensible and latent gained from windows and door in total are listed below Table 42:

Table 42 Summer sensible and latent gained form windows and door

Item	Through windows	Total
Sensible heat (W)	13820.6	9518.3
Latent heat (W)	15728	7511

8.2.2 Internal Loads of Room 213 and Infiltration

8.2.2.1 Internal Loads Caused by People

Based on the assumption that this shopping mall located in Temperate Town opens between from 9am to 9pm. So there should be no people in room 212 and room 213 at 7am. In this situation, internal loads caused by people are 0.

8.2.2.2 Internal Loads Caused by Equipment

Most equipment should be switched off between 9pm and 9am except 2*freezer (small) – 0.5m3, There two freezers need to run all day long and they only produce sensible heat. So $Q_{sens} = 2200W$

8.2.2.3 Internal Loads Caused by Lights

For the sake of convenience and food storage, these following equipment should keep running all day long. Internal loads are listed below in table 43

Table 43 Internal loads caused by lights

Item	Sensible heat (W)	Latent heat (W)	Total(W)
2*Ice maker (large) - 100kg/day	5460		5460
2*Display case (refrigerated), 1.5 m3	1920		1920
4*Freezer (large) - 2 m3	2160		2160
2*Water cooler, 30L/h	700		700
1*Hot water urn (large) - 50L	800		800
TOTAL	11040		11040

8.2.2.4 Internal Loads Caused by Infiltration

Usually infiltration happens where there are windows or doors in a room. This is mainly due to the pressure difference between inside and outside. $Q_{sens} = 1.2\forall_{zone}AC_{hour}\Delta t$ $Q_{lat} = 2.9\forall_{zone}AC_{hour}\Delta w$

(1) Through windows

From Table 44 in DA09[2], AC_{hour} consists of considerations of exposure, construction, location of window, type of window, degree of fenestration and partitioning.

Exposure: $Ch_1 = +0.5$h
Construction: $Ch_2 = +0.5$h
Location of windows: $Ch_3 = 0$
Type of windows: Ch= 0
Degree of fenestration: $Ch_5 =$ +0.25h (interpolated)

$$\text{Openable window area per wall area} = \frac{2}{6} = 33.3\%$$

Partitioning: $Ch_6 = 0$
Total $Ch = Ch_1 + Ch_2 + Ch_3 + Ch_4 + Ch_5 + Ch_6 = 1.25h$
So sensible heat of infiltration of room 212: $Q_{sens} = 1.2\forall_{zone}AC_{hour}\Delta t = 1.2 * (436 * 4.5) * 1.25 * (21 - 2.1) * \frac{1000}{3600} = 15450.8W$

On Psychrometric Chart, moisture content of winter set point of 212 and 213 is 12.5g/kg, and moisture content of external summer condition is 3.6g/kg
So latent heat of infiltration of room 212: $Q_{slat} = 2.9\forall_{zone}AC_{hour}\Delta w = 2.9 * (436 * 4.5) * 1.25 * (12.5 - 3.6) * \frac{1000}{3600} = 15728W$

(2) Through door
Since the door is closed at 7am in winter. So there is theoretically no infiltration through door. Summer sensible and latent gained from windows and door in total are listed below in table 44:

Table 44 Summer sensible and latent gained from windows and door

Item	Through windows	Total
Sensible heat (W)	15450.8	15450.8
Latent heat (W)	15728	15728

8.2.3 Summary of Internal Loads of 212 and 213

Internal loads of 212 and 213 are listed in table 45 and 46

Table 45 Internal loads in summer

Internal Loads in Summer					
Room	People (W)	Equipment (W)	Lights (W)	Infiltration (W)	Total (W)
212-Sensible	5600	13295	10425.9	9518.3	38839.1
212-Latent	4450	3390	0	7511	15351
213-Sensible	7200	92911	11705.3	8709.8	120526.1
213-Latent	7200	23870	0	6873	37943

Table 46 Internal loads in winter

Internal Loads in Winter

Room	People (W)	Equipment (W)	Lights (W)	Infiltration (W)	Total (W)
212-Sensible	0	2200	0	9518.3	11718.3
212-Latent	0	0	0	7511	7511
213-Sensible	0	11040	0	15450.8	26490.8
213-Latent	0	0	0	15728	15728

9 Cooling and Heating Load Summary

9.1 Cooling Load in Summer

Internal loads of 212 and 213 are listed in table 47 and 48.

Table 47 Total Heating Load of 212 in Summer

Total Heating Load of 212 in Summer		
Item	Sensible heat (W)	Latent Heat (W)
Heat Gain Through Exposed Walls	9010	0
Heat Gain Through Partitions	-120.3	0
Internal Loads	38839.1	15351
Total	47728.8	15351

Table 48 Total Heating Load of 213 in Summer

Total Heating Load of 213 in Summer		
Item	Sensible heat (W)	Latent Heat (W)
Heat Gain Through Exposed Walls	7568.1	0
Heat Gain Through Partitions	-317.8	0
Internal Loads	120526.1	37943
Total	127776.4	37943

9.2 Heating Load in Winter

Heating load in winter is listed in table 49 and 50.

Table 49 Total Heating Load of 212 in winter

Total Heating Load of 212 in winter		
Item	Sensible heat (W)	Latent Heat (W)
Heat Gain Through Exposed Walls	20508.8	0
Heat Gain Through Partitions	40.1	0

Internal Loads	11718.3	7511
Total	32267.2	7511

Table 50 Total Heating Load of 213 in winter

Total Heating Load of 213 in winter		
Item	Sensible heat (W)	Latent Heat (W)
Heat Gain Through Exposed Walls	18904.9	0
Heat Gain Through Partitions	106	0
Internal Loads	26490.8	15728
Total	45501.7	15728

10 Psychrometric Charts

10.1 Discussion of Features of Psychrometric Charts and the Information Provided

Psychrometric charts can provide dry bulb temperature, wet bulb temperature, specific volume, relative humidity and enthalpy of gas.

10.2 Psychrometric Charts (Relevant Points and Values) and Calculation of Reheat Capacity and Total Cooling Coil Load

10.2.1 Room 212

OA and RM points can be determined in figure

Outside air mass flow rate can be determined by using this: $\dot{m_{OA}} = \frac{\dot{V_{OA}}}{v}$

According to psychrometric chart: $\text{v} = 0.888m^3/kg$ (interpolated)

$\dot{V_{OA}}$ can be found in project specification, $V_{OA} = 800L/s$

Therefore, $\dot{m_{OA}} = \frac{\dot{V_{OA}}}{v} = \frac{800}{1000*0.888} = 0.9m^3/kg$

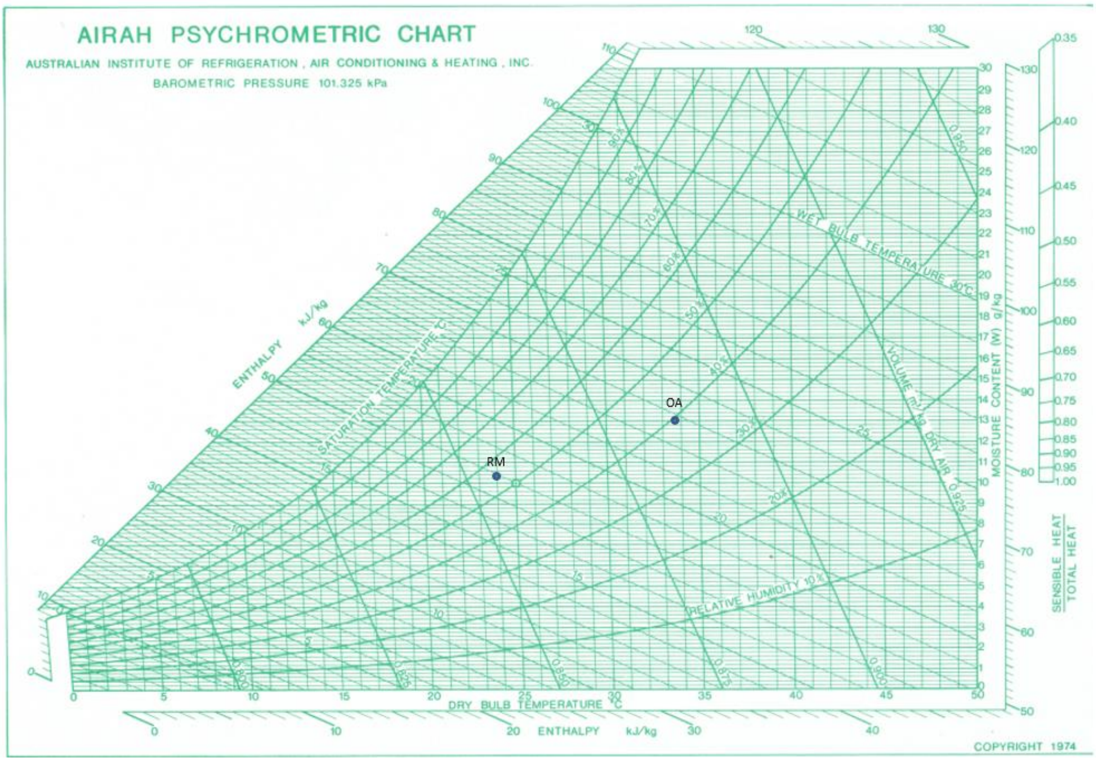


Figure 17 OA and RM

$$SHF_{212} = \frac{Q_S}{Q_S + Q_L} = \frac{38839.1}{38839.1 + 15351} = 0.7$$

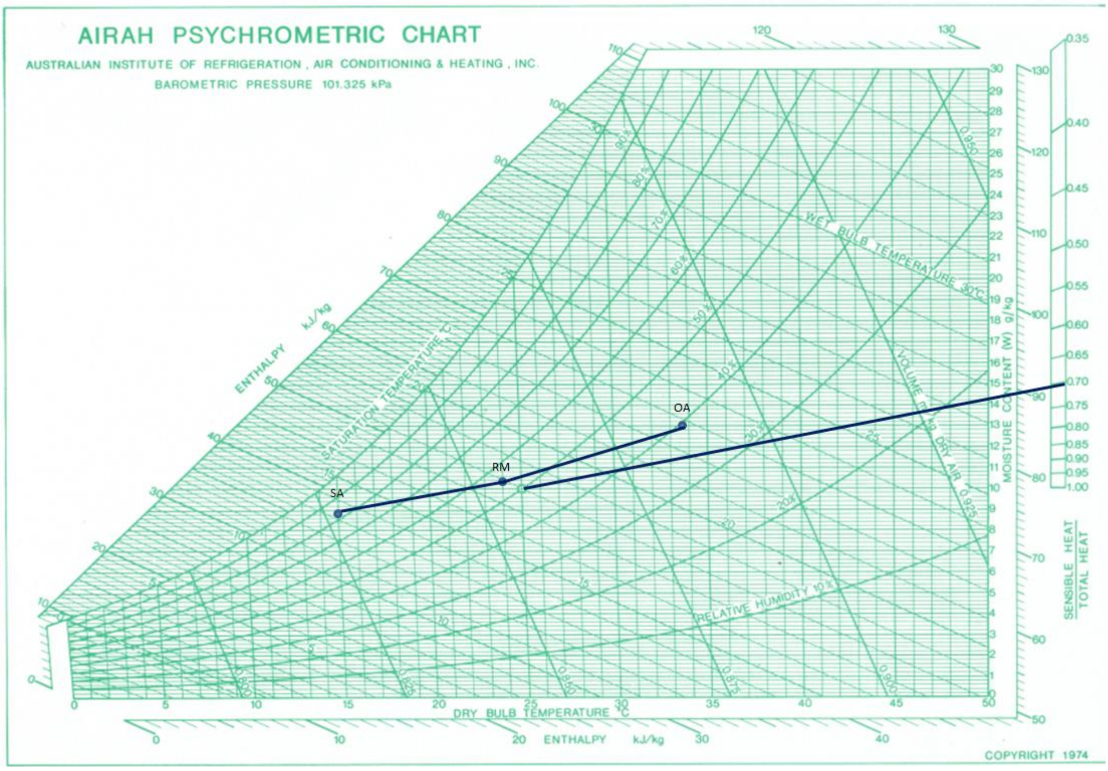


Figure 18 SHF & room load line

Mass flow rate of supply air can be calculated by $Q_s = C_p \dot{m}_{SA} \Delta T$, where $C_p = 1.02kJ/kgK$ (SA Assumption), $w_{SA} = 8.4g/kg\ DA \quad h_{SA} = 37.5kJ/kg$

$$\dot{m}_{SA} = \frac{Q_s}{C_p \Delta T} = \frac{35015.3}{1000 * 1.02 * (24 - 15)} = 3.81kg/s$$

Hence, mass ratio rate: $\frac{\dot{m}_{OA}}{\dot{m}_{SA}} = \frac{0.9}{3.81} = 0.24$

We can now scale off this ratio 0.24 from RM.

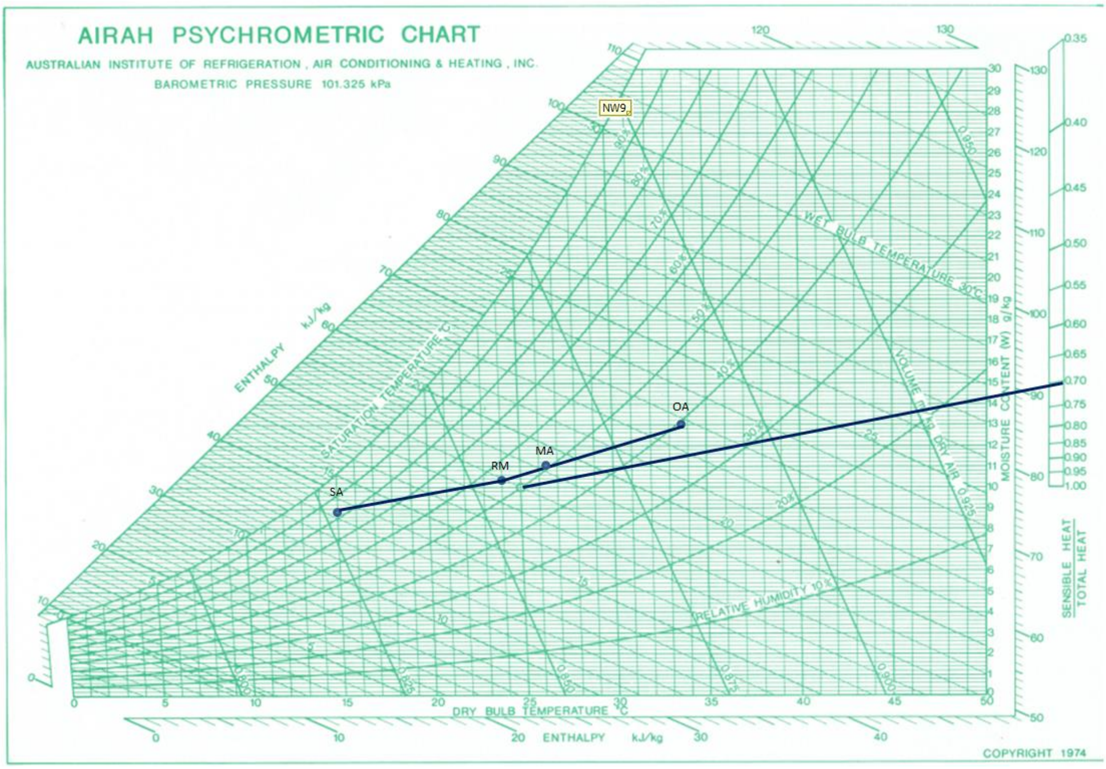


Figure 19 MA point

Therefore mixed air conditions: $t_{MA} = 26.4℃\ DB \quad w_{MA} = 11g/kg\ DA \quad h_{MA} = 55kJ/kg$

A reheat is used in our system, we know reheat process only changes sensible heat $w_W = w_{SA}$.

ADP temperature can be calculated by using $\frac{W_{MA} - W_W}{W_{MA} - W_{ADP}} = \eta_c$

$$W_{ADP} = 7.9g/kg\ DA$$

Hence, we can obtain cooling coil load line and air off condition: $h_W = 36kJ/kg$

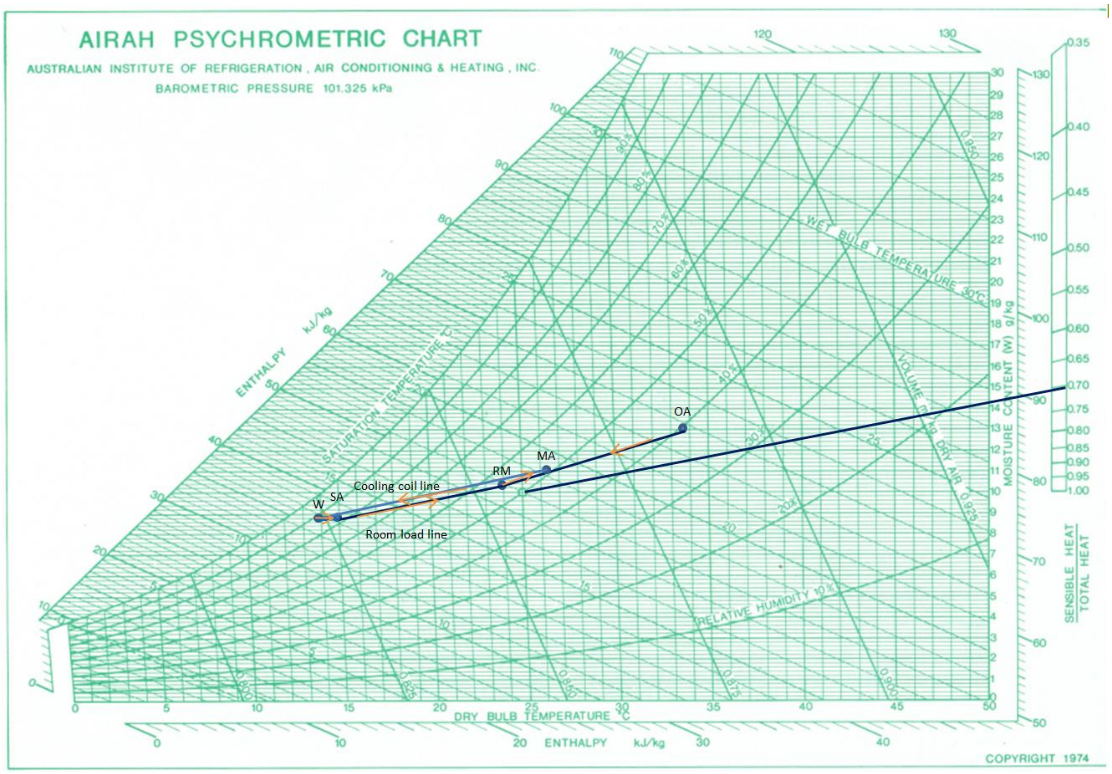


Figure 20 Cooling coil line and room load line.

Hence cooling coil load $\dot{Q_{ref}} = \dot{m_{MA}}(h_{MA} - h_W) = 3.81 * (55 - 36) = 72.4KW$

And reheat load $\dot{Q_{reheat}} = \dot{m_{MA}}(h_{SA} - h_W) = 3.81 * (37.5 - 36) = 5.7KW$

10.2.2 Room 213

Outside air mass flow rate can be determined by using this: $\dot{m_{OA}} = \frac{\dot{V_{OA}}}{v}$

According to psychrometric chart: $\mathrm{v} = 0.888m^3/kg$ (interpolated)

$\dot{V_{OA}}$ can be found in project specification, $V_{OA} = 800L/s$

Therefore, $\dot{m_{OA}} = \frac{\dot{V_{OA}}}{v} = \frac{800}{1000*0.888} = 0.9m^3/kg$

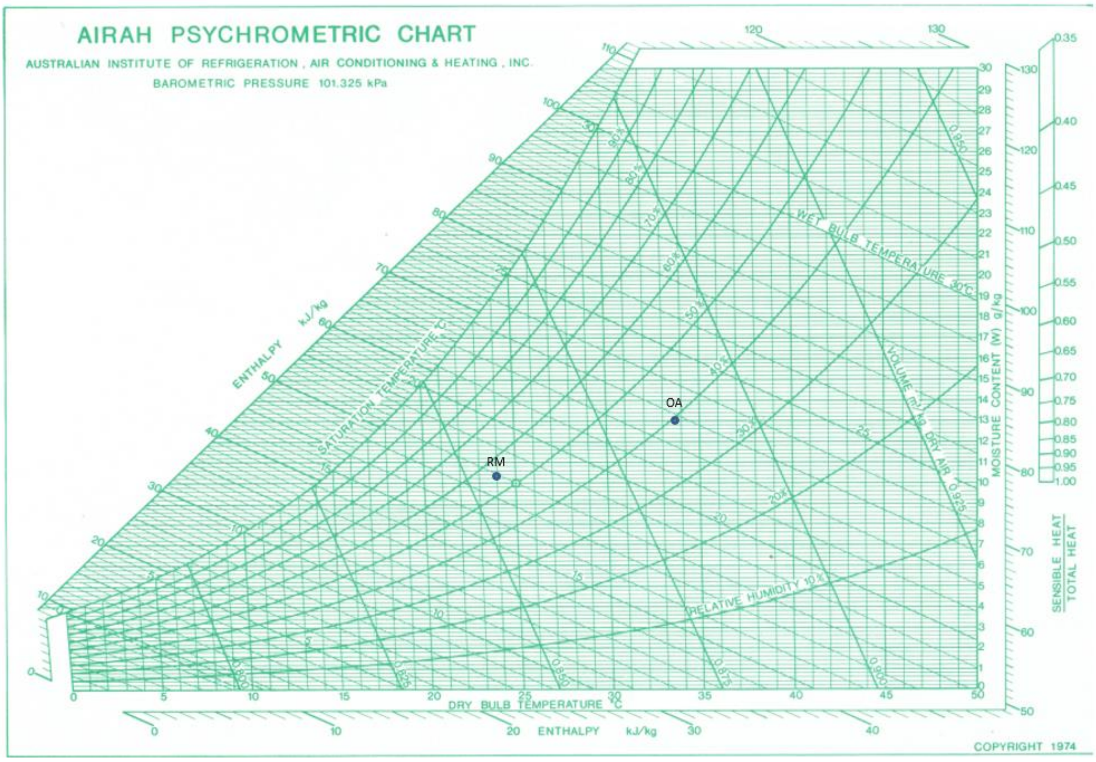


Figure 21 RM and OA Points

$$SHF_{212} = \frac{Q_S}{Q_S + Q_L} = \frac{120526.1}{120526.1 + 37943} = 0.74$$

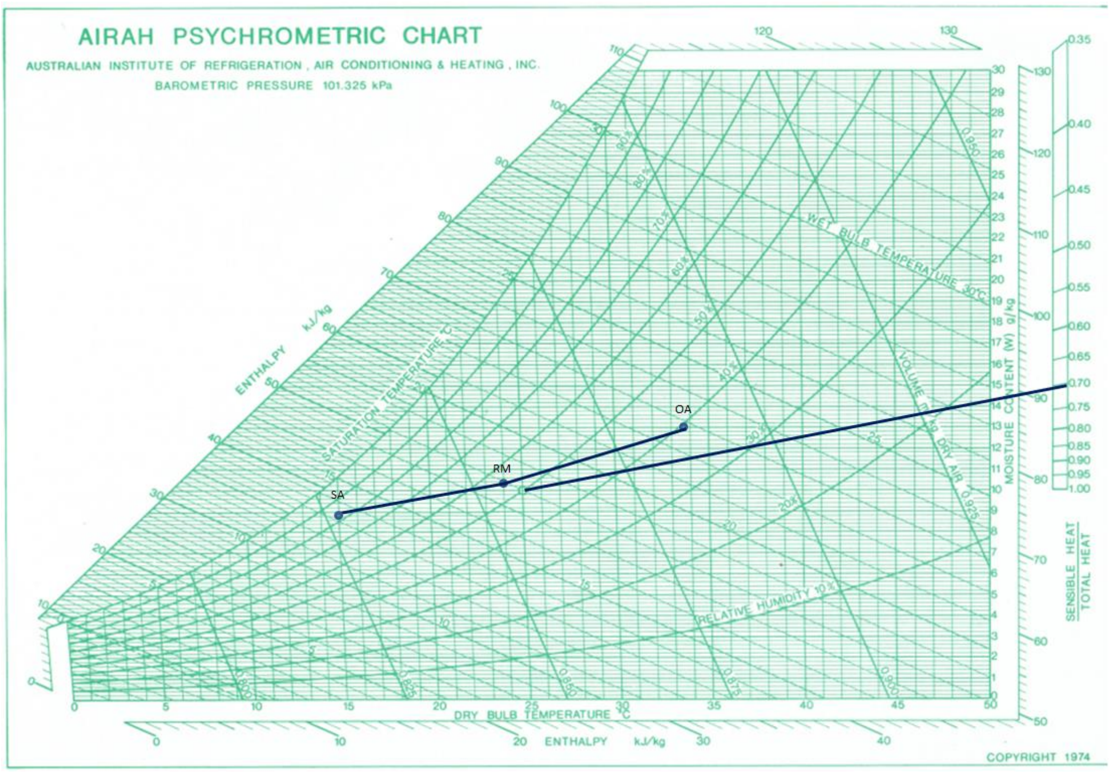


Figure 22 Room load line

Mass flow rate of supply air can be calculated by $Q_s = C_p \dot{m}_{SA} \Delta T$, where $C_p = 1.02kJ/kgK$ (SA Assumption), $w_{SA} = 8.6g/kg\ DA \quad h_{SA} = 38kJ/kg$

$$\dot{m}_{SA} = \frac{Q_s}{C_p \Delta T} = \frac{120526.1}{1000 * 1.02 * (24 - 15)} = 13.1kg/s$$

Hence, mass ratio rate: $\frac{\dot{m}_{OA}}{\dot{m}_{SA}} = \frac{0.9}{13.1} = 0.07$

We can now scale off this ratio 0.07 from RM.

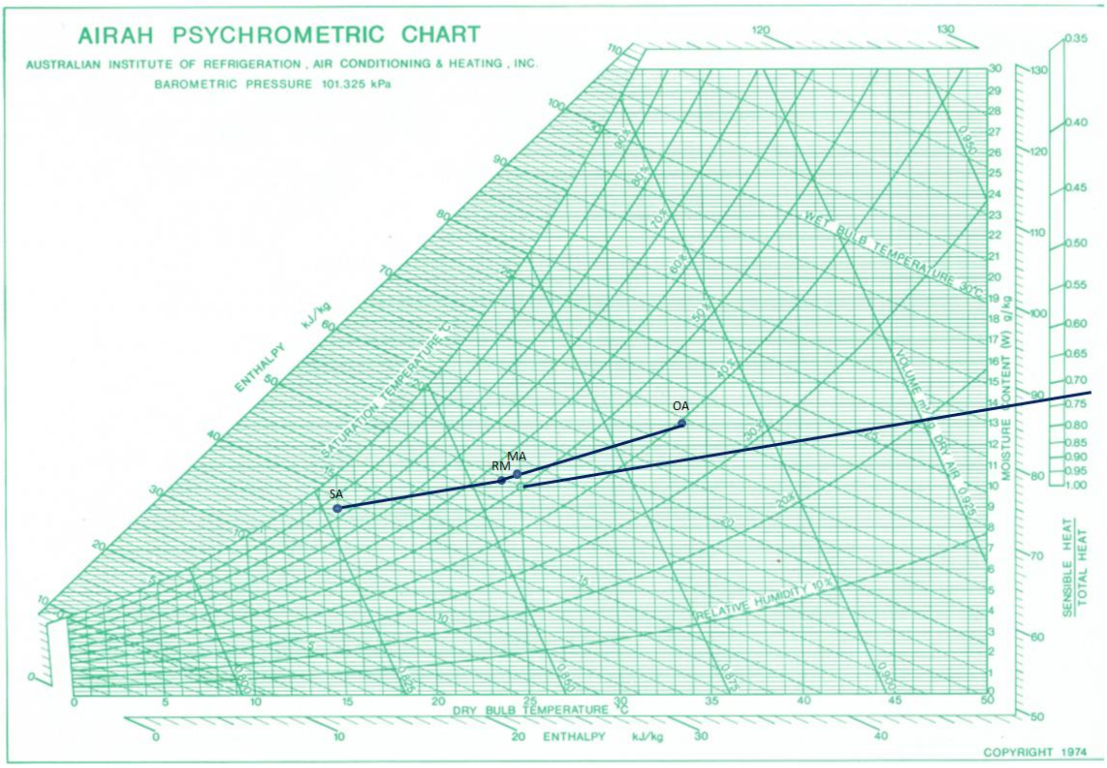


Figure 23 MA point

Therefore mixed air conditions: $t_{MA} = 24.8°\text{C}\ DB \quad w_{MA} = 10.6g/kg\ DA \quad h_{MA} = 53kJ/kg$

ADP temperature can be calculated by using $\frac{W_{MA} - W_W}{W_{MA} - W_{ADP}} = \eta_c$

$$W_{ADP} = 8.4g/kg\ DA$$

Then can draw the cooling coil load line and find that cooling coil load line and room load line intersect at point SA, which means that Air off condition is the same as supply air condition and there is no need for a reheat system.

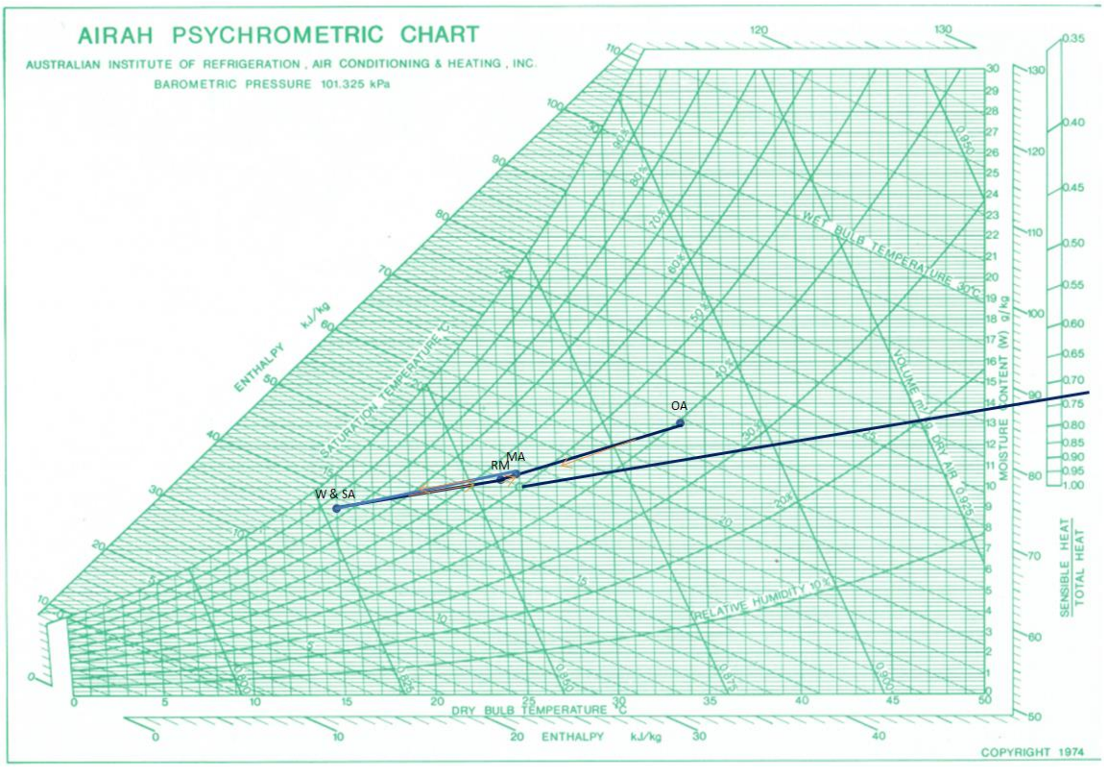


Figure 24 cooling coil line and room load line

Hence, we can obtain cooling coil load line and air off condition: $h_W = h_{SA} = 38kJ/kg$
Cooling coil load $\dot{Q_{ref}} = \dot{m_{MA}}(h_{MA} - h_W) = 13.1 * (53 - 38) = 196.5KW$

11 Conclusion

In this assignment, the aim is to design the HVAC system for a building. In chapter 2, design day and design time are selected (3pm on 22^{nd} December and 7am on 21^{st} June). In chapter 3, U-values of all surfaces of room 212 and 213 are calculated and corrected as NCC requires. Storage mass is calculated based on each room's mass and floor area. In chapter 4, external loads of conduction and radiation of each wall are calculated. In chapter 5, external loads of partitions are calculated. In chapter 6, external loads under winter conditions are calculated. In chapter 7, internal loads under summer conditions caused by people, lights, equipment and infiltration are calculated. In chapter 8, internal loads under winter conditions are calculated. In chapter 9, a summary of cooling load in summer and heating load in winter is made. In chapter 10, Calculation total cooling coil load is finished based on psychrometric chart.

12 References

[1] ASHRAE Guide and Data Books (Fundamentals), American Society of Heating, Refrigeration and Air Conditioning Engineers
[2] AIRAH Design Manual DA09
[3] NCC 2016, Section J – Energy Efficiency
[4] Assignment 1 – Building specification
[5] Assignment 1 – Assignment helpers
[6] Assignment 1 – Project Specifications