Gina Cody School of Engineering and Computer Science
Mechanical Engineering Department

Heating, Air Conditioning and Ventilation Course

MECH 6181

PROJECT
COOLING LOAD DESIGN OF AN OFFICE

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Table of Contents

LIST OF FIGURES

1 Introduction

This project provides an overview of the method and cooling load design estimate for the office under consideration. Phoenix , Arizona, USA, has been chosen for this location. The air is 43 °C (109.4 °F) thermally and has a relative humidity of 40%, recorded data in June. The computation is done for the sixth floor of the six-story building under consideration. Conference room, Admin office, Lunch area, Lobby, Board room, Common working space, Cabin 1, cabin 2, and Washroom are conditioned at DBT 22° C (71.6° F). The floor height for the building is 4 m, and the total area of the plan is 481.7 m^2 . The proper Fan is also chosen after determining the machine capacity and the necessary cooling load. The plan's layout is shown below:

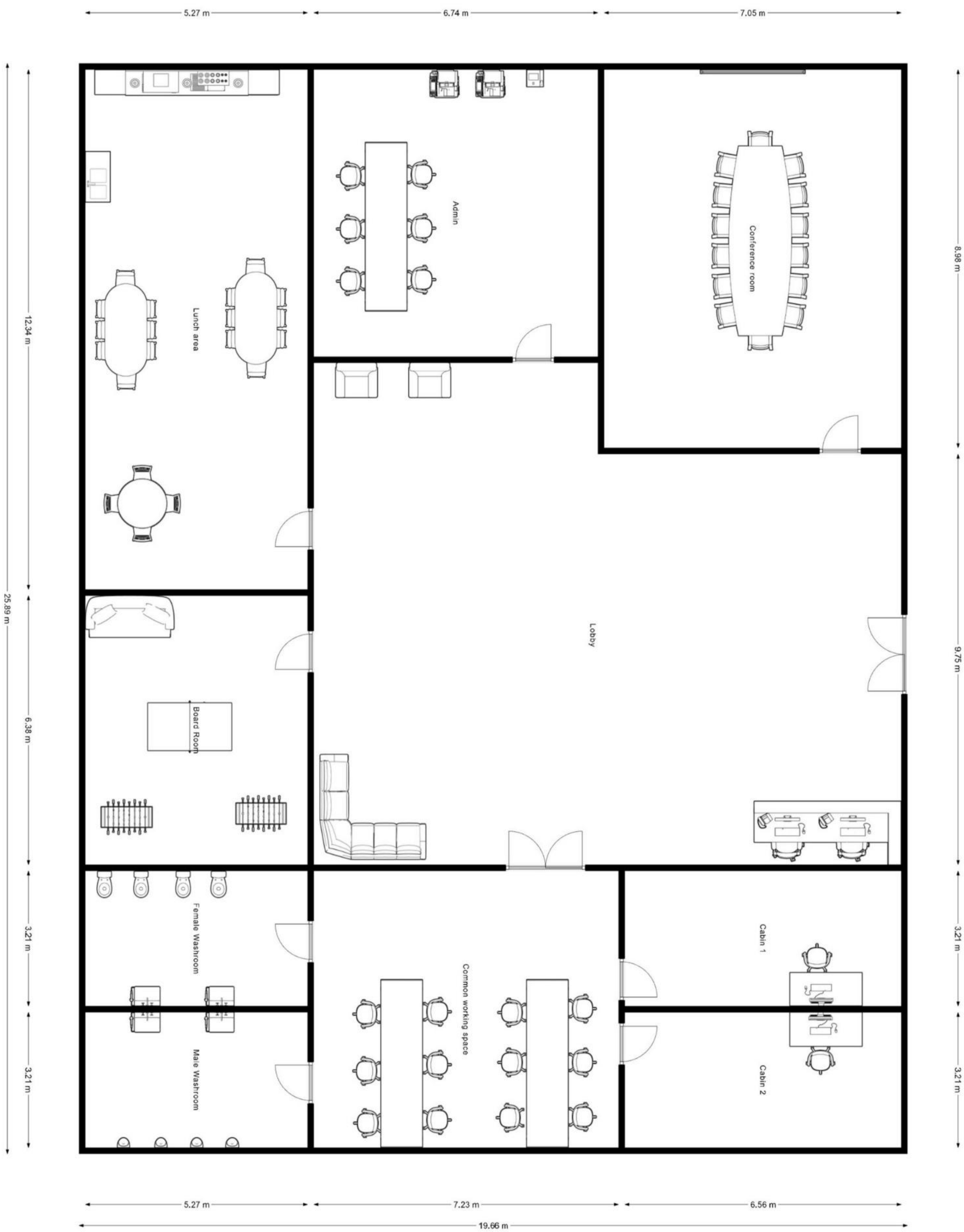

Figure 1.1 Floor plan layout (all dimensions are in meters) (North side is on right side in this page)

1.1 Assumptions

For the calculation of the Cooling load for the given plan, certain assumptions are taken, which are stated below:

Type of Plan: Office

Location: Phoenix, Arizona, USA

Latitude: 33.4482° N (approximately 32N)

Longitude: 112.0777° W

Outside Dry Bulb Temperature: 43° C and Relative humidity: 40%

Inside Dry Bulb Temperature: 22° C and Relative humidity: 40%

Month: June

Timing Considered: 12 00 hr, 14 00 hr and 16 00 hr.

Total working hour: 10 hr (8 00 hr to 18 00 hr)

Number of floors: 6

The major assumption is that the heat transfer through the floor is neglected.

Wall construction details:

Material selection: Heavyweight concrete wall + Finish

Wall type: Group E

Code number of layers: A0, A1, C5, E1, E0

A0: Outside surface resistance

A1: 1 inch Stucco (asbestos cement or wood siding plaster, etc)

C5: 4 inches heavyweight concrete

E1: 0.75 inches plaster

E0: inside surface resistance

Floor height: 4 m

Elevation of floor: 6th floor

There is no difference in the temperature between each room. Hence, there is no need to consider the partition between them. Therefore, heat transfer is zero between adjacent rooms.

Door:

Entrance door specification:

Type: Double Hung type

Height: 2 m

Width: 1.88 m

From Table 5-8 Transmission Coefficients U for Wood Solid core flush door.

Description of door: Wood- Solid core flush door with No Strom Door.

$U = 2.27 \frac{W}{m^2 \,°C}$

Windows:

Details of the window:

Description: Insulating glass 13 mm air space. Clear out and clear in. From Table 22

From Table 22 Interior solar attenuation coefficients for Single and Insulating glass with draperies: SC (Shading coefficient) = 0.64

Details of roof:

Without suspended ceiling: Steel sheet 25.4 mm insulation

Room construction details:

76.2 mm concrete floor with medium air circulation (No heat transfer through floor)

Furniture: Ordinary furniture with no carpet

Details of Light:

Fluorescent light

Light fixture: Recessed not vented

Input Light Power: 30 $\frac{W}{m^2 \,°C}$

2 Methodology

1. We calculated the overall heat transfer coefficient for various building components, including the roof, walls, and glass windows, based on the stated assumptions.

2. **Cooling Load Calculation – Walls and Roof**
   Using the CLTD (Cooling Load Temperature Difference) table, we extracted CLTD values at 12:00 PM, 2:00 PM, and 4:00 PM. Corrections were made using the LM (Latitude and Month) adjustment table based on a geographic latitude of 24° N and wall orientation. These values were applied in the corrected CLTD equation to determine adjusted CLTD values.
   The cooling load for walls and the roof at the specified times was then calculated using the formula:
   $q = U \cdot A_{eff} \cdot CLTD_{CORR}$

3. **Cooling Load Calculation – Glass Windows**
   Heat transfer through windows occurs via two mechanisms: conduction and solar radiation.
   Conduction:
   a. $q_{cond} = U \cdot A \cdot \Delta T.$
   Solar Radiation:
   b. $q_{solar} = A \cdot SC \cdot SHGF \cdot CLF$

   SHGF (Solar Heat Gain Factor) values were taken from relevant tables based on wall orientation and latitude (24° N). CLF (Cooling Load Factor) values were obtained for 12:00 PM, 2:00 PM, and 4:00 PM using the CLF table for internally shaded glass. The SC (Shading Coefficient) was assumed to be 0.64.

4. **Cooling Load Calculation – Internal Lighting**
   The heat gain from lighting was calculated as follows:
   $q = Input \cdot CLF \cdot A,$
   Given that the space is in use from 8:00 AM to 6:00 PM, the CLF was selected from the appropriate table for a 10-hour lighting duration, considering times at 4:00, 6:00, and 8:00 hours. The input power density was assumed to be 30 W/m².

5. **Cooling Load Due to Occupants**
   People contribute both sensible and latent heat to the space. The cooling load is calculated using:
   $q_{sensible} = Number\ of\ people \cdot Sensible\ heat\ gain\ per\ person\ .\ CLF$
   $q_{latent} = Number\ of\ people \cdot Latent\ heat\ gain\ per\ person$
   Values for heat gains were chosen based on moderate office activity, suitable for environments like offices, hotels, or apartments.

6. **Cooling Load – Appliances**

   Appliances also add to the cooling load via sensible and latent heat. The calculations used were:

   $q_{sensible} = SHGF \cdot CLF$

   $q_{latent} = LHGF$

   These gains vary depending on the room's function (e.g., kitchen or theatre) and the presence or absence of appliance hoods. CLF values were selected accordingly.

7. **Cooling Load – Infiltration and Ventilation**

   Infiltration-related heat transfer was estimated using the ACH (Air Changes per Hour) method based on room activity level and occupancy. We calculated the volume flow rate and specific humidity with the psychrometric chart. The cooling load was then computed as follows:

   $q_{sensible} = 1.232 \cdot \dot{Q} \cdot \Delta T$

   $q_{latent} = 3012 \cdot \dot{Q} \cdot \Delta\omega$

8. **Total Cooling Load and Equipment Sizing**

   The total cooling load was determined by summing the room loads for the entire floor area. The actual air conditioning capacity required was found using the psychrometric chart, applying the principles of adiabatic mixing and cooling dehumidification.

9. **Duct and Fan Design**

   - Based on the calculated cooling load, volume flow rate, and pressure losses (determined via the Moody diagram), we designed duct sizes (diameter and area) for both main and branch lines, referencing path 0 to 9 in Figure 6.1.
   - Finally, the fan specifications were selected according to the maximum pressure loss in the main duct line, ensuring they meet the system's ideal performance requirements.

3 Manual calculation of cooling load for conference room

The floor plan of the conference room:

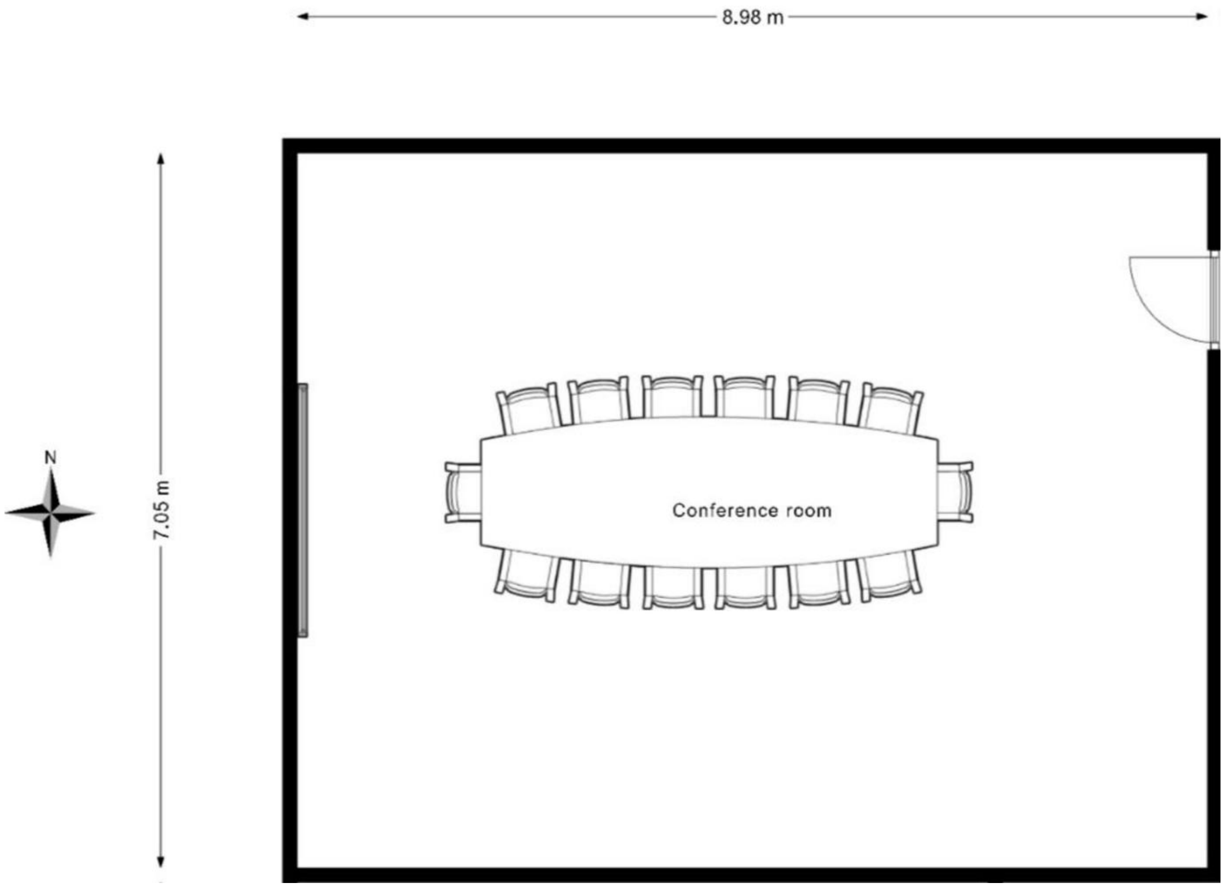

Figure 3.1 Conference room floor plan (all dimensions are in meters)

3.1 Wall

The wall is made of Heavyweight concrete wall + finish.

Also, the outside temperature is $T_o = 43$°C and the room is maintained at $T_R = 22$°C.

For the given specifications of wall, the overall heat transfer coefficient

$$U = 0.585 \frac{BTU}{h \cdot ft^2 \cdot °F}$$

$$= 3.3228 \frac{W}{m^2 \, °C}$$

Now,

$$CLTD_{CORR} = (CLTD + LM) \cdot K + (25.5 - T_R) + (T_o - 29.4) \quad (1)$$

For North facing wall from CLTD Table

Time of the day	12:00	14:00	16:00
$CLTD$ (°C)	5.00	7.22	9.44

Also, for West facing wall from CLTD Table

Time of the day	12:00	14:00	16:00
$CLTD$ (°C)	5.00	7.77	15.00

Now, for the correction of $CLTD$ the values of LM for 32° Latitude during the month of June is

North facing wall $= 1$

West facing wall $= 0$

Here, $K = 1$ for dark coloured or light in industrial area walls

Hence from the equation (1) we get,

For North facing wall,

Time of the day	12:00	14:00	16:00
$CLTD_{CORR}$(°C)	23.10	25.32	27.54

For West facing wall,

Time of the day	12:00	14:00	16:00
$CLTD_{CORR}$(°C)	22.21	24.87	32.10

Hence, the heating load – From North and West wall

$$A_{eff} = (Total\ area\ of\ wall - Total\ area\ of\ windows\ and\ doors)$$

$Aeff$, north $= ((8.98 \times 4) - 6) = 29.92\ m^2$

$Aeff, west = (7.05 \times 4) = 28.2 m^2$

North wall:

$q_{12,north} = U \cdot A_{eff} \cdot CLTD_{CORR}$

$= 3.3228 \times 29.92 \times 23.10$

$= 2296.698$ W

Similarly,

$q_{14,north} = 2517.42\ W$

$q_{16,north} = 2738.141\ W$

West wall:

$$q_{12,west} = U \cdot A_{eff} \cdot CLTD_{CORR}$$
$$= 3.3228 \times 28.20 \times 22.10$$
$$= 2070.96 \text{ W}$$

Similarly,

$q_{14,west} = 2330.533\ W$

$q_{16,west} = 3008.046\ W$

3.2 Roof

Now, calculate the cooling load from the roof (without a suspended ceiling) made of steel sheet with 25.4 mm insulation. Therefore, from the CLTD Table:-

Time of the day	12:00	14:00	16:00
$CLTD$ (°C)	40.00	44.00	39.00

Area of the roof:

$$A = 8.98 \times 7.05$$
$$= 63.309\ m^2$$

Also, the Overall heat transfer coefficient $U = 1.209\ \frac{W}{m^2\ °C}$, $K = 1$, $f = 0.75$.

Hence,

Time of the day	12:00	14:00	16:00
$CLTD_{CORR}$ (°C)	44.325	47.325	43.575

The heat gain from the roof:

$$q_{12} = U \cdot A_{eff} \cdot CLTD_{CORR}$$
$$= 1.209 \times 63.309 \times 44.325$$
$$= 3392.661\ W$$
$$q_{14} = 3622.283\ W$$
$$q_{16} = 3335.256\ W$$

3.3 Glass window

Only one on the north side wall

Area of the window

$$A = h \times w$$
$$= 2 \times 3$$
$$= 6.0\ m^2$$

The type of the window is double glazing, ¼ inch airspace and aluminium with thermal break. Hence, the overall heat transfer coefficient $U = 3.7\ \frac{W}{m^2\ ℃}$.

The heat transfer due to conduction will be,

$$q_{cond} = U \cdot A \cdot \Delta T$$
$$= 3.7 \times 6 \times (43\text{-}22)$$
$$= 466.2\ \mathrm{W}$$

CLF for North side during different time of the day:

Time of the day	12:00	14:00	16:00
CLF	0.89	0.86	0.75

SC for insulating glass, 6 mm airspace (3 mm out and 3 mm in) = 0.64

Lastly, $SHGF = 138.468\ \frac{W}{m^2}$

Heat transfer due to solar radiation will be,

$$q_{12,north} = A \cdot SC \cdot SHGF \cdot CLF$$
$$= 6 \times 0.64 \times 138.468 \times 0.89$$
$$= 473.2282\ W$$

$$q_{14,north} = 457.2767\ W$$

$$q_{16,north} = 398.7878\ W$$

3.4 Internal lights

Fluorescent light having input $= 30\ \frac{W}{m^2}$

CLF Values for different time during the day:

Time of the day	12:00	14:00	16:00
CLF	0.79	0.83	0.86

Therefore, heat gain from the light in the room:

$q_{12} = Input \cdot CLF \cdot A$

$=30\times0.79\times(8.98\times7.05)$

$=1500.423\ W$

$q_{14} = 1576.394\ W$

$q_{16} = 1633.372\ W$

3.5 People

The number of people in the room is taken as 14.

Sensible heat gain per person $= 73\ W$

Latent heat gain per person $= 59\ W$

CLF for people during different time of the day

Time of the day	12:00	14:00	16:00
CLF	0.74	0.80	0.85

$q_{12,sensible} = Number\ of\ people \cdot Sensible\ heat\ gain\ per\ person \cdot CLF$

$= 14 \times 73 \times 0.74$

$= 756.28\ W$

$q_{14,sensible} = 817.6\ W$

$q_{16,sensible} = 868.7\ W$

$q_{latent} = Number\ of\ people \cdot Latent\ heat\ gain\ per\ person$

$= 14 \times 59$

$= 826\ W$

3.6 Appliances

Items:

Name of the Item	Heat gain (W)
14 Computers	$14 \times 55 = 770$
Large Monitor	80
Water cooler	350
Total	**1200**

CLF for 10 hours of operation for each appliance

Time of the day	12:00	14:00	16:00
CLF	0.77	0.83	0.87

Heat gain from the appliances:

$$q_{12} = SHGF\,.\,CLF$$
$$= 1200 \times 0.77$$
$$= 924\ W$$
$$q_{14} = 996\ W$$
$$q_{16} = 1044\ W$$

3.7 Infiltration air

Assuming air changes once per hour

$$\therefore\ ACH = 1.0$$

$$Volume: V = l \cdot b \cdot h$$
$$= 8.98 \times 7.05 \times 4$$
$$= 253.236\ m^3$$

$$Volume\ flow\ rate\ \dot{Q} = \frac{V \cdot ACH \cdot 1000}{3600}$$
$$= \frac{253.236 \cdot 1 \cdot 1000}{3600}$$
$$= 70.343\ \frac{L}{s}$$

From the psychometric chart:

$$\omega_2 = 0.022$$
$$\omega_1 = 0.0065$$
$$\Delta\omega = 0.0155$$

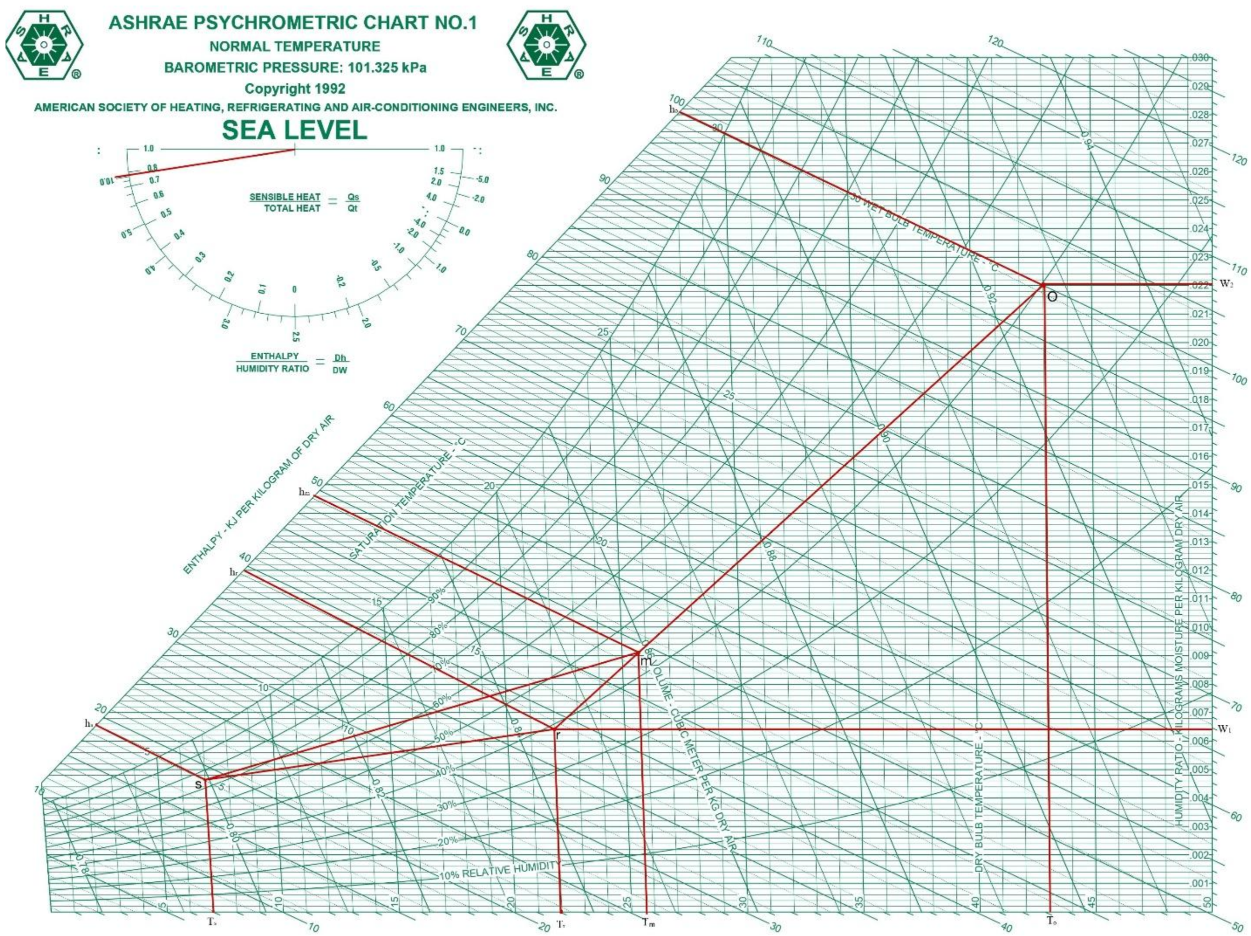

Figure 3.2 Psychometric chart (SI) for humidity ratios

Sensible heat gain due to ventilation and infiltration air:

$$q_{sensible} = 1.232 \cdot \dot{Q} \cdot \Delta T$$
$$= 1.232 \times 70.343 \times (43\text{-}22)$$
$$= 1819.923\ W$$

Latent heat gain due to ventilation and infiltration air:

$$q_{\text{latent}} = 3012 \cdot \dot{Q} \cdot \Delta\omega$$
$$= 3012 \times 70.343 \times 0.0155$$
$$= 3284.049\ W$$

3.8 Total heat gained from the space

$$q_{12,sensible} = wall + roof + window + lights + people + appliances + ventilation\ and\ infiltration$$

$$=(2296.698 + 2070.96) + 3392.661 + (466.2 + 473.2282) + 1500.423 + 756.28 + 924 + 1819.923$$

$$= 13700.374\ W$$

$$q_{12,latent} = people + ventilation\ and\ infiltration\ air$$

$$= 826 + 3284.049$$

$$= 4110.049\ W$$

$$q_{12,total} = q_{12,sensible} + q_{12,latent}$$

$$= 13700.374 + 4110.049$$

$$= 17810.42\ W$$

$$= 5.063\ ton$$

$$q_{14,total} = 18713.68\ W$$

$$= 5.321\ ton$$

$$q_{16,total} = 19422.47\ W$$

$$= 5.522\ ton$$

4 Excel data sheet for each room

4.1 Conference Room

Contents	U (W/m² C)	Length (m)	Width (m)	Height (m)	Area (m²)	LM	Effective Area (m²)	SHGF (W/m²)	SC	CLTD/CLF for window			Corrected CLTD			Cooling Load Q (W)		
										12:00	14:00	16:00	12:00	14:00	16:00	12:00	14:00	16:00
Roof	1.209	8.98	7.05		63.309	2	63.309			40	44	39	44.325	47.325	43.575	3392.661	3622.283	3335.256
Wall (North)	3.323	8.98		4	35.92	1	29.92			5	7.22	9.44	23.1	25.32	27.54	2296.698	2517.42	2738.141
Wall (West)	3.323		7.05	4	28.2	0	28.2			5	7.77	15	22.1	24.87	32.1	2070.96	2330.533	3008.046
Glass Window (Conduction)	3.7		3	2	6		6									466.2	466.2	466.2
Glass Solar (North)	3.7		3	2	6		6	138.468	0.64	0.89	0.86	0.75				473.2282	457.2767	398.7878
															Total	**8699.748**	**9393.712**	**9946.431**

Infiltration									
Length (m)	Width (m)	Height (m)	Volume (m^3)	ACH	Infiltration rate	Temp. Diff (C)	Humidity Ratio Diff.	Q (sensible) (W)	Q (Latent) (W)
8.98	7.05	4	253.236	1	70.343333	21	0.0155	1819.923	3284.049

	Quantity	Input (W)	Latent Heat (W)	Sensible Heat (W)	CLF			Cooling Load (Q) (W)		
					12:00	14:00	16:00	12:00	14:00	16:00
Lights		1899.27			0.79	0.83	0.86	1500.423	1576.394	1633.372
People (Sensible)				73	0.74	0.8	0.85	756.28	817.6	868.7
People (Latent)	14		59					826	826	826
Computer	14			55	0.77	0.83	0.87	592.9	639.1	669.9
Large Monitor	1			80	0.77	0.83	0.87	61.6	66.4	69.6
Water Cooler	1			350	0.77	0.83	0.87	269.5	290.5	304.5
Total Sensible								**3180.703**	**3389.994**	**3546.072**
Total Latent								**826**	**826**	**826**

	Total Sensible (W)	Total Latent (W)	Total Cooling Load (W)	Total Cooling Load (Tons)
12:00	13700.374	4110.049	17810.42	5.063503
14:00	14603.629	4110.049	18713.68	5.320299
16:00	15312.426	4110.049	19422.47	**5.52181**

Mass flow rate (kg/s)	Volume flow rate (m³/s)	Duct diameter (m)
0.3184	0.269049	0.276028

Figure 4.1 Excel sheet for Conference Room

4.2 Admin room

Contents	U (W/m² C)	Length (m)	Width (m)	Height (m)	Area (m²)	LM	Effective Area (m²)	SHGF (W/m²)	SC	CLTD/CLF for window			Corrected CLTD			Cooling Load Q (W)		
										12:00	14:00	16:00	12:00	14:00	16:00	12:00	14:00	16:00
Roof	1.209	6.81	6.74		45.8994	2	45.8994			40	44	39	44.325	47.325	43.575	2459.7	2626.177	2418.08
Wall (West)	3.323		6.74	4	26.96	0	22.96			5	7.77	15	22.1	24.87	32.1	1686.143	1897.484	2449.104
Glass Window (Conduction)	3.7		2	2	4		4									310.8	310.8	310.8
Glass Solar (West)	3.7		2	2	4		4	673.458	0.64	0.17	0.53	0.82				293.0889	913.7478	1413.723
															Total	**4749.732**	**5748.208**	**6591.707**

Infiltration									
Length (m)	Width (m)	Height (m)	Volume (m³)	ACH	Infiltration rate	Temp. Diff (C)	Humidity Ratio Diff.	Q (sensible) (W)	Q (Latent) (W)
6.81	6.74	4	183.5976	1	50.999333	21	0.0155	1319.455	2380.955

	Quantity	Input (W)	Latent Heat (W)	Sensible Heat (W)	CLF			Cooling Load (Q) (W)		
					12:00	14:00	16:00	12:00	14:00	16:00
Lights		1376.982			0.79	0.83	0.86	1087.816	1142.895	1184.205
People (Sensible)				73	0.74	0.8	0.85	324.12	350.4	372.3
People (Latent)	6		59					354	354	354
Computer	6			55	0.77	0.83	0.87	254.1	273.9	287.1
Laser printer	1			320	0.77	0.83	0.87	246.4	265.6	278.4
Office copier	2			1100	0.77	0.83	0.87	1694	1826	1914
Total Sensible								**3606.436**	**3858.795**	**4036.005**
Total Latent								**354**	**354**	**354**

	Total Sensible (W)	Total Latent (W)	Total Cooling Load (W)	Total Cooling Load (Tons)
12:00	9675.6223	2734.955	12410.58	3.528327
14:00	10926.458	2734.955	13661.41	3.88394
16:00	11947.167	2734.955	14682.12	**4.174127**

Mass flow rate (kg/s)	Volume flow rate (m³/s)	Duct diameter (m)
0.24069	0.203383	0.239992

Figure 4.2 Excel sheet for Admin

4.3 Lunch Area

Contents	U (W/m^2 C)	Length (m)	Width (m)	Height (m)	Area (m^2)	LM	Effective Area (m^2)	SHGF (W/m^2)	SC	CLTD/CLF for window			Corrected CLTD			Cooling Load Q (W)		
										12:00	14:00	16:00	12:00	14:00	16:00	12:00	14:00	16:00
Roof	1.209	12.34	5.27		65.0318	2	65.0318			40	44	39	44.325	47.325	43.575	3484.984	3720.855	3426.017
Wall (South)	3.323	12.34		4	49.36	-4	39.36			7.22	13.33	17.77	20.32	26.43	30.87	2657.719	3456.866	4037.589
Wall (West)	3.323		5.27	4	21.08	0	21.08			5	7.77	15	22.1	24.87	32.1	1548.079	1742.115	2248.568
Glass Window (Conduction)	3.7		5	2	10		10									777	777	777
Glass Solar (South)	3.7		5	2	10		10	188.82	0.64	0.83	0.68	0.35				1003.012	821.7446	422.9568
															Total	**9470.795**	**10518.58**	**10912.13**

Infiltration									
Length (m)	**Width (m)**	**Height (m)**	**Volume (m^3)**	**ACH**	**Infiltration rate**	**Temp. Diff (C)**	**Humidity Ratio Diff.**	**Q (sensible) (W)**	**Q (Latent) (W)**
12.34	5.27	4	260.1272	1	72.2575556	21	0.0155	1869.4475	3373.416

	Quantity	Input (W)	Latent Heat (W)	Sensible Heat (W)	CLF			Cooling Load (Q) (W)		
					12:00	14:00	16:00	12:00	14:00	16:00
Lights		1950.954			0.79	0.83	0.86	1541.2537	1619.292	1677.82
People (Sensible)				81	0.74	0.8	0.85	1198.8	1296	1377
People (Latent)	20		81					1620	1620	1620
Refrigerator	1			310	0.77	0.83	0.87	238.7	257.3	269.7
Microwave Oven	2			400	0.77	0.83	0.87	616	664	696
Water cooler	1			350	0.77	0.83	0.87	269.5	290.5	304.5
Coffee maker (sensible)				1050	0.77	0.83	0.87	808.5	871.5	913.5
Coffee maker (latent)	1		450					450	450	450
Vending Machine	1			257.5	0.77	0.83	0.87	198.275	213.725	224.025
Steam Kettle (sensible)				21	0.77	0.83	0.87	32.34	34.86	36.54
Steam Kettle (latent)	2		14					28	28	28
Total Sensible								**4903.3687**	**5247.177**	**5499.085**
Total Latent								**2098**	**2098**	**2098**

	Total Sensible (W)	Total Latent (W)	Total Cooling Load (W)	Total Cooling Load (Tons)
12:00	16243.611	5471.416	21715.03	6.173582
14:00	17635.205	5471.416	23106.62	6.569212
16:00	18280.663	5471.416	23752.08	**6.752716**

Mass flow rate (kg/s)	Volume flow rate (m^3/s)	Duct diameter (m)
0.38938	0.329025	0.3052477

Figure 4.3 Excel sheet for Lunch Area

4.4 Board Room

Contents	U (W/m² C)	Length (m)	Width (m)	Height (m)	Area (m²)	LM	Effective Area (m²)	SHGF (W/m²)	SC	CLTD/CLF for window			Corrected CLTD			Cooling Load Q (W)		
										12:00	14:00	16:00	12:00	14:00	16:00	12:00	14:00	16:00
Roof	1.209	6.38	5.27		33.6226	2	33.6226			40	44	39	44.325	47.325	43.575	1801.799	1923.748	1771.312
Wall (South)	3.323	6.38		4	25.52	-4	21.52			7.22	13.33	17.77	20.32	26.43	30.87	1453.103	1890.035	2207.543
Partition Wall (Sharing with washroom)	2.164		5.27	4	21.08	0	21.08									364.937	364.937	364.937
Glass Window (Conduction)	3.7		2	2	4		4									310.8	310.8	310.8
Glass Solar (South)	3.7		2	2	4		4	188.82	0.64	0.83	0.68	0.35				401.2047	328.6979	169.1827
															Total	**4331.843**	**4818.218**	**4823.775**

Infiltration									
Length (m)	**Width (m)**	**Height (m)**	**Volume (m^3)**	**ACH**	**Infiltration rate**	**Temp. Diff (C)**	**Humidity Ratio Diff.**	**Q (sensible) (W)**	**Q (Latent) (W)**
6.38	5.27	4	134.4904	1	37.358444	21	0.0155	966.5377	1744.116

	Quantity	Input (W)	Latent Heat (W)	Sensible Heat (W)	CLF			Cooling Load (Q) (W)		
					12:00	14:00	16:00	12:00	14:00	16:00
Lights		1008.678			0.79	0.83	0.86	796.8556	837.2027	867.4631
People (Sensible)				81	0.74	0.8	0.85	419.58	453.6	481.95
People (Latent)	7		139					973	973	973
Water cooler	1			350	0.77	0.83	0.87	269.5	290.5	304.5
Vending Machine	1			767.5	0.77	0.83	0.87	590.975	637.025	667.725
Total Sensible								**2076.911**	**2218.328**	**2321.638**
Total Latent								**973**	**973**	**973**

	Total Sensible (W)	**Total Latent (W)**	**Total Cooling Load (W)**	**Total Cooling Load (Tons)**
12:00	7375.2917	2717.116	10092.41	2.869272
14:00	8003.0831	2717.116	10720.2	3.047753
16:00	8111.9505	2717.116	10829.07	**3.078704**

Mass flow rate (kg/s)	**Volume flow rate (m^3/s)**	**Duct diameter (m)**
0.17753	0.150009	0.206109

Figure 4.4 Excel sheet for Board room

4.5 Washrooms

Contents	U ($W/m^2 C$)	Length (m)	Width (m)	Height (m)	Area (m^2)	LM	Effective Area (m^2)	SHGF (W/m^2)	SC	CLTD/CLF for window			Corrected CLTD			Cooling Load Q (W)		
										12:00	14:00	16:00	12:00	14:00	16:00	12:00	14:00	16:00
Roof	1.209	6.42	5.27		33.8334	2	33.8334			40	44	39	38.325	41.325	37.575	1567.668	1690.382	1536.99
Wall (South)	3.323	6.42		4	25.68	-4	25.68			7.22	13.33	17.77	12.32	18.43	22.87	1051.323	1572.717	1951.603
Wall (East)	3.323		5.27	4	21.08	0	21.08			20	20.55	18.88	29.1	29.65	27.98	2038.421	2076.948	1959.967
															Total	**4657.412**	**5340.047**	**5448.559**

Infiltration									
Length (m)	Width (m)	Height (m)	Volume (m^3)	ACH	Infiltration rate	Temp. Diff (C)	Humidity Ratio Diff.	Q (sensible) (W)	Q (Latent) (W)
6.42	5.27	4	135.3336	1	37.592667	13	0.0155	602.0841	1755.051

	Quantity	Input (W)	Latent Heat (W)	Sensible Heat (W)	CLF			Cooling Load (Q) (W)		
					12:00	14:00	16:00	12:00	14:00	16:00
Lights		1015.002			0.79	0.83	0.86	801.8516	842.4517	872.9017
People (Sensible)				73	0.74	0.8	0.85	540.2	584	620.5
People (Latent)	10		59					590	590	590
Total Sensible								**1342.052**	**1426.452**	**1493.402**
Total Latent								**590**	**590**	**590**

	Total Sensible (W)	Total Latent (W)	Total Cooling Load (W)	Total Cooling Load (Tons)
12:00	6601.5478	2345.051	8946.599	2.543518
14:00	7368.5831	2345.051	9713.634	2.761586
16:00	7544.0452	2345.051	9889.096	**2.81147**

Mass flow rate (kg/s)	Volume flow rate (m^3/s)	Duct diameter (m)
0.26024	0.227892	0.245134

Figure 4.5 Excel sheet for Washrooms

4.6 Common Working Space

Contents	U (W/m² C)	Length (m)	Width (m)	Height (m)	Area (m²)	LM	Effective Area (m²)	SHGF (W/m²)	SC	CLTD/CLF for window			Corrected CLTD			Cooling Load Q (W)		
										12:00	14:00	16:00	12:00	14:00	16:00	12:00	14:00	16:00
Roof	1.209	6.57	7.23		47.5011	2	47.5011			40	44	39	44.325	47.325	43.575	2545.53	2717.82	2502.46
Wall (East)	3.323		7.23	4	28.92	0	22.92			20	20.55	18.88	37.1	37.65	35.98	2825.65	2867.54	2740.35
Partition Wall (Sharing with washroom)	2.164	6.42		4	25.68		23.68									409.948	409.948	409.948
Doors on partition wall (Qty: 2)	2.87	1		2	2		2									91.84	91.84	91.84
Glass Window (Conduction)	3.7		3	2	6		6									466.2	466.2	466.2
Glass Solar (East)	3.7		3	2	6		6	673.458	0.64	0.27	0.22	0.17				698.241	568.937	439.633
															Total	**7037.42**	**7122.29**	**6650.43**

Infiltration									
Length (m)	Width (m)	Height (m)	Volume (m^3)	ACH	Infiltration rate	Temp. Diff (C)	Humidity Ratio Diff.	Q (sensible) (W)	Q (Latent) (W)
6.57	7.23	4	190.004	1	52.779	21	0.0155	1365.5	2464.04

	Quantity	Input (W)	Latent Heat (W)	Sensible Heat (W)	CLF			Cooling Load (Q) (W)		
					12:00	14:00	16:00	12:00	14:00	16:00
Lights		1425.03			0.79	0.83	0.86	1125.78	1182.78	1225.53
People (Sensible)				73	0.74	0.8	0.85	648.24	700.8	744.6
People (Latent)	12		59					708	708	708
Computer	12			55	0.77	0.83	0.87	508.2	547.8	574.2
shredder	1			1310	0.77	0.83	0.87	1008.7	1087.3	1139.7
Water cooler	1			350	0.77	0.83	0.87	269.5	290.5	304.5
Total Sensible								**3560.42**	**3809.18**	**3988.53**
Total Latent								**708**	**708**	**708**

	Total Sensible (W)	Total Latent (W)	Total Cooling Load (W)	Total Cooling Load (Tons)
12:00	11963.33	3172.04	15135.4	4.30299
14:00	12296.96	3172.04	15469	**4.39784**
16:00	12004.46	3172.04	15176.5	4.31468

Mass flow rate (kg/s)	Volume flow rate (m^3/s)	Duct diameter (m)
0.2536	0.21428	0.24634

Figure 4.6 Excel sheet for Common Working Area

4.7 Cabin 1

Contents	U (W/m² C)	Length (m)	Width (m)	Height (m)	Area (m²)	LM	Effective Area (m²)	SHGF (W/m²)	SC	CLTD/CLF for window			Corrected CLTD			Cooling Load Q (W)		
										12:00	14:00	16:00	12:00	14:00	16:00	12:00	14:00	16:00
Roof	1.209	6.56	3.21		21.0576	2	21.0576			40	44	39	44.325	47.325	43.575	1128.454	1204.83	1109.36
Wall (North)	3.323	3.21		4	12.84	1	11.34			5	7.22	9.44	23.1	25.32	27.54	870.4731	954.129	1037.785
Glass Window (Conduction)	3.7		1.5	1	1.5		1.5									116.55	116.55	116.55
Glass Solar (North)	3.7		1.5	1	1.5		1.5	138.468	0.64	0.89	0.86	0.75				118.3071	114.3192	99.69696
															Total	**2233.784**	**2389.828**	**2363.392**

Infiltration									
Length (m)	**Width (m)**	**Height (m)**	**Volume (m³)**	**ACH**	**Infiltration rate**	**Temp. Diff (C)**	**Humidity Ratio Diff.**	**Q (sensible) (W)**	**Q (Latent) (W)**
6.56	3.21	4	84.2304	1	23.397333	21	0.0155	605.3358	1092.328

	Quantity	Input (W)	Latent Heat (W)	Sensible Heat (W)	CLF			Cooling Load (Q) (W)		
					12:00	**14:00**	**16:00**	**12:00**	**14:00**	**16:00**
Lights		631.728			0.79	0.83	0.86	499.0651	524.3342	543.2861
People (Sensible)				73	0.74	0.8	0.85	54.02	58.4	62.05
People (Latent)	1		59					59	59	59
Computer	1			55	0.77	0.83	0.87	42.35	45.65	47.85
Paper shredder	1			1310	0.77	0.83	0.87	1008.7	1087.3	1139.7
Laser Printer (Small desktop)	1			130	0.77	0.83	0.87	100.1	107.9	113.1
Total Sensible								**1704.235**	**1823.584**	**1905.986**
Total Latent								**59**	**59**	**59**

	Total Sensible (W)	Total Latent (W)	Total Cooling Load (W)	Total Cooling Load (Tons)
12:00	4543.3553	1151.328	5694.683	1.618998
14:00	4818.7483	1151.328	5970.076	1.697293
16:00	4874.7139	1151.328	6026.042	**1.713204**

Mass flow rate (kg/s)	Volume flow rate (m³/s)	Duct diameter (m)
0.09879	0.083475	0.153751

Figure 4.7 Excel sheet for Cabin 1

4.8 Cabin 2

Contents	U (W/m^2 C)	Length (m)	Width (m)	Height (m)	Area (m^2)	LM	Effective Area (m^2)	SHGF (W/m^2)	SC	CLTD/CLF for window			Corrected CLTD			Cooling Load Q (W)		
										12:00	14:00	16:00	12:00	14:00	16:00	12:00	14:00	16:00
Roof	1.209	6.56	3.21		21.0576	2	21.0576			40	44	39	44.325	47.325	43.575	1128.454	1204.83	1109.36
Wall (North)	3.323	3.21		4	12.84	1	12.84			5	7.22	9.44	23.1	25.32	27.54	985.6151	1080.337	1175.058
Wall (East)	3.323		6.56	4	26.24	0	20.24			20	20.55	18.88	37.1	37.65	35.98	2495.254	2532.246	2419.926
Glass Window (Conduction)	3.7		3	2	6		6									466.2	466.2	466.2
Glass Solar (East)	3.7		3	2	6		6	673.458	0.64	0.27	0.22	0.17				698.2413	568.9373	439.6334
															Total	**4788.149**	**4772.213**	**4435.119**

Infiltration									
Length (m)	Width (m)	Height (m)	Volume (m^3)	ACH	Infiltration rate	Temp. Diff (C)	Humidity Ratio Diff.	Q (sensible) (W)	Q (Latent) (W)
6.56	3.21	4	84.2304	1	23.397333	21	0.0155	605.3358	1092.328

	Quantity	Input (W)	Latent Heat (W)	Sensible Heat (W)	CLF			Cooling Load (Q) (W)		
					12:00	14:00	16:00	12:00	14:00	16:00
Lights		631.728			0.79	0.83	0.86	499.0651	524.3342	543.2861
People (Sensible)				73	0.74	0.8	0.85	54.02	58.4	62.05
People (Latent)	1		59					59	59	59
Computer	1			55	0.77	0.83	0.87	42.35	45.65	47.85
Paper shredder	1			1310	0.77	0.83	0.87	1008.7	1087.3	1139.7
Laser Printer (Small desktop)	1			130	0.77	0.83	0.87	100.1	107.9	113.1
Total Sensible								**1704.235**	**1823.584**	**1905.986**
Total Latent								**59**	**59**	**59**

	Total Sensible (W)	Total Latent (W)	Total Cooling Load (W)	Total Cooling Load (Tons)
12:00	7097.7203	1151.328	8249.048	2.345204
14:00	7201.1331	1151.328	8352.461	**2.374605**
16:00	6946.441	1151.328	8097.769	2.302196

Mass flow rate (kg/s)	Volume flow rate (m^3/s)	Duct diameter (m)
0.13693	0.115702	0.181013

Figure 4.8 Excel sheet for Cabin 2

4.9 Lobby

Contents	U (W/m^2 C)	Length (m)	Width (m)	Height (m)	Area (m^2)	LM	Effective Area (m^2)	SHGF (W/m^2)	SC	CLTD/CLF for window			Corrected CLTD			Cooling Load Q (W)		
										12:00	**14:00**	**16:00**	**12:00**	**14:00**	**16:00**	**12:00**	**14:00**	**16:00**
Roof	1.209				150.4	2	150.4			40	44	39	44.325	47.325	43.575	8059.774	8605.275	7923.399
Wall (North)	3.323	9.75		4	39	1	35.24			5	7.22	9.44	23.1	25.32	27.54	2705.068	2965.036	3225.003
Main Door	2.27		1.88	2	3.76		3.76									179.2392	179.2392	179.2392
															Total	**10944.08**	**11749.55**	**11327.64**

Infiltration									
Length (m)	**Width (m)**	**Height (m)**	**Volume (m^3)**	**ACH**	**Infiltration rate**	**Temp. Diff (C)**	**Humidity Ratio Diff.**	**Q (sensible) (W)**	**Q (Latent) (W)**
		4	601.6	1	167.11111	21	0.0155	4323.499	7801.749

	Quantity	Input (W)	Latent Heat (W)	Sensible Heat (W)	CLF			Cooling Load (Q) (W)		
					12:00	**14:00**	**16:00**	**12:00**	**14:00**	**16:00**
Lights		4512			0.79	0.83	0.86	3564.48	3744.96	3880.32
People (Sensible)				73	0.74	0.8	0.85	540.2	584	620.5
People (Latent)	10		59					590	590	590
Computer	2			55	0.77	0.83	0.87	84.7	91.3	95.7
Water Cooler	1			350	0.77	0.83	0.87	269.5	290.5	304.5
Laser Printer (Small desktop)	1			130	0.77	0.83	0.87	100.1	107.9	113.1
Total Sensible								**4558.98**	**4818.66**	**5014.12**
Total Latent								**590**	**590**	**590**

	Total Sensible (W)	Total Latent (W)	Total Cooling Load (W)	Total Cooling Load (Tons)
12:00	19826.56	8391.749	28218.31	8.022465
14:00	20891.709	8391.749	**29283.46**	**8.325287**
16:00	20665.26	8391.749	29057.01	8.260908

Mass flow rate (kg/s)	Volume flow rate (m^3/s)	Duct diameter (m)
0.48006	0.405648	0.338932

Figure 4.9 Excel sheet for Lobby

5 Machine capacity

For the calculation of the volume flow rate, we require the total cooling load of the system, which we can find in the Excel sheet provided.

q_{total} =19422.475+14682.122+23752.079+10829.067+9889.0965+15469.004+6026.0418+8352.461+29283.458

$= 137705.8\ W$

Now to find the Sensible Heat Factor (SHF) we also require total sensible heat, which is given as,

$q_{sensible} = 15312.426 + 11947.1667 + 18280.6627 + 8111.950467 + 7544.045245 + 12296.96351 + 4874.713879 + 7201.133057 + 20891.70879$

$= 106460.7704\ W$

$$\text{SHF} = \frac{q_{sensible}}{q_{total}}$$

$$\frac{106460.770}{137705.8}$$

SHF = 0.773

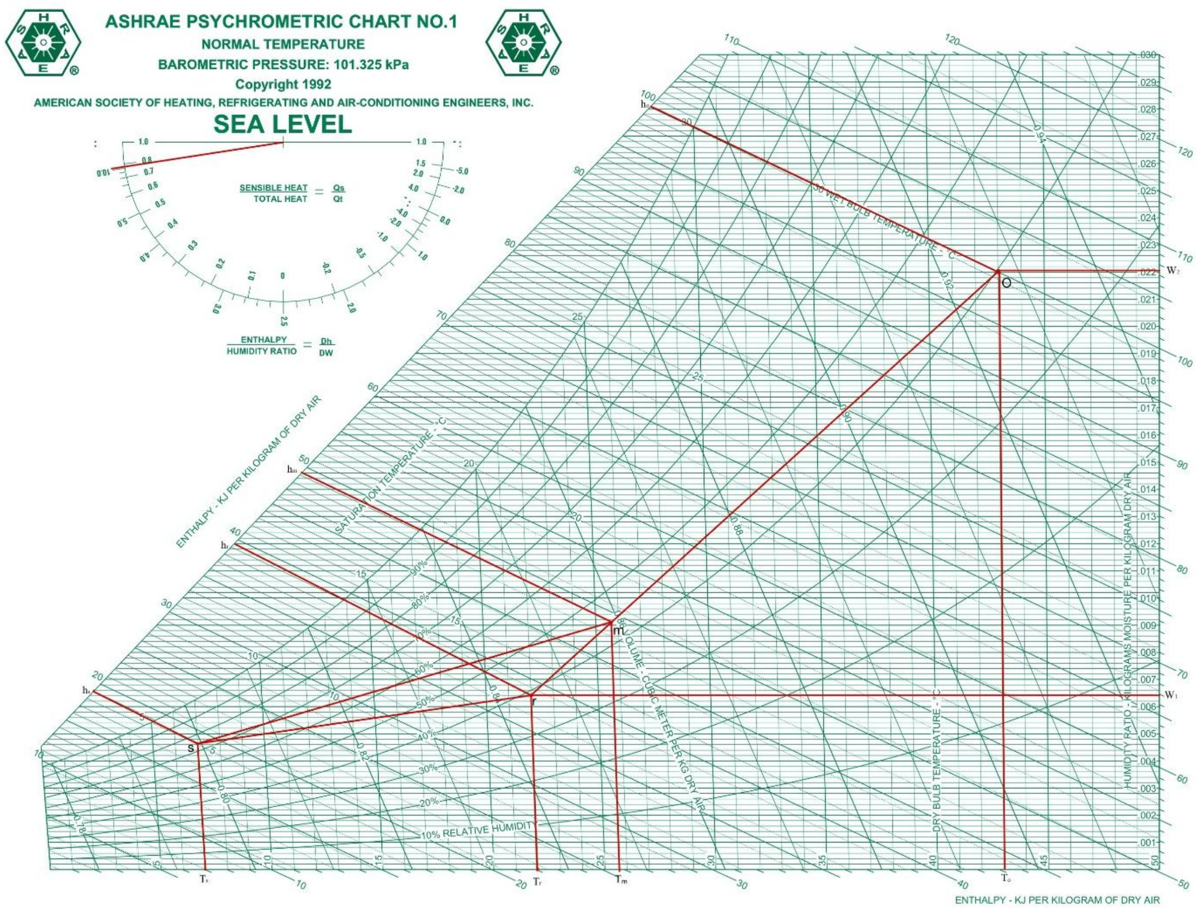

Figure 5.1 Psychometric chart for machine capacity calculation

We have considered supplying 7 °C air to the conditioned space, which is supposed to be maintained at 22 °C. Hence, from Figure 5.1, the enthalpies and specific volumes of the considered points are:

$H_{supply} = 19\,\frac{kJ}{kg}$; $H_{rooms} = 39\,\frac{kJ}{kg}$; $\vartheta_{supply} = 0.799$; $\vartheta_{outside} = 0.927$

$$\dot{q}_{total} = \dot{m}_{\,supply}(H_{rooms} - H_{supply})$$

- $\dot{m}_{\,supply} = \frac{\dot{q}total}{Hrooms - Hsupply}$

$$= \frac{137705.5}{(39-19)3 \times 10^{3}}$$

$$= 6.885\,\frac{kg}{s}$$

$$\dot{m}_{\,supply} = \frac{\dot{Q}_{supply}}{\vartheta}$$

$$Q_{supply} = \vartheta supply\,.\,\dot{m}_{\,supply}$$

$$= 6.885 \times 0.799$$

$$= 5.501\,\frac{m^{3}}{s}$$

Now, we have assumed the Air Change per Hour (ACH) = 2

Hence, total infiltration from the outside is,

$$Q_{outside} = \frac{ACH \times Volume}{3600}$$

$$= \frac{2 \times 451.7 \times 4}{3600}$$

$$= 1.07\ \frac{m^3}{s}$$

$$\dot{m}_{outside} = \frac{\dot{Q}_{supply}}{\vartheta_{outside}}$$

$$= \frac{1.07}{0.927}$$

$$= 1.15\ \frac{kJ}{kg}$$

To find the properties of the mixed air (recirculated air and outside air) adiabatic mixing is considered and the temperature of the mixed air is found. This is shown below in the calculations.

$$\frac{\dot{m}_{outside}}{\dot{m}_{supply}} = \frac{22\ ℃ - T_{mix}}{22\ ℃ - 43\ ℃}$$

$$\frac{1.15}{6.885} = \frac{22\ ℃ - T_{mix}}{-21\ ℃}$$

$$T_{mix} = 25.507\ ℃$$

Therefore, from the psychometric chart

$$H_{mix} = 49\ \frac{kJ}{kg}$$

Finally, the machine capacity:

$$q_{machine} = \dot{m}_{supply}\ (H_{mix} - H_{supply})$$

$$= 6.885 \times (49 - 19)$$

$$= 206.55\ kW$$

$$= 58.722\ tons$$

6 Duct design and fan selection

6.1 Duct design

Calculating mass flow rate for each room by using below equation:

$$\therefore \; \dot{m}_{\,duct} = \frac{q_{cooling\ load}}{H_{43℃} - H_{22℃}}$$

$$\therefore \; Q_{duct} = \frac{\dot{m_{duct}}}{\vartheta_{22℃}}$$

$$\therefore \; A \times \mathrm{V} = \frac{\dot{m_{duct}}}{\vartheta_{22℃}}$$

$$\therefore \; \frac{\pi d^2}{4} \times V = \frac{m_{duct}}{\vartheta_{22℃}}$$

$$\therefore \; \mathrm{d} = \sqrt{\frac{4 \times m_{duct}}{\pi \times \mathrm{V} \times \vartheta_{22℃}}}$$

From this relation, we can find the duct diameter. After getting all the diameters, we can see each duct's Darcey factor.

Here, we have assumed the $V = 6.3\,\frac{m}{s}$. Due to this assumption the ratios:

$$\therefore \; \frac{Q_S}{Q_C} = \frac{A_S \times \cancel{V}}{A_C \times \cancel{V}}$$

$$\therefore \; \frac{Q_S}{Q_C} = \frac{A_S}{A_C}$$

For this reason, for all the Tee–straight, the pressure loss coefficient will always be 0.13and the pressure loss coefficient of the pleated elbow (90º) is 0.43. These values are used to find the largest pressure drop in the ducting system. This duct line is points 0 to 9 in Figure 6.1. Finally, the tabulated data, including equivalent length, the pressure drop per meter of duct in the considered section and the pressure drop in the section, is given in Figure 6.1**.** Therefore, the total drop in the duct was found to be **63.285 *Pa***.

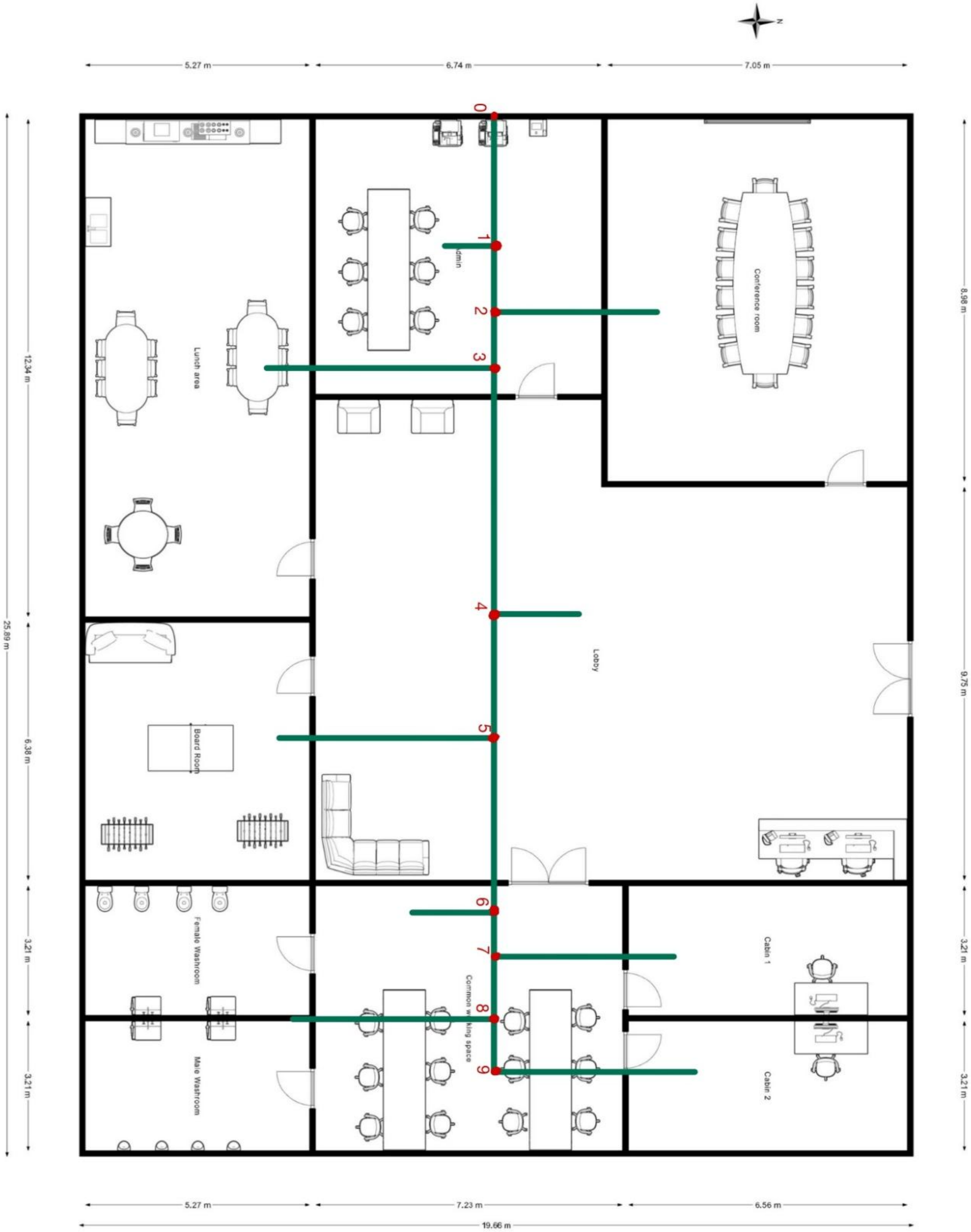

Figure 6.1 Duct Design for the layout

Room	Volume flow rate of room (m^3/s)	Duct Location	Volume flow rate (m^3/s)	Diameter (m)	Diameter (inches)	Darcy Factor	Fitting Type	C	Length of pipe (m)	Equivalent length of fitting (m)	Length of pipe + Eq. length of fitting (m)	Pressure loss per m (Pa/m)	Pressure lose in a section (Pa)
Admin	0.20338	0-1	1.99847	0.635688	25	0.014	Diverging Tee- Main	0.13	3	5.9	8.9	0.7	6.23
Conference room	0.26905	1-2	1.79509	0.602473	24	0.014	Diverging Tee- Main	0.13	1.5	5.6	7.1	0.45	3.195
Lunch Area	0.32902	2-3	1.52604	0.555492	22	0.0145	Diverging Tee- Main	0.13	1.5	5	6.5	0.7	4.55
Lobby	0.40565	3-4	1.19701	0.491976	19	0.01525	Diverging Tee- Main	0.13	7	4.2	11.2	0.75	8.4
Board room	0.15001	4-5	0.79136	0.400021	16	0.016	Diverging Tee- Main	0.13	3	3.3	6.3	1.2	7.56
Common working area	0.21428	5-6	0.64136	0.360118	14	0.017	Diverging Tee- Main	0.13	4.7	2.8	7.5	1.5	11.25
Cabin 1	0.08348	6-7	0.42707	0.293863	12	0.019	Diverging Tee- Main	0.13	1	2	3	1.7	5.1
Washrooms	0.22789	7-8	0.34360	0.263584	10	0.022	Diverging Tee- Main	0.13	1.2	1.6	2.8	2	5.6
Cabin 2	0.11570	8-9	0.11570	0.152957	6	0.028	Eblow Pleated -90⁰	0.43	1.5	2.3	3.8	3	11.4
Total flow rate	**1.99847**												**63.285**

Figure 6.2 Duct design tabulated data

6.2 Fan selection

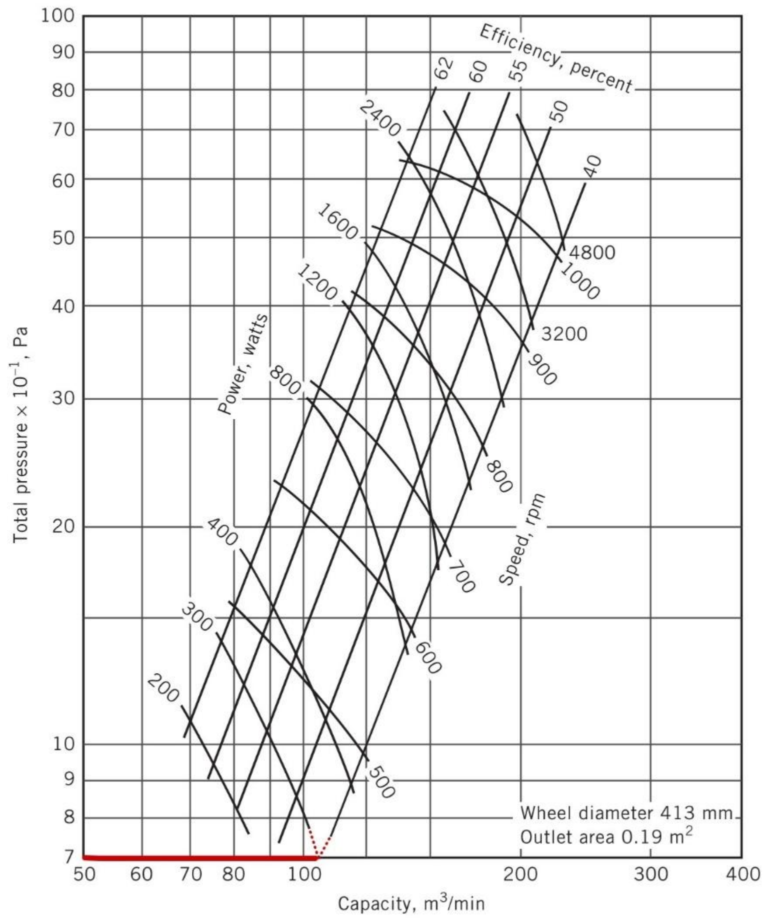

Figure 6.3 Performance data for a forward curved blade fan

We can use the total pressure drop in Figure 6.2 to find all the required fan characteristics. They found that the specifications for the Fan are:

Forward curved blade fan;

Wheel diameter $= 413\ mm$

Outlet area $= 0.19\ m^2$

Power $= 300\ W$

Speed $= 420\ rpm$

Efficiency $= 40\%$

7 Results

All the major findings for this project have been tabulated below:

Properties	**Results**
$q_{cooling\ load,\ total}$	$137.705\ kW\ (39.15\ tons)$
$q_{cooling\ load,\ sensible}$	$106.461\ kW\ (30.27\ tons)$
$q_{cooling\ load,\ latent}$	$31.245\ kW\ (8.88\ tons)$
$q_{machine,\ total}$	$206.550\ kW\ (58.72\ tons)$
Total duct length	$57.1\ meters$
Total pressure drop in a line (0 to 9)	$63.285\ Pa$
Fan type	Forward curved blade
Fan wheel diameter	$413\ mm$
Fan outlet area	$0.19\ m^2$
Fan speed	$420\ rpm$
Fan power	$300\ W$
Fan efficiency	40%

As per our calculation, we found the maximum cooling load to be at 16:00 hours, and the cooling load is shown above in the table, along with the latent and sensible heat gain of the space, according to our assumptions. We can easily find the machine capacity from this cooling load using fundamental concepts, which were also calculated for its latent and sensible heat component. Finally, the required duct data was also estimated using the necessary assumptions to deliver the cooled air from the air conditioning unit.

To find the Excel data sheet and the floor plan file, you can use this link:

HVAC Excel Calculations & Floor plan

8 Conclusion

In conclusion, the calculated cooling load typically remains below the actual capacity of the installed HVAC equipment. Even certified professionals use standardized assumptions and idealized conditions to estimate cooling loads effectively. In our design process, we've sized the ductwork based on the volumetric flow rate and maintained consistent inlet velocities across all rooms, providing a generalized framework for duct sizing. Nevertheless, in practical scenarios, it's essential to carefully assess project-specific details, such as space dimensions, architectural layout, HVAC system type, and targeted comfort and efficiency standards, to ensure optimal performance.

9 References

[1] Heating, Ventilating, and Air Conditioning Analysis and Design, Sixth Edition, Faye C. McQuiston, Jerald D. Parker, Jeffrey D. Spitler, ISBN 0-471-47015-5.

[2] 2021 ASHRAE HANDBOOK FUNDAMENTALS, I-P Edition.