MSc Environmental Design of Buildings

EDBDL 2 years

Climate Comfort and Energy Assignment

Student Number: C1773063

Student Name: Maithilee Shetty

INDEX

1. Introduction

In the last few decades the global trend of office space design has been synonymous to unrestricted glass facades and extensively air conditioned spaces which result in high energy consumption. There is an increasing need to revive the conventional passive approach of design and carefully integrate it with cutting edge solutions to provide thermally, visually and psychologically comfortable working spaces. This paper aims to study a small passive office space in the city of Pune, India, calculate the energy balance of the space and optimize it by altering the building fabric, building layout, occupancy patterns and building services.

1.1 Climate and Weather

Pune is a metropolitan city in the Midwestern part of India as seen in Figure 1, located at latitude of 18.53 degrees north and longitude: 73.85 degrees east. The Koppen Geiger Classification of Pune is Aw i.e tropical savanna / tropical wet and dry climate. There are two distinct seasons wet and dry.

Figure 1: Satellite image

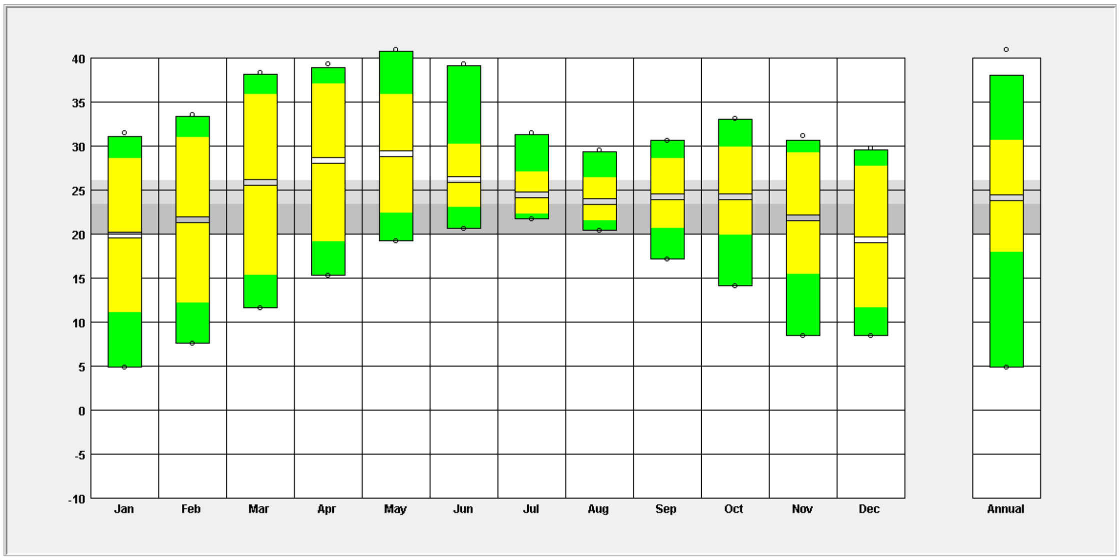

Figure 2: Temperature Range

The average summer temperature ranges from 25 to 29 degrees in the months of March to June, May being the warmest. The average winter temperature ranges from 19 to 23 degrees. The monthly average temperature is more than 18 degrees C in every month as seen in Figure 2.

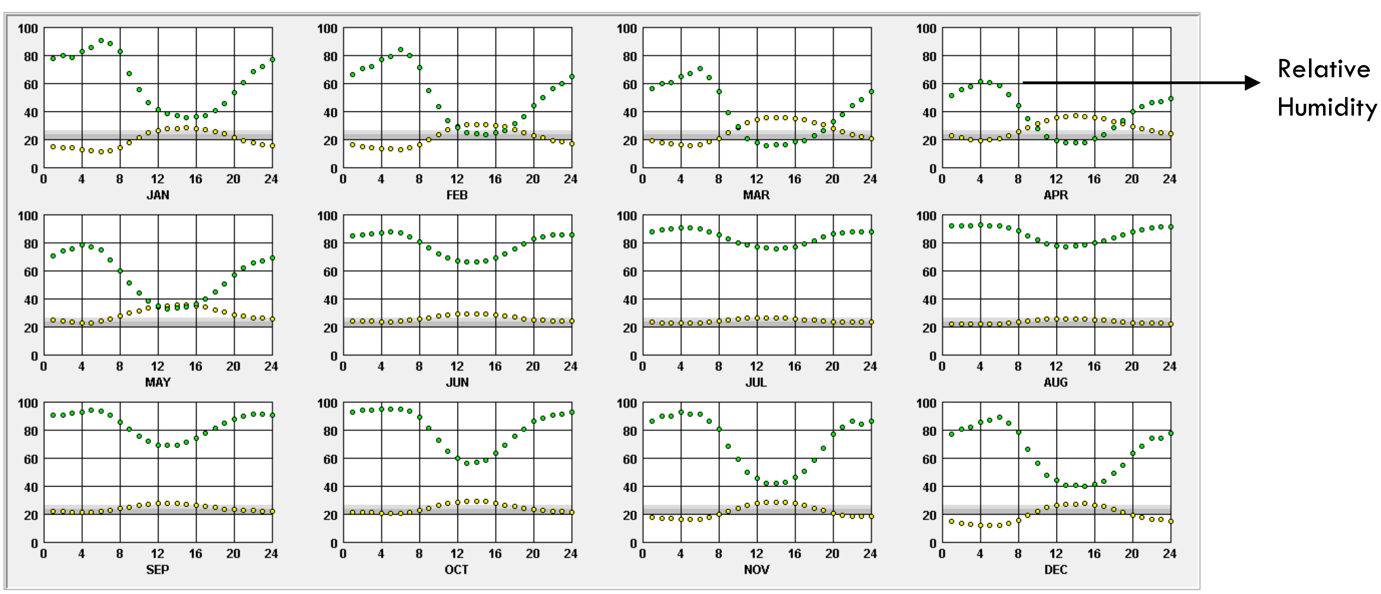

Figure 3: Relative Humidity

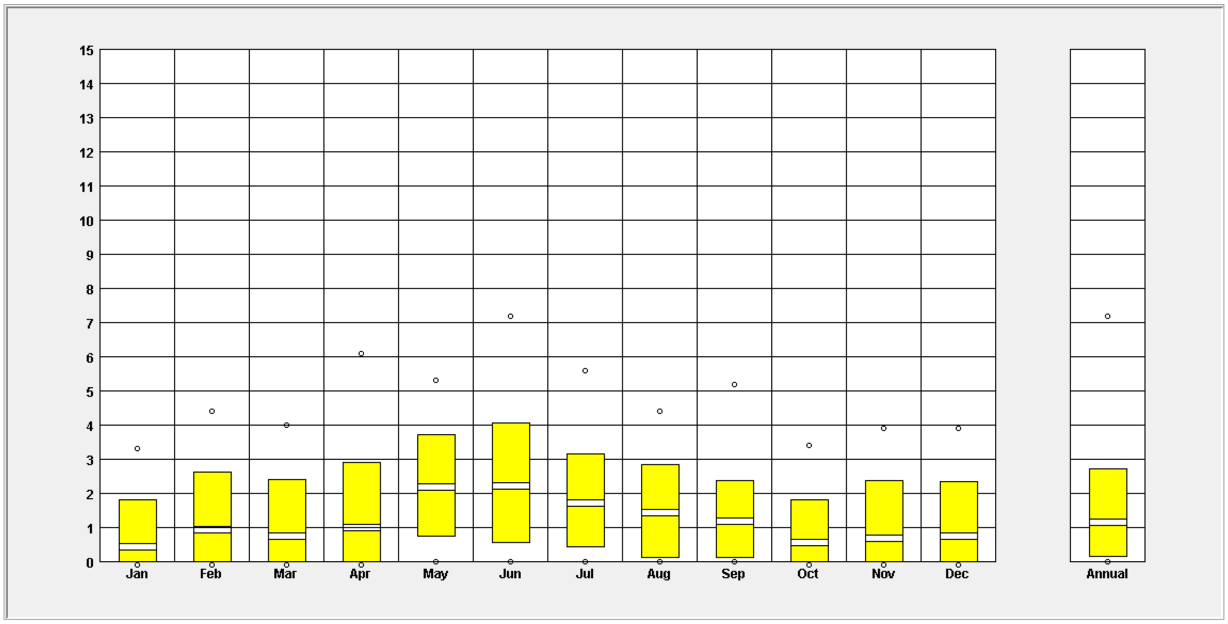

Figure 4: Wind Speed

The relative humidity falls between 30% and 70% in all months, except June to October which exceeds 70%. The average wind speed in the months of May to September ranges between 1m/s to 2m/s and all other months 0 m/s.

1.2 Building and Occupants

The chosen office space is on the top floor of a typical small G+4 floors commercial building in the city of Pune. A new construction scenario is assumed, wherein substantial modifications are feasible. The space is used as a city center IT office with a floor area of 6m^2/person and an occupant density of 13. (The Chartered Institution of Building Services Engineers 2015, Table 6.2) The space is used in two shifts, the first from 9.00 am to 6.00 pm and two night shifts between 9.00 pm to 6.00 am, the functioning of the space is considered as 24 hours. Lighting and standard equipment such as computers, phones, printers, scanners which aid the functioning are considered in the space. A met level of 1.2 suitable for seated typing work and a 1.0 clo level of a typical business suit are considered. (Latif, E. 2019)

The site and building layout are shown in Figure

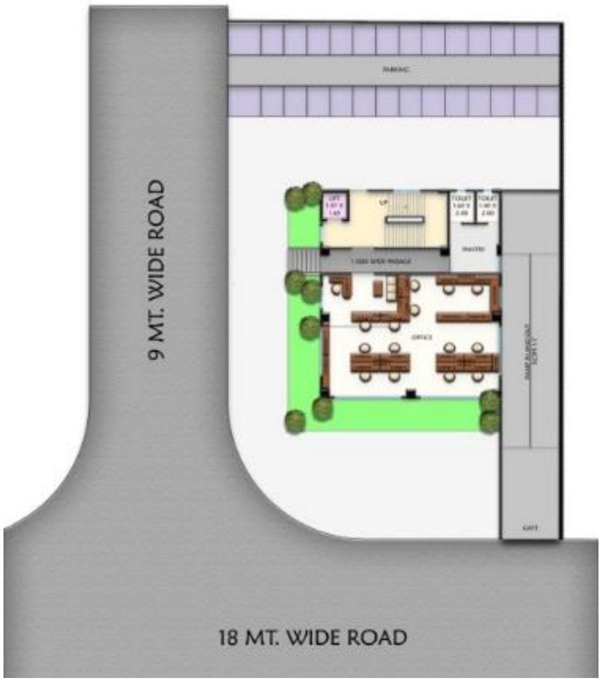

Figure 5: Site Layout

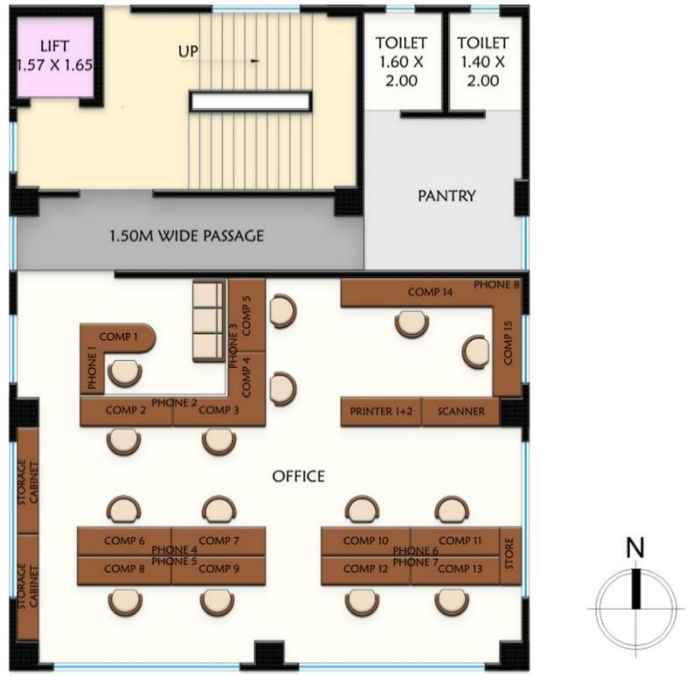

Figure 6: Building Layout

Building details are :

Particulars	**Area (sq.mt)**
Floor	80.30 (10.30 mt x 7.80 mt)
Roof	80.30
North Wall	32.90
East Wall	17.50
South Wall	18.80
West Wall	17.50
North Glazing	Area : 4.20 WWR : 13%
East Glazing	Area : 10.80 WWR :62%
South Glazing	Area : 18.30 WWR :97%
West Glazing	Area : 10.80 WWR :62%

Table 1: Building Area

2. Methodology

Weather data is obtained by importing the Energy Plus file provided by the Indian Society of Refrigeration, Heating and Air Conditioning Engineers into the software Climate Consultant 6.0. The heat balance equation is referred from the lectures conducted in Welsh School of Architecture. The adaptive comfort formula, ventilation requirements, other values are referred from codes and publications such as the Energy Conservation Building Code, National Building Code and CIBSE Guide A .A typical small commercial building in Pune in design stage is selected. Calculations are done for five scenarios to understand the baseline case and the effect of suggested solutions on the heat balance of the space. Further possibilities are discussed with reference to the current and best practices based on analysis of peer reviewed journal articles.

3. Heat Balance

A steady state condition is assumed in the heat balance calculations which are carried out for average conditions for all months in the year.

3.1 Baseline Case

This scenario consists of specifications as per typical construction practices. Following steps were carried out to calculate the heat balance:

A. Deriving Internal Comfort temperature

Internal comfort temperature is calculated (Table 2) on the basis of the adaptive thermal comfort formula for naturally ventilated buildings, which is:

Internal Operative Temperature = (0.54 x outdoor temperature) + 12.38 (BEE 2017)

Particulars	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Mean Outdoor Temp	19	21	25	28	29	26	24	23	24	24	21	19
Internal Comfort Temp	23.09	24.17	26.33	27.95	28.49	26.87	25.79	25.25	25.79	25.79	24.17	23.09
(T_o – T_i)	-4.09	-3.17	-1.33	0.05	0.51	-0.87	-1.79	-2.25	-1.79	-1.79	-3.17	-4.09

Table 2: Internal Comfort Temperature

The adaptive comfort range for Pune is between 23 deg C in December & January to 29 deg C in May

B. Heat Gain/Loss through Building Fabric:

Heat transfer is calculated for walls, glazing and roof using the following formula and specifications:

$Q_{fabric} = UA\,(T_o - T_i)$ (Latif, E. 2019)

Sr.No	Particulars	Area (sq.mt)	U Value
1	Walls	15mm thick Internal Plaster +150 mm Autoclaved Aerated Concrete block wall +25 mm thick External plaster	1.003 W/m2K
2	Glazing	Double glazing , clear glass, wooden frame	0.33
3	Roof	RCC roof slab with cement plaster and insulation	3.4

Table 3: Building specifications are considered as per typical construction practices in the city

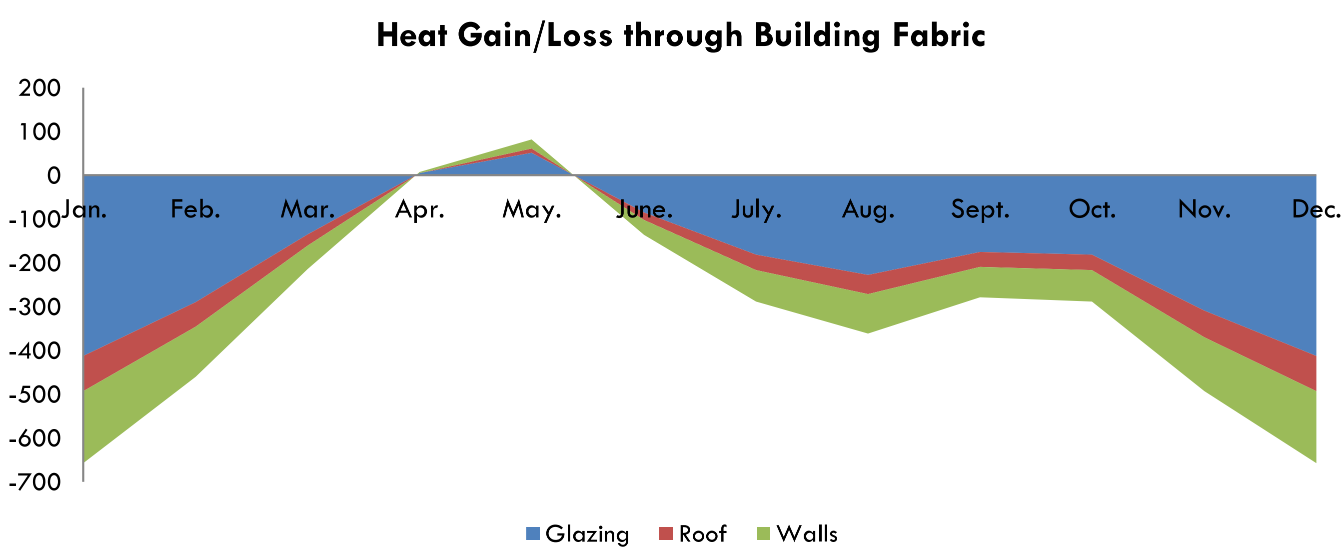

Figure 7: Heat Gain/Loss through building fabric

The building fabric is losing heat through conduction in the months of June to March and gaining heat in the months of April and May, seen in Figure 7. Maximum contribution in the fabric heat loss/gain is that of glazing.

C. Heat Gain/Loss through Ventilation

It is assumed that air changes per hour values consider heat gains/losses of ventilation and infiltration:

$Q_{ventilation} = nV/3\ (T_o - T_i)$ (Latif, E. 2019)

Volume	281.2	cu.mt
Air Changes per hour	6	at 50 Pascal pressure difference (Bureau of Indian Standards 2016)
Air Changes per hour	0.6	at 5 pascals pressure difference
nV/3	56.2	W/C

Table 4: Air change rate calculation

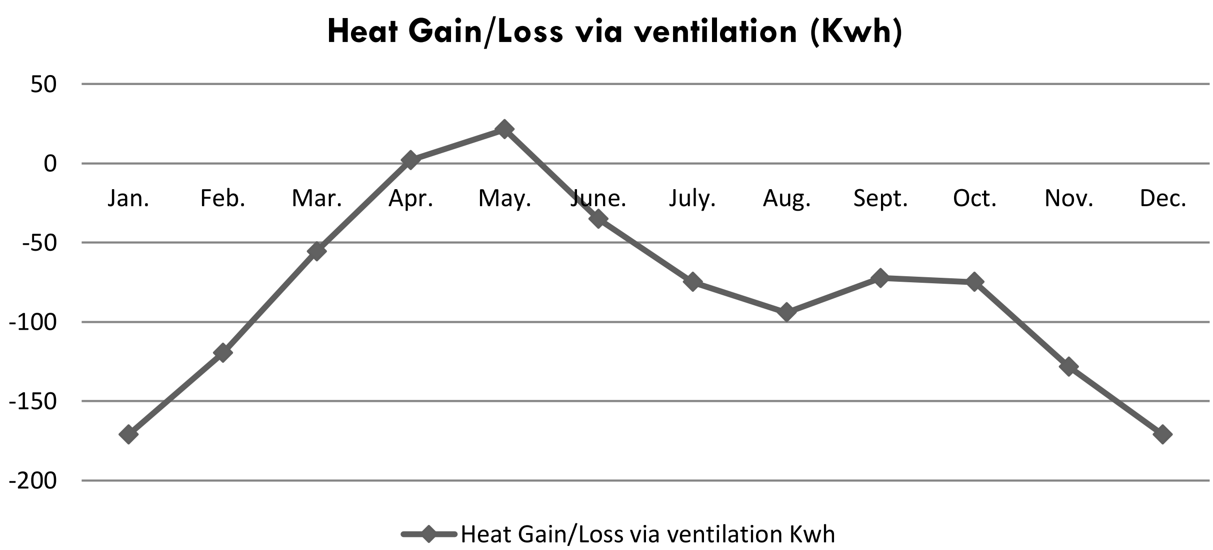

Figure 8: Heat Gain/Loss via ventilation

The space gains heat through ventilation in April and May and looses heat in all other months, seen in Figure 8

D. Solar Heat Gains

Q_{solar} = Irradiance x Area x SHGC value (Latif, E. 2019)

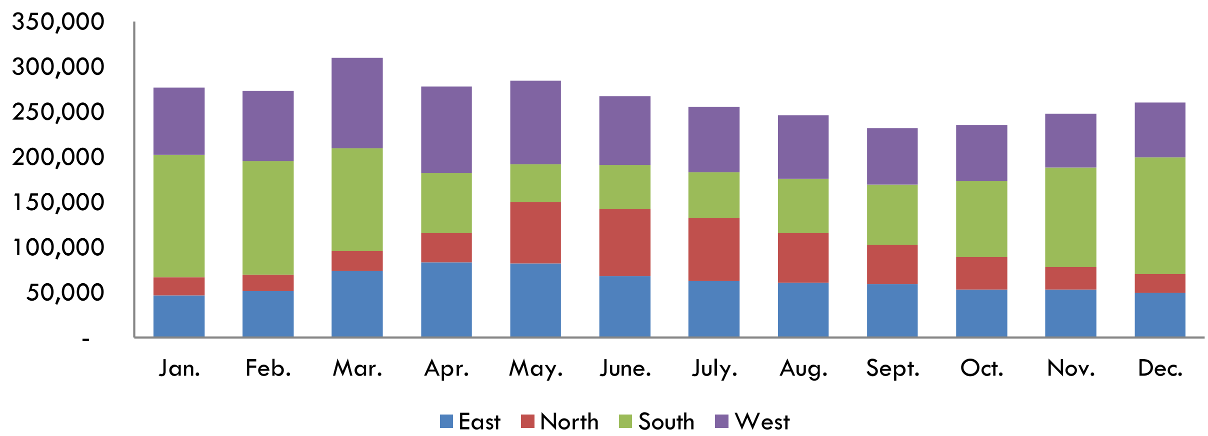

Figure 9: Orientation wise solar radiation

The total surface radiation for the tropical city of Pune is high. The highest solar radiation in the East and West orientation is in the months of March, April and May, as seen in Figure 9

E. Occupant Heat Gains

$Q_{occupants}$ (W) = (Sensible + Latent heat) (W/ m^2) x Floor area (m^2)

City center offices having floor space area of $6m^2$/person have a the sensible heat gain of 13.5 W/m^2 and the Latent heat gain of 10 W/$m2^2$ (The Chartered Institution of Building Services Engineers 2015, Table 6.2)

$Q_{occupants}$ = 23.5 x 80.3 = 1887.99 Watts

F. Incidental Heat Gains

$Q_{incidental}$ (W) = (Lighting gain + Equipment gain) (W/ m^2) x Floor area (m^2)

City center offices having floor space area of $6m^2$/person have a lighting gain of 10 W/ m^2 and the Equipment gain of 25 W/ m^2 (The Chartered Institution of Building Services Engineers 2015, Table 6.2)

Lighting gain : 10 x 80.3 = 803.4Watts

Equipment gain : 25 x 80.3 = 2008.50 Watts

$Q_{incidental}$ = 803.4 + 2008.50 = 2811.9 Watts

G. Heat Balance

Heat Balance calculations are done in Table 5 considering the combinedeffect of calculations done in point 3.1 (A) to 3.1(F)

$$Q_{fabric} + Q_{ventilation} + Q_{solar} + Q_{heating/cooling} + Q_{occupants} + Q_{incidental} = 0$$ (Latif, E. 2019)

Field	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Q(f)	-657.9	-460.5	-213.9	7.78	82.04	-135.4	-287.9	-361.9	-278.5	-287.9	-493.4	-657.9
Q(v)	-171.1	-119.8	-55.6	2.0	21.3	-35.2	-74.9	-94.1	-72.5	-74.9	-128.4	-171.1
Q(s)	2231.5	2174.9	2335.5	1858.8	1561.0	1446.6	1410.4	1479.7	1494.7	1638.6	1906.9	2094
Q(o)	1404.7	1268.7	1404.7	1359.4	1404.7	1359.4	1404.7	1404.7	1359.4	1404.7	1359.4	1404.7
Q(i)	2092.1	1889.6	2092.1	2024.6	2092.1	2024.6	2092.1	2092.1	2024.6	2092.1	2024.6	2092.1
Total Heat Gain	5728.2	5333.2	5832.2	5252.5	5161.1	4830.5	4907.1	4976.4	4878.6	5135.3	5290.9	5590.8
Total Heat Loss	-829.0	-580.3	-269.5	0.00	0.00	-170.6	-362.8	-456.0	-351.1	-362.8	-621.8	-829.0
Net Heat Gain	**4899.0**	**4753.0**	**5562.7**	**5252.5**	**5161.1**	**4659.9**	**4544.3**	**4520.3**	**4527.5**	**4772.5**	**4669.0**	**4761.7**

Table 5: Baseline Case Heat Balance Calculation

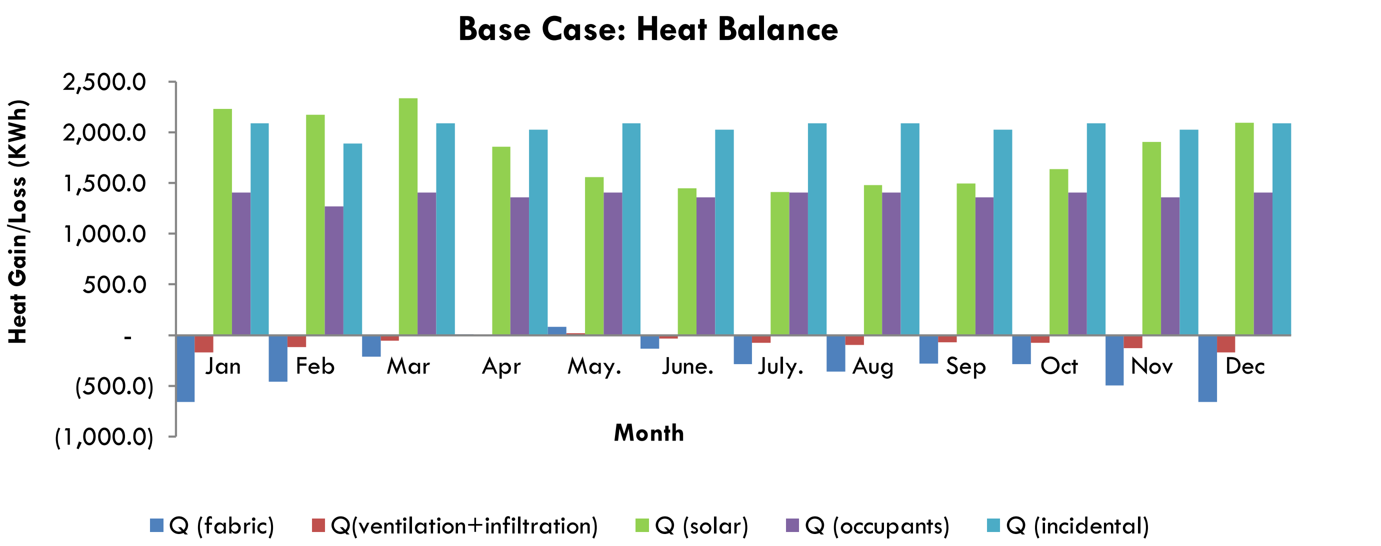

Figure 10: Baseline Case Heat Balance along with breakup

4. Discussions

4.1 Result of Baseline Case

Heat balance calculations in Table 5 and Figure 10 show that the selected high occupancy office space has a net heat gain throughout the year. Solar radiation through glazing has the most significant contribution to the heat gain of the space. Due to its high occupant density, the occupant and incidental load have a large effect on the cooling loads. It is interesting to observe that inspite of the internal comfort temperature being higher than the average external temperature in some months and the space losing heat through the building fabric and ventilation; this does not have a remarkable effect on its thermal performance. The impact of solar radiaiton through the windows/glazing is much higher and thus the building needs cooling throughout the year. Highest cooling loads are in the summer months. (March-May)

4.2 Optimization of Baseline Case

Five scenarios have been calculated to explore design strategies aiming to control solar gain such as reducing glazing U value, reducing the glazing SHGC, optimizing window wall ratio, modifying lighting and equipment schedules, these are described below:

Scenario	**Considerations**	**Values** **U values in W/m²K**
I **(Baseline)**	Typical Construction Practices	Wall U Value : 1.003 Fenestration U Value : 3.40 Glazing SHGC : 0.59
II	ECBC Compliant Building *(For Wall, Glazing U Values ,SHGC specifications)*	Wall U Value : 0.63 Fenestration U Value : 3.00 Glazing SHGC : 0.27
III	ECBC+ Compliant Building (*For Wall, Glazing U Values ,SHGC specifications)*	Wall U Value : 0.63 Fenestration U Value : 3.00 Glazing SHGC : 0.25
IV	Window Wall Ratio optimization	WWR Less than 40%
V	Lighting and Equipment Schedule Optimization	Lighting and equipment closed for 4 non-working hours

Table 6: Description of Scenarios

Scenario I

Total Cooling load: **58083 KWh**

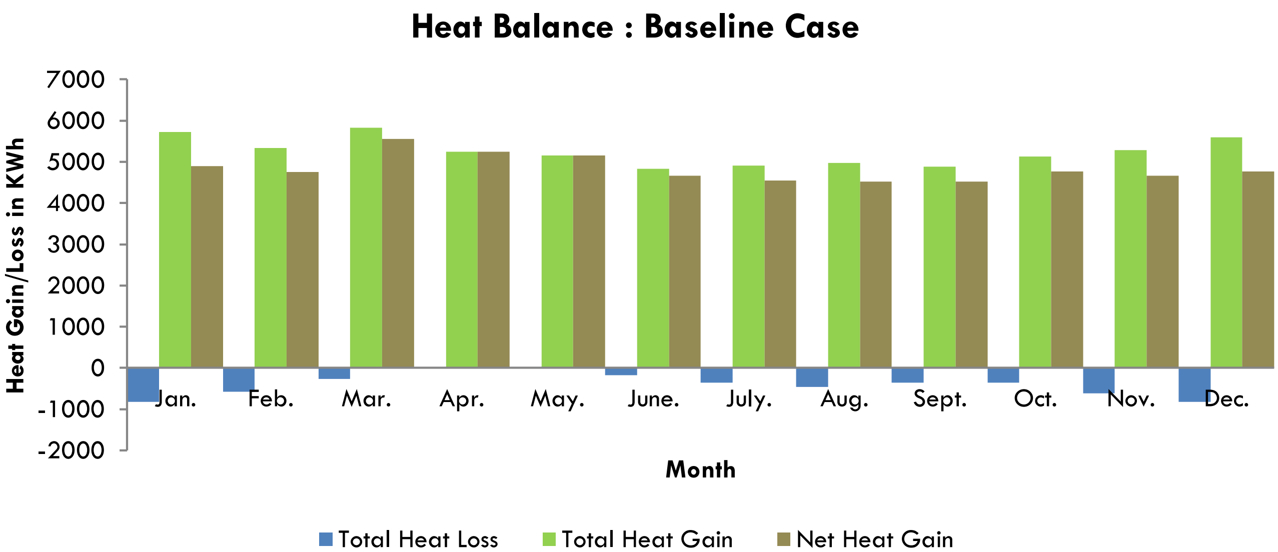

Figure 11: Baseline Case Heat Balance

Scenario II

Total Cooling load: **46975 KWh**

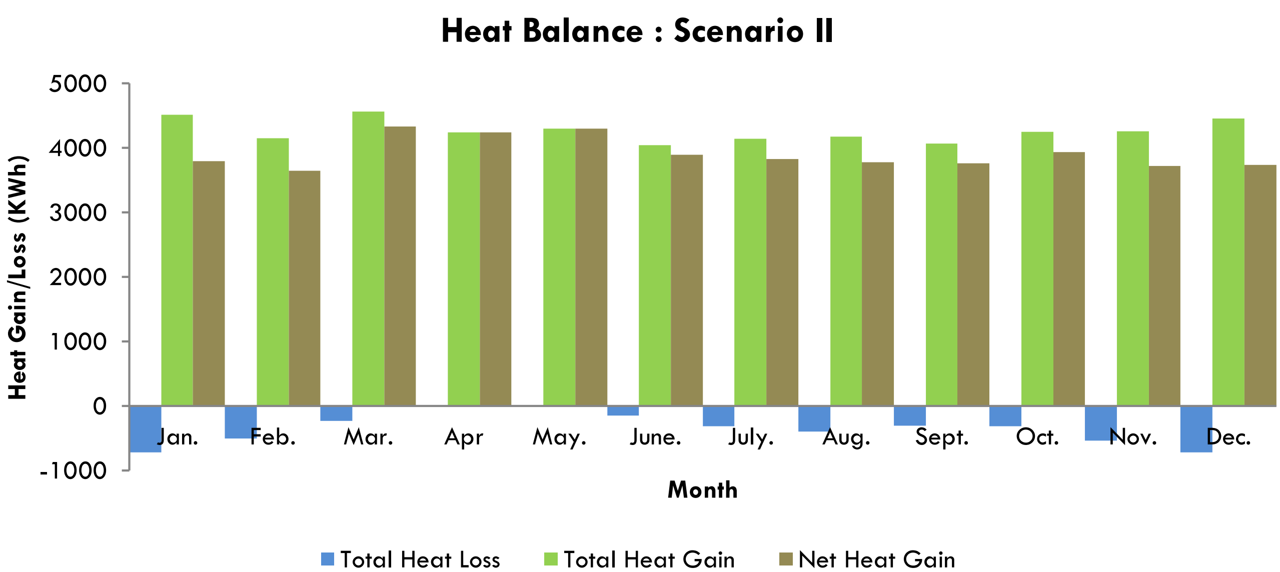

Figure 12: Scenario II Heat Balance

Scenario III

Total Cooling load: **46972 KWh**

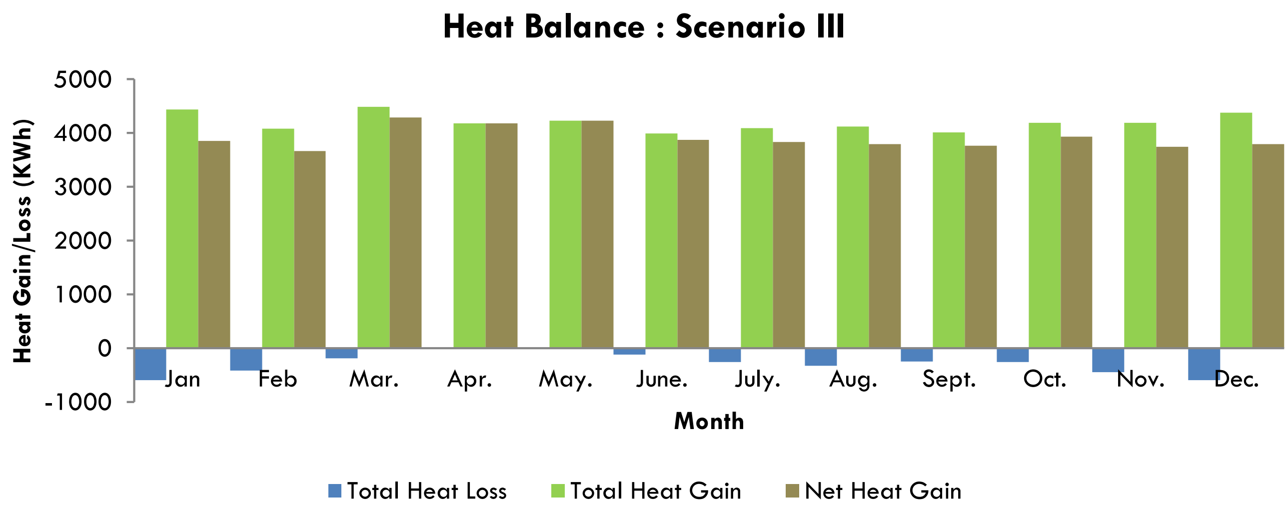

Figure 13: Scenario III Heat Balance

Scenario IV

Total Cooling load: **44217 KWh**

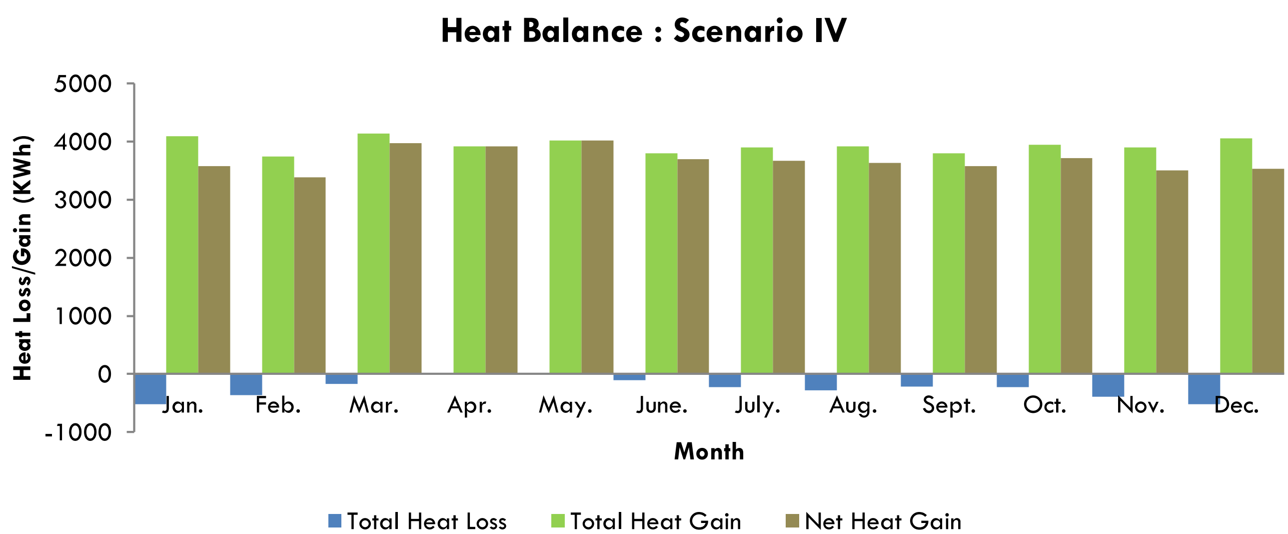

Figure 14: Scenario IV Heat Balance

Scenario V

Total Cooling load: **40112 KWh**

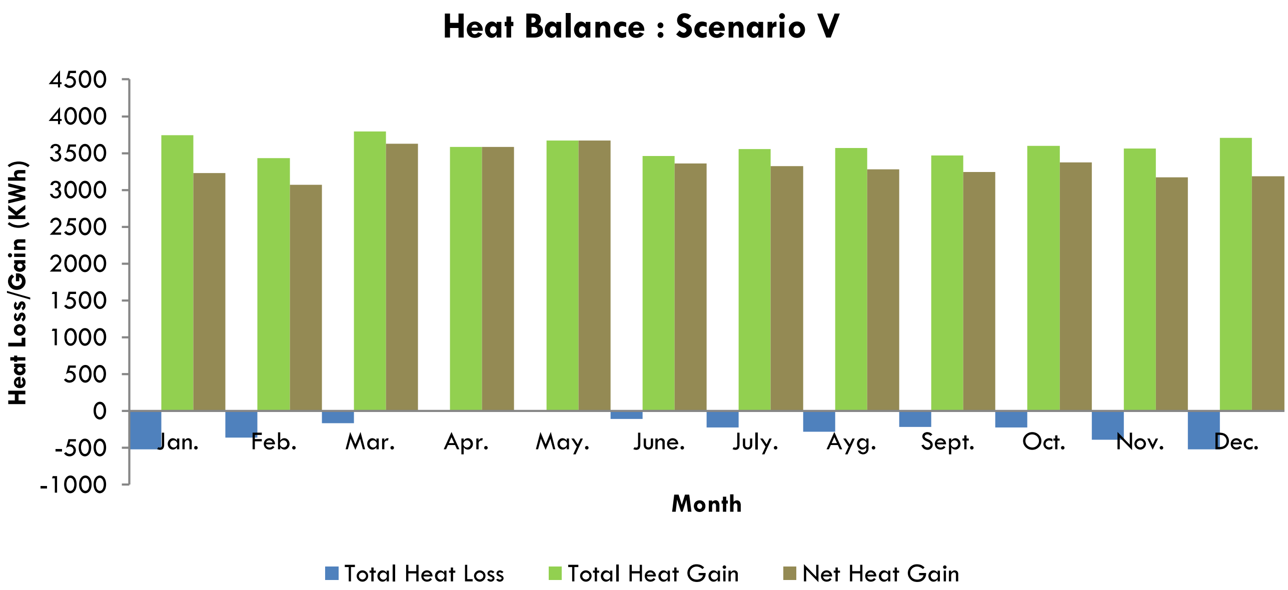

Figure 15: Scenario V Heat Balance

4.3 Results of Optimization

Modifications done in Scenario II i.e reducing the U value of wall, fenestration and reducing SHGC of glass resulted in significant reduction(19%) in the cooling load as compared to the baseline case.

The changes suggested in Scenario III did not result in significant reduction as compared to Scenario II and are nor critical to improving the thermal performance of the space

The changes suggested in Scenario IV i.e modifications to the window wall ratio and Scenario V i.e modifications in the schedule of lighting and equipment resulted in significant reduction in the cooling load as compared to Scenario II

Incorporation of suggested changes has resulted in a reduction of 17,971 KWh in the cooling load. The cooling load reduced by 30% from 58083 KWh in the Baseline case to 40112 KWh in Scenario V.

4.4 Typical Practice

Modern commercial buildings in India typically have reinforced concrete framing with a generous amount of glazing which allow high solar radiation to enter the building leading to higher cooling loads an example is shown in Figure 16.

Figure 16: Typical modern commercial building

4.5 Current Best Practices

<u>Orientation</u>

It has been argued by Sharma and Dibakar (2016) that the first step in improving the energy performance of a building is optimization of orientation. They identified four cities in India where buildings have a higher cooling demand and carried out manual calculations and building simulations for 9 building typologies including commercial for all eight directions to conclude that maximum glazing in the North-South direction is most effective followed by glazing in the NW-SE orientation.

<u>Self-Shading</u>

The strategy of inclined wall self shading which was used in Putrajaya, Malaysia (Fig 17) has proven to have considerable impact on reducing the direct solar gains and cooling loads. Projections with 45% and above self shading were able to achieve zero solar heat gain through walls and least conduction through windows. (Kandar, M.Z. et al. 2019)

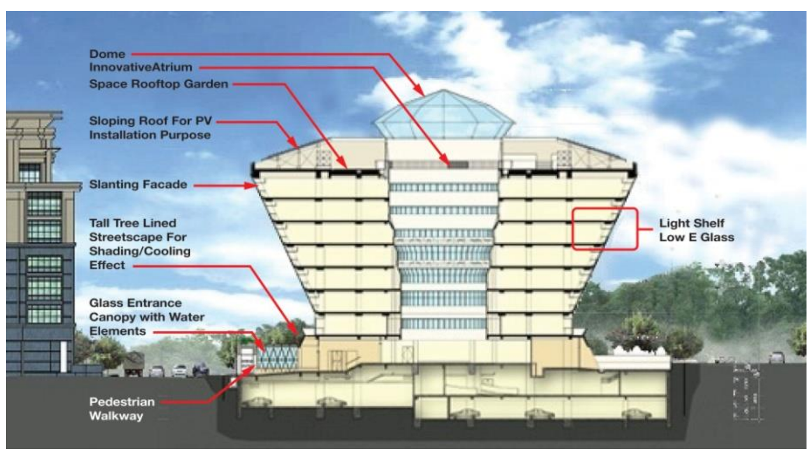

Figure 17: Self shading example

<u>Exterior shading devices</u>

Use of exterior shading devices such as louvers, pipes, vertical fins protect interior spaces from harsh light and reduce the solar heat gain into the space. This strategy has been effectively used in Suzlon One Earth office campus and Collectors office campus, Pune (Figure 18 and 19) to achieve thermal and visual comfort indoors and to reduce cooling loads.


Figure 18 and19: Exterior shading device example

<u>High performance glass</u>
Low E Double Glazed Unit (DGU glass) can be used to reduce solar heat gain control. In a study carried out by Bui, V.P. et al. (2017) in Singapore it was observed through field measurements and simulation that ipasol Ultraselect 62/29 and Stopray Ace 42T, which are low E DGU glasses, can reduce upto 60% energy consumption in comparison to clear float glass.

4.6 Cutting Edge Solutions

Dynamic shading systems comprise of movable elements which work within an algorithm. They consist of three components; a sensor network to obtain information, the controller to determine suitable actions and mechanical actuators to perform the actions. These intelligent facades operate in response to outdoor weather parameters and indoor conditions and can be programmed to respond to sun angles , solar radiation levels and other factors which differ from site to site to regulate the flux of solar loads, enhance performance of the building and provide comfortable conditions for the users. They can range from simple shading systems such as louvers, venetian blinds, vertical fins or roller shades to complex shading models such as folding panels, kinetic cladding, origami panels, hexagonal based grid and solar screens. Inspite of reliance on active energy, dynamic facades are considered an effective component of passive design as they contribute in reducing energy consumption of the building and in utilizing passive sources. (Al-Masrani, S and Al-Odaidi, K. 2019)


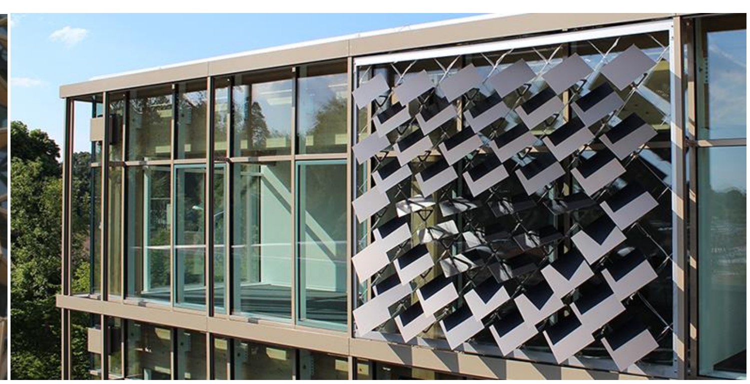

Figure 20 and Figure 21Dynamic Shading system example

5. Conclusions and Recommendations

5.1 Conclusions

Based on the calculations above, it is evident that solar gain through glazing, occupant loads and incidental loads have the highest impact on the heat balance As the office space has a net heat gain throughout the year, design strategies which focus on controlling solar gain through glazing combined with strategies which aid in reducing lighting and equipment load would result in improving the thermal performance of the space as seen in scenario I through V. As the building is in design stage, significant improvement in the cooling load during peak summer months can be achieved if the planning is modified such that the staircase/buffer space is planned on the east-west side and maximum window openings are planned on the north-south facade. Modifying the envelope and planning built in features for self shading would contribute in limiting solar gains .Further improvement in performance can be expected by incorporating external shading devices such as louvers and use of Low E glass. Dynamic solutions such as intelligent facades can be explored to further improve the performance, subject to cost feasibility. Thermal comfort can be improved by reducing the clo value of occupants from 1.0 (Typical Business suit) to 0.5 (Trousers and shirt) and strategies which lead to an increased wind speed in the months of June to October where relative humidity exceeds 70% would further increase the comfort in the space.

5.2 Recommendations

Steady state conditions have been considered for simplifying the calculations for the purpose of this paper; results could have been more accurate by taking the dynamic conditions and thermal mass into consideration. The heat balance calculations are done for average conditions, further calculations for average high, average low; design high and design low conditions in addition to the calculations above can be done to obtain more information to predict the performance of the space and lead to well informed choices regarding the possible solutions. The building is located at a junction, there are no obstructions the South and West Side due to roads, the impact of shading due to adjacent buildings on the North and East side has not been considered in the calculation which should be considered for further accuracy. Aspect of thermal comfort through modifications of clo levels and RH have been considered conceptually in the paper, which could be considered in detail.

6. References

The Chartered Institution of Building Services Engineers London. 2015. *ISBN 978-1-906846-55-8. Environmental Design CIBSE Guide A, incorporating corrections as f June 2018*. Lavenham Great Britain: The Lavenham Press Ltd.

Bureau of Energy Efficiency Ministry of Power Government of India. 2017. *Energy Conservation Building Code 2017*.New Delhi India: Bureau of Energy Efficiency

Latif, E. 2019. Heat balance methods: part 2. *Climate Comfort & Energy*. Welsh School of Architecture, Cardiff University. Available at: https://learningcentral.cf.ac.uk/webapps/blackboard/content/listContent.jsp?course_id=_392644_1&content_id=_5208953_1 [Accessed: 24.01.2020]

Latif, E. 2019. Unit 6: Comfort. *Climate Comfort & Energy*. Welsh School of Architecture, Cardiff University. Available at: https://learningcentral.cf.ac.uk/webapps/blackboard/content/listContent.jsp?course_id=_392644_1&content_id=_5088949_1

Bureau of Indian Standards. 2016. *National Building Code*. Volume 2 Part 8 Building Services, Sub section 5, 5.2.2.1. New Delhi: Bureau of Indian Standards

Sharma, P and Dibakar, R. 2016. Quantitative Assessment of orientation impact on heat gain profile of naturally cooled buildings in India. *Advances in Building Energy Research* 11:2, 208-226. DOI: 10.1080/17512549.2016.1215261

Kandar, M.Z. et al. 2019. Influence of inclined wall self-shading strategy on office building heat gain and energy performance in hot humid climate of Malaysia. *Heliyon 5*. https://doi.org/10.1016/j.heliyon.2019.e02077

Bui, V.P. et al. 2017. Evaluation of building glass performance metrics for the tropical climate. *Energy and Buildings 157,* 195-203. http://dx.doi.org/10.1016/j.enbuild.2017.01.009
Ligett R, Milne M. UCLA Energy Design Tools Group. 2018. *Climate Consultant*. Version 6.0

Al-Masrani, S and Al-Odaidi, K. 2019. Dynamic Shading Systems: A review of design parameters, platforms and evaluation strategies. *Automation in Construction 202*. 195-216, https://doi.org/10.1016/j.autcon.2019.01.014

7. List of Figures and Tables

List of Tables:

Appendix A : Heat Balance Calculations

Baseline Case

Temperature	January	February	March	April	May	June	July	August	September	October	November	December
Mean Outdoor temperature	19	21	25	28	29	26	24	23	24	24	21	19
Internal Comfort Temperature	23.09	24.17	26.33	27.95	28.49	26.87	25.79	25.25	25.79	25.79	24.17	23.09
(To-Ti)	-4.09	-3.17	-1.33	0.05	0.51	-0.87	-1.79	-2.25	-1.79	-1.79	-3.17	-4.09
Q (fabric)												
Walls												
U value	1.003	W/m2K										
Heat Gain/Loss through Fabric via conduction UA(To-Ti)	January	February	March	April	May	June	July	August	September	October	November	December
North Wall	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.00	0.0	0.0	0.0
East Wall	-71.99	-55.80	-23.4	0.9	9.0	-15.3	-31.5	-39.6	-31.5	-31.5	-55.8	-72.0
South Wall	-77.2	-59.8	-25.1	0.9	9.6	-16.42	-33.8	-42.5	-33.8	-33.8	-59.8	-77.2
West Wall	-72.0	-55.8	-23.4	0.9	9.0	-15.3	-31.5	-39.6	-31.5	-31.5	-55.8	-72.0
Total	-221.16	-171.41	-71.92	2.70	27.58	-47.04	-96.79	-121.67	-96.79	-96.79	-171.41	-221.16
Number of hours	744	672	744	720	744	720	744	744	720	744	720	744
Heat Gain/Loss through Fabric via conduction KWh	-164.5	-115.2	-53.5	1.9	20.5	-33.9	-72.0	-90.5	-69.7	-72.0	-123.4	-164.5
Glazing												
U Value	3.4	W/m2K										
Heat Gain/Loss through Glazing via conduction UA(To-Ti)	January	February	March	April	May	June	July	August	September	October	November	December
North Window/Glazing	0	0	0	0	0	0	0	0	0	0	0	0
East Window/Glazing	-150.2	-116.4	-48.8	1.8	18.7	-31.9	-65.7	-82.6	-65.7	-65.7	-116.4	-150.2
South Window/Glazing	-254.3	-197.1	-82.7	3.1	31.7	-54.1	-111.30	-139.9	-111.3	-111.3	-197.1	-254.3
West Window/Glazing	-150.18	-116.40	-48.84	1.84	18.73	-31.95	-65.73	-82.62	-65.73	-65.73	-116.40	-150.18
Total	-554.7	-429.9	-180.4	6.8	69.2	-118.0	-242.8	-305.1	-242.8	-242.8	-429.9	-554.7
Number of hours	744	672	744	720	744	720	744	744	720	744	720	744
Heat Gain/Loss through glazing via conduction KWh	-412.7	-288.9	-134.2	4.9	51.5	-85.0	-180.6	-227.0	-174.8	-180.6	-309.5	-412.7
Roof												
U Value	0.33											
Heat Gain/Loss through Roof via conduction UA(To-Ti)	January	February	March	April	May	June	July	August	September	October	November	December
Roof	-108.4	-84.0	-35.3	1.3	13.5	-23.1	-47.5	-59.7	-47.5	-47.5	-84.0	-108.4
Number of hours	744	672	744	720	744	720	744	744	720	744	720	744
Heat Gain/Loss through Roof via conduction KWh	-80.7	-56.5	-26.2	1.0	10.1	-16.6	-35.3	-44.4	-34.2	-35.3	-60.5	-80.7
Total Heat Gain/Loss through Building fabric via conduction (Kwh)	**-657.9**	**-460.6**	**-213.9**	**7.8**	**82.0**	**-135.4**	**-287.9**	**-361.9**	**-278.6**	**-287.9**	**-493.5**	**-657.9**

Baseline Case

Q (ventilation)

Volume	281.2	cu.mt										
Air Changes per hour	6	at 50 Pascal pressure difference										
Air Changes per hour	0.6	at 5 pascals pressure difference										
nV/3	56.2	W/C										
nV/3 (To-Ti)	January	February	March	April	May	June	July	August	September	October	November	December
Heat Gain/Loss	-230.0	-178.3	-74.8	2.8	28.7	-48.9	-100.7	-126.5	-100.7	-100.7	-178.3	-230.0
Total Number of hours	744	672	744	720	744	720	744	744	720	744	720	744
Heat Gain/Loss via ventilation Kwh	-171.1	-119.8	-55.6	2.0	21.3	-35.2	-74.9	-94.1	-72.5	-74.9	-128.4	-171.1

Q (solar)

Solar Radiation Monthlu Total	January	February	March	April	May	June	July	August	September	October	November	December
(Wh /sq.mt)												
N	20388	18627	21925	32429	68021	74219	69565	54904	43511	36202	24973	21078
E	46293	51220	73494	83161	82081	67780	62533	60908	58890	53085	52959	49379
S	135699	125582	113843	66609	41658	49186	50908	59700	67007	83856	110153	129099
W	74122	77449	100261	95757	92350	75956	72605	70213	62221	62070	59785	60646
Total	276502	272878	309523	277956	284110	267141	255611	245725	231629	235213	247870	260202
Glazing g value (Non North)	0.59											
Solar Gain through glazing (Watts)	January	February	March	April	May	June	July	August	September	October	November	December
(IAG)												
North Window/Glazing	0	0	0	0	0	0	0	0	0	0	0	0
East Window/Glazing	294979.0	326373.8	468303.8	529901.9	523020.1	431894.2	398460.3	388105.8	375247.1	338257.6	337454.7	314643.0
South Window/Glazing	1464181.4	1355019.7	1228356.9	718705.8	449486.5	530713.0	549293.2	644158.2	723000.2	904799.5	1188542.1	1392967.9
West Window/Glazing	472305.4	493505.0	638863.1	610163.6	588454.2	483991.6	462639.1	447397.2	396472.2	395510.0	380950.0	386436.3
Total (Wh)	2231465.734	2174898.601	2335523.723	1858771.277	1560960.819	1446598.797	1410392.583	1479661.236	1494719.461	1638567.192	1906946.826	2094047.182
Heat Gains through Solar irradiance (Kwh)	2231.5	2174.9	2335.5	1858.8	1561.0	1446.6	1410.4	1479.7	1494.7	1638.6	1906.9	2094.0

Q (occupants)

Incidental Gains	January	February	March	April	May	June	July	August	September	October	November	December
Number of Occupants	13											
Floor area per person/m2	6	6-3, Table 6.2 CIBSE Guide A										
Floor Area	80.34											
Sensible + Latent heat gain per person	23.5											
Total Sensible + Latent Heat gain	1887.99	1887.99	1887.99	1887.99	1887.99	1887.99	1887.99	1887.99	1887.99	1887.99	1887.99	1887.99
Number of hours	744	672	744	720	744	720	744	744	720	744	720	744
Total Heat Gain through Occupant Gains (Kwh)	1404.7	1268.7	1404.7	1359.4	1404.7	1359.4	1404.7	1404.7	1359.4	1404.7	1359.4	1404.7

Q (incidental)

Total Floor area	80.34											
Lighting heat gain (W/m2)	10	6-3, Table 6.2 CIBSE Guide A										
Total Lighting heat gain (W))	803.4											
Equipment heat gain (W/m2)	25	6-3, Table 6.2 CIBSE Guide A										
Total Equipment heat gain (W)	2008.5											
Total incidental heat gain	2811.9	2811.9	2811.9	2811.9	2811.9	2811.9	2811.9	2811.9	2811.9	2811.9	2811.9	2811.9
Number of hours	744	672	744	720	744	720	744	744	720	744	720	744
Total Heat Gain/Loss through Incidental Gains (Kwh)	2092.1	1889.6	2092.1	2024.6	2092.1	2024.6	2092.1	2092.1	2024.6	2092.1	2024.6	2092.1

Baseline Case

Heat Balance

Heat Balance (Kwh)	Q (January)	(February)	Q (March)	Q (April)	Q (May)	Q (June)	Q (July)	Q (August)	eptember)	(October)	November)	December)
(To-Ti)	-4.09	-3.17	-1.33	0.05	0.51	-0.87	-1.79	-2.25	-1.79	-1.79	-3.17	-4.09
Q (fabric) (Fabric + Glazing + Roof) sum UA (To-Ti)	-657.90	-460.57	-213.94	7.78	82.04	-135.43	-287.93	-361.93	-278.65	-287.93	-493.47	-657.90
Q(ventilation+infiltration) Ventilation nV/3 (To- Ti)	-171.1	-119.8	-55.6	2.0	21.3	-35.2	-74.9	-94.1	-72.5	-74.9	-128.4	-171.1
Q (solar) Solar irradiance IAS	2231.5	2174.9	2335.5	1858.8	1561.0	1446.6	1410.4	1479.7	1494.7	1638.6	1906.9	2094.0
Q (occupants) Occupant Gains Sensible Heat Gain + Latent Heat Gain	1404.7	1268.7	1404.7	1359.4	1404.7	1359.4	1404.7	1404.7	1359.4	1404.7	1359.4	1404.7
Q (incidental) Incidental Gains Lighting+Equipment	2092.1	1889.6	2092.1	2024.6	2092.1	2024.6	2092.1	2092.1	2024.6	2092.1	2024.6	2092.1

Heat Balance (Kwh)	Q (January)	(February)	Q (March)	Q (April)	Q (May)	Q (June)	Q (July)	Q (August)	eptember)	(October)	November)	December)		
Total Heat Gain	5728.2	5333.2	5832.2	5252.50	5161.05	4830.52	4907.1	4976.4	4878.6	5135.3	5290.9	5590.8		
Total Heat Loss	-829.03	-580.37	-269.59			-170.66	-362.83	-456.07	-351.12	-362.83	-621.82	-829.03		
Net Heat Gain	4899	4752.9	5562.7	5252.5	5161.1	4659.9	4544.3	4520.3	4527.5	4772.5	4669.0	4761.7		
Cooling Load in KWh (Monthly)	4899	4753	5563	5253	5161	4660	4544	4520	4528	4772	4669	4762	**58083**	KWh

Scenario II

Heat Balance													
Heat Balance (Kwh)	**Q (January)**	**Q (February)**	**Q (March)**	**Q (April)**	**Q (May)**	**Q (June)**	**Q (July)**	**Q (August)**	**Q (September)**	**Q (October)**	**Q (November)**	**Q (December)**	
(To-Ti)	-4.09	-3.17	-1.33	0.05	0.51	-0.87	-1.79	-2.25	-1.79	-1.79	-3.17	-4.09	
Q (fabric) (Fabric + Glazing + Roof) sum UA (To-Ti)	-548.16	-383.74	-178.25	6.49	68.35	-112.84	-239.90	-301.56	-232.17	-239.90	-411.15	-548.16	
Q(ventilation+infiltration) Ventilation nV/3 (To- Ti)	-171.1	-119.8	-55.6	2.0	21.3	-35.2	-74.9	-94.1	-72.5	-74.9	-128.4	-171.1	
Q (solar) Solar irradiance IAS	1021.2	995.3	1068.8	850.6	714.3	662.0	645.4	677.1	684.0	749.9	872.7	958.3	
Q (occupants) Occupant Gains Sensible Heat Gain + Latent Heat Gain	1404.7	1268.7	1404.7	1359.4	1404.7	1359.4	1404.7	1404.7	1359.4	1404.7	1359.4	1404.7	
Q (incidental) Incidental Gains Lighting+Equipment	2092.1	1889.6	2092.1	2024.6	2092.1	2024.6	2092.1	2092.1	2024.6	2092.1	2024.6	2092.1	
Heat Balance (Kwh)	**Q (January)**	**Q (February)**	**Q (March)**	**Q (April)**	**Q (May)**	**Q (June)**	**Q (July)**	**Q (August)**	**Q (September)**	**Q (October)**	**Q (November)**	**Q (December)**	
Total Heat Gain	4517.9	4153.6	4565.5	4243.05	4300.75	4045.92	4142.2	4173.9	4067.9	4246.6	4256.6	4455.0	
Total Heat Loss	-719.29	-503.54	-233.90			-148.07	-314.80	-395.70	-304.64	-314.80	-539.51	-719.29	
Net Heat Gain	3799	3650.1	4331.6	4243.1	4300.7	3897.9	3827.4	3778.2	3763.3	3931.8	3717.1	3735.7	
Cooling Load in KWh (Monthly)	3799	3650	4332	4243	4301	3898	3827	3778	3763	3932	3717	3736	**46975** KWh

Scenario III

Heat Balance													
Heat Balance (Kwh)	**Q (January)**	**Q (February)**	**Q (March)**	**Q (April)**	**Q (May)**	**Q (June)**	**Q (July)**	**Q (August)**	**Q (September)**	**Q (October)**	**Q (November)**	**Q (December)**	
(To-Ti)	-4.09	-3.17	-1.33	0.05	0.51	-0.87	-1.79	-2.25	-1.79	-1.79	-3.17	-4.09	
Q (fabric) (Fabric + Glazing + Roof) sum UA (To-Ti)	-419.89	-293.95	-136.54	4.97	52.36	-86.44	-183.77	-230.99	-177.84	-183.77	-314.94	-419.89	
Q(ventilation+infiltration) Ventilation nV/3 (To- Ti)	-171.1	-119.8	-55.6	2.0	21.3	-35.2	-74.9	-94.1	-72.5	-74.9	-128.4	-171.1	
Q (solar) Solar irradiance IAS	945.5	921.6	989.6	787.6	661.4	613.0	597.6	627.0	633.4	694.3	808.0	887.3	
Q (occupants) Occupant Gains Sensible Heat Gain + Latent Heat Gain	1404.7	1268.7	1404.7	1359.4	1404.7	1359.4	1404.7	1404.7	1359.4	1404.7	1359.4	1404.7	
Q (incidental) Incidental Gains Lighting+Equipment	2092.1	1889.6	2092.1	2024.6	2092.1	2024.6	2092.1	2092.1	2024.6	2092.1	2024.6	2092.1	
Heat Balance (Kwh)	**Q (January)**	**Q (February)**	**Q (March)**	**Q (April)**	**Q (May)**	**Q (June)**	**Q (July)**	**Q (August)**	**Q (September)**	**Q (October)**	**Q (November)**	**Q (December)**	
Total Heat Gain	4442.3	4079.9	4486.3	4178.53	4231.84	3996.89	4094.3	4123.7	4017.3	4191.0	4191.9	4384.0	
Total Heat Loss	-591.02	-413.75	-192.19			-121.66	-258.66	-325.13	-250.32	-258.66	-443.30	-591.02	
Net Heat Gain	3851	3666.1	4294.2	4178.5	4231.8	3875.2	3835.7	3798.6	3767.0	3932.4	3748.6	3793.0	
Cooling Load in KWh (Monthly)	3851	3666	4294	4179	4232	3875	3836	3799	3767	3932	3749	3793	**46972** KWh

Scenario IV

Heat Balance													
Heat Balance (Kwh)	**Q (January)**	**Q (February)**	**Q (March)**	**Q (April)**	**Q (May)**	**Q (June)**	**Q (July)**	**Q (August)**	**Q (September)**	**Q (October)**	**Q (November)**	**Q (December)**	
(To-Ti)	-4.09	-3.17	-1.33	0.05	0.51	-0.87	-1.79	-2.25	-1.79	-1.79	-3.17	-4.09	
Q (fabric) (Fabric + Glazing + Roof) sum UA (To-Ti)	-348.19	-243.75	-113.23	4.12	43.42	-71.68	-152.39	-191.55	-147.47	-152.39	-261.16	-348.19	
Q(ventilation+infiltration) Ventilation nV/3 (To- Ti)	-171.1	-119.8	-55.6	2.0	21.3	-35.2	-74.9	-94.1	-72.5	-74.9	-128.4	-171.1	
Q (solar) Solar irradiance IAS	597.0	587.0	646.3	532.7	458.2	416.6	403.9	419.0	418.1	450.4	514.6	558.9	
Q (occupants) Occupant Gains Sensible Heat Gain + Latent Heat Gain	1404.7	1268.7	1404.7	1359.4	1404.7	1359.4	1404.7	1404.7	1359.4	1404.7	1359.4	1404.7	
Q (incidental) Incidental Gains Lighting+Equipment	2092.1	1889.6	2092.1	2024.6	2092.1	2024.6	2092.1	2092.1	2024.6	2092.1	2024.6	2092.1	
Heat Balance (Kwh)	**Q (January)**	**Q (February)**	**Q (March)**	**Q (April)**	**Q (May)**	**Q (June)**	**Q (July)**	**Q (August)**	**Q (September)**	**Q (October)**	**Q (November)**	**Q (December)**	
Total Heat Gain	4093.8	3745.3	4143.1	3922.75	4019.69	3800.51	3900.6	3915.7	3802.0	3947.2	3898.6	4055.7	
Total Heat Loss	-519.32	-363.55	-168.87			-106.90	-227.28	-285.69	-219.95	-227.28	-389.52	-519.32	
Net Heat Gain	3574	3381.8	3974.2	3922.7	4019.7	3693.6	3673.3	3630.0	3582.1	3719.9	3509.0	3536.3	
Cooling Load in KWh (Monthly)	3574	3382	3974	3923	4020	3694	3673	3630	3582	3720	3509	3536	**44217** KWh

Scenario V

Heat Balance													
Heat Balance (Kwh)	**Q (January)**	**Q (February)**	**Q (March)**	**Q (April)**	**Q (May)**	**Q (June)**	**Q (July)**	**Q (August)**	**Q (September)**	**Q (October)**	**Q (November)**	**Q (December)**	
(To-Ti)	-4.09	-3.17	-1.33	0.05	0.51	-0.87	-1.79	-2.25	-1.79	-1.79	-3.17	-4.09	
Q (fabric) (Fabric + Glazing + Roof) sum UA (To-Ti)	-348.19	-243.75	-113.23	4.12	43.42	-71.68	-152.39	-191.55	-147.47	-152.39	-261.16	-348.19	
Q(ventilation+infiltration) Ventilation nV/3 (To- Ti)	-171.1	-119.8	-55.6	2.0	21.3	-35.2	-74.9	-94.1	-72.5	-74.9	-128.4	-171.1	
Q (solar) Solar irradiance IAS	597.0	587.0	646.3	532.7	458.2	416.6	403.9	419.0	418.1	450.4	514.6	558.9	
Q (occupants) Occupant Gains Sensible Heat Gain + Latent Heat Gain	1404.7	1268.7	1404.7	1359.4	1404.7	1359.4	1404.7	1404.7	1359.4	1404.7	1359.4	1404.7	
Q (incidental) Incidental Gains Lighting+Equipment	1743.4	1574.7	1743.4	1687.1	1743.4	1687.1	1743.4	1743.4	1687.1	1743.4	1687.1	1743.4	
Heat Balance (Kwh)	**Q (January)**	**Q (February)**	**Q (March)**	**Q (April)**	**Q (May)**	**Q (June)**	**Q (July)**	**Q (August)**	**Q (September)**	**Q (October)**	**Q (November)**	**Q (December)**	
Total Heat Gain	3745.1	3430.4	3794.4	3585.32	3671.01	3463.08	3552.0	3567.0	3464.6	3598.5	3561.1	3707.0	
Total Heat Loss	-519.32	-363.55	-168.87			-106.90	-227.28	-285.69	-219.95	-227.28	-389.52	-519.32	
Net Heat Gain	3226	3066.8	3625.5	3585.3	3671.0	3356.2	3324.7	3281.3	3244.7	3371.2	3171.6	3187.7	
Cooling Load in KWh (Monthly)	3226	3067	3626	3585	3671	3356	3325	3281	3245	3371	3172	3188	**40112** KWh

Appendix B: Sample Solar Radiation values for N,E,S,W orientation on for January 1

North				East				South				West			
Pune	Maharashtra	IND		Pune	Maharashtra	IND		Pune	Maharashtra	IND		Pune	Maharashtra	IND	
Tilt Degrees	90	Bearing Degrees	180	Tilt Degrees	90	Bearing Degrees	-90	Tilt Degrees	90	Bearing Degrees	0	Tilt Degrees	90	Bearing Degrees	90
month	day	hour	Tot Surface Rad	month	day	hour	Tot Surface Rad	month	day	hour	Tot Surface Rad	month	day	hour	Tot Surface Rad
			(Wh/sq.m)				(Wh/sq.m)				(Wh/sq.m)				(Wh/sq.m)
1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0
1	1	2	0	1	1	2	0	1	1	2	0	1	1	2	0
1	1	3	0	1	1	3	0	1	1	3	0	1	1	3	0
1	1	4	0	1	1	4	0	1	1	4	0	1	1	4	0
1	1	5	0	1	1	5	0	1	1	5	0	1	1	5	0
1	1	6	0	1	1	6	0	1	1	6	0	1	1	6	0
1	1	7	0	1	1	7	0	1	1	7	0	1	1	7	0
1	1	8	0	1	1	8	0	1	1	8	0	1	1	8	0
1	1	9	29	1	1	9	115.7312	1	1	9	106.933846	1	1	9	29
1	1	10	33	1	1	10	408.36948	1	1	10	529.9851	1	1	10	33
1	1	11	24	1	1	11	318.16605	1	1	11	728.25635	1	1	11	24
1	1	12	43.5	1	1	12	43.5	1	1	12	711.2839	1	1	12	43.5
1	1	13	166	1	1	13	166	1	1	13	336.6406	1	1	13	258.11264
1	1	14	168	1	1	14	168	1	1	14	396.51855	1	1	14	350.6662
1	1	15	153.5	1	1	15	153.5	1	1	15	320.75073	1	1	15	336.09158
1	1	16	78	1	1	16	78	1	1	16	107.4176	1	1	16	114.12575
1	1	17	51.5	1	1	17	51.5	1	1	17	71.5374	1	1	17	80.37666
1	1	18	34.5	1	1	18	34.5	1	1	18	63.114994	1	1	18	93.31033
1	1	19	0	1	1	19	0	1	1	19	0	1	1	19	0
1	1	20	0	1	1	20	0	1	1	20	0	1	1	20	0
1	1	21	0	1	1	21	0	1	1	21	0	1	1	21	0
1	1	22	0	1	1	22	0	1	1	22	0	1	1	22	0
1	1	23	0	1	1	23	0	1	1	23	0	1	1	23	0
1	1	24	0	1	1	24	0	1	1	24	0	1	1	24	0

- Values were obtained by importing the epw file of Pune into Climate Consultant 6.0 and exporting radiation data
- Total radiation value obtained for each orientation month wise
- Total monthly values obtained by adding the total radiation values of each hour of each day of the month.