CANDIDATE CODE : RWVW7

BARC0147 : Urban Physics

2021-2022

Topic : Design Builder

COURSEWORK 1

Citations referenced as [number]

SUBMISSION 1 : TUTORIAL EXERCISES

TUTORIAL 1

A building is created in Design Builder using a pre-existing DXF drawing provided. The rendered building model is then visualized to reveal sun paths and shadows for summer-winter solstices and equinox at 3pm as well as internal views with shadows

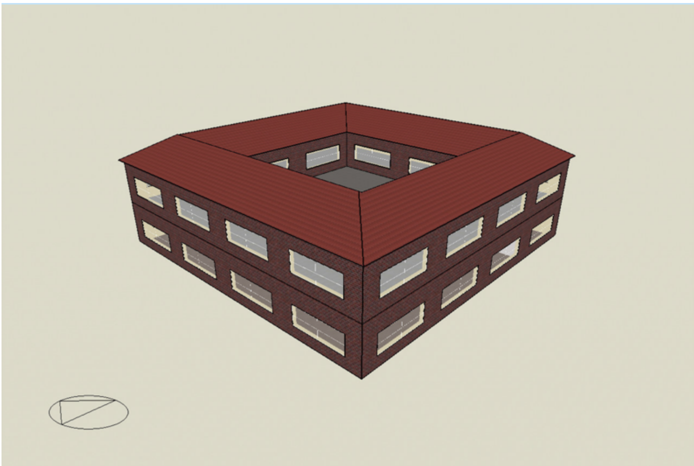


Figure 1. Rendered Axonometric View of The Building Model

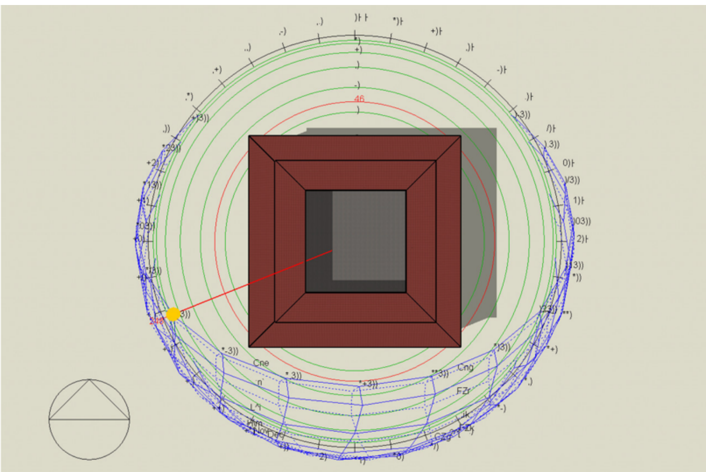


Figure 2. Plan View Of The Building Model With Sun Path and Shadows For Summer Solstice At 3:00 pm

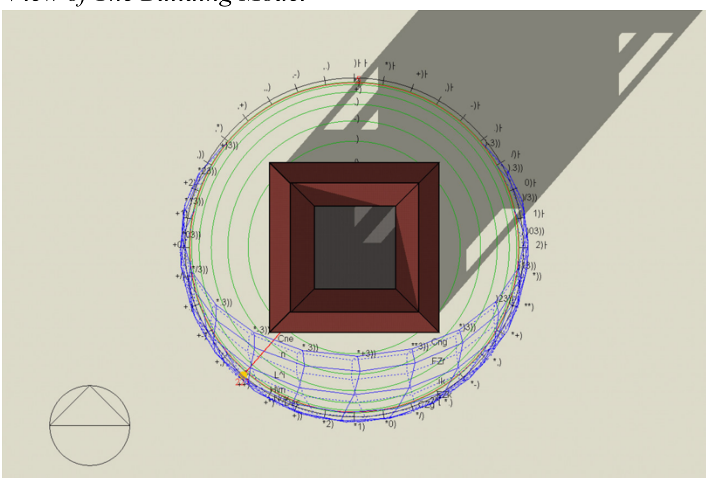


Figure 3. Plan View Of The Building Model With Sun Path and Shadows For Winter Solstice At 3:00 pm

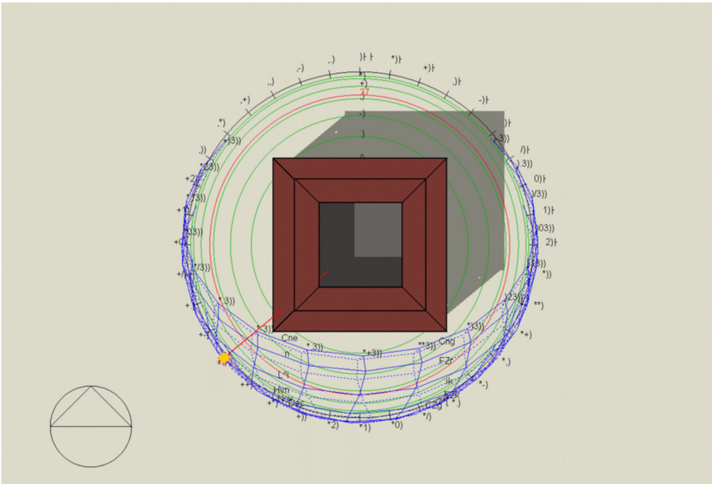


Figure 4. Plan View Of The Building Model With Sun Path and Shadows For March Equinox At 3:00 pm

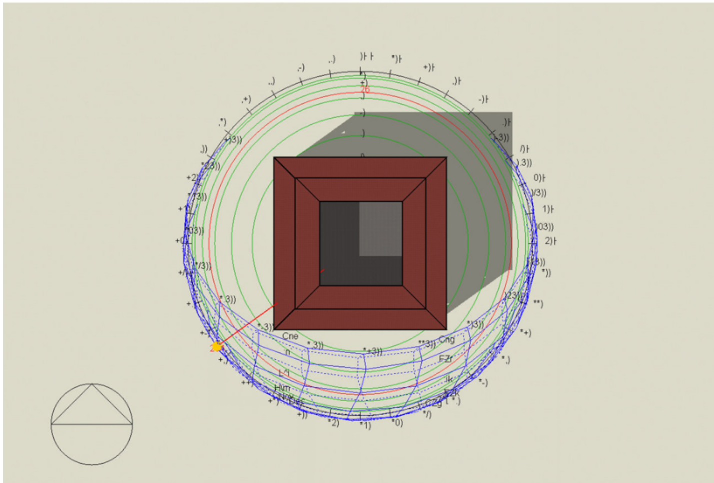


Figure 5. Plan View Of The Building Model With Sun Path and Shadows For September Equinox At 3:00 pm

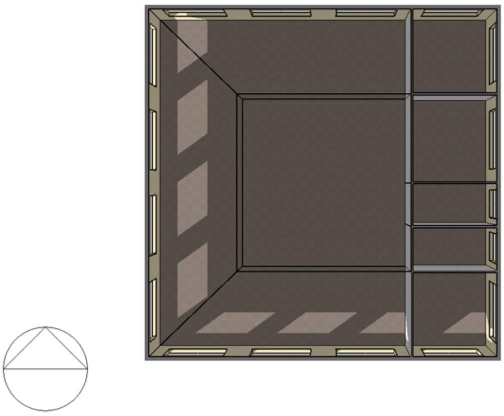


Figure 6. Internal Plan View Of The Ground Floor showing its Shadows

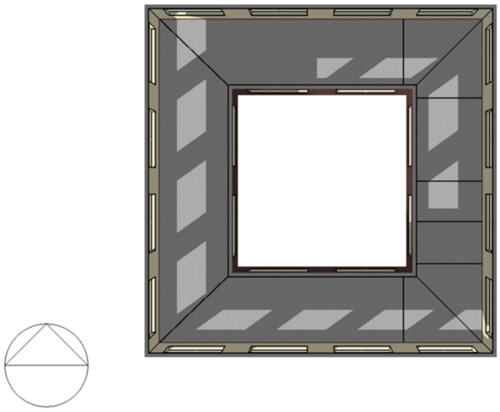


Figure 7. Internal Plan View Of The First Floor showing its Shadows

TUTORIAL 2

The tutorial model is changed to have customized occupancy and equipment schedules

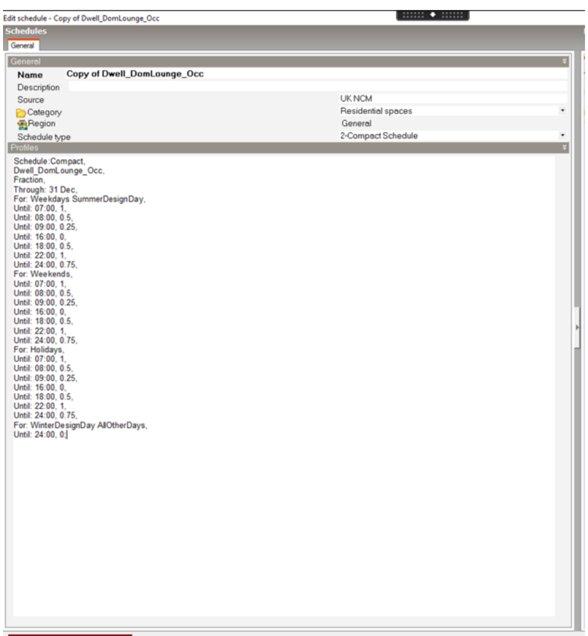


Figure 8. Screenshot showing customization of Occupancy Template

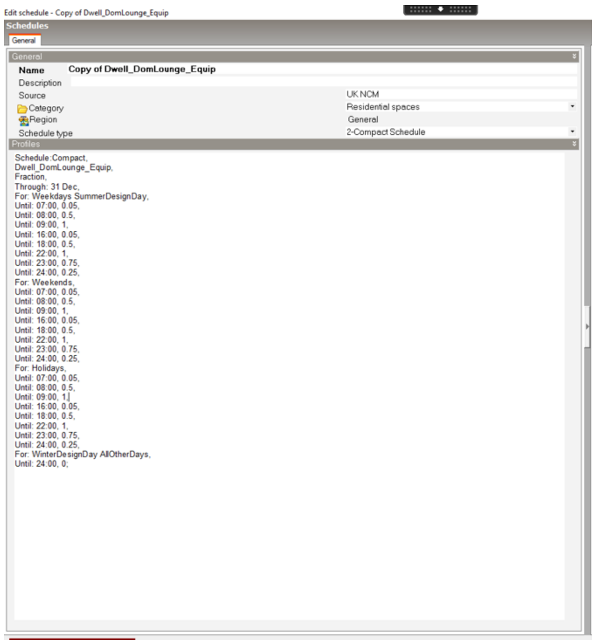


Figure 9. Screenshot showing customization of Equipment Template

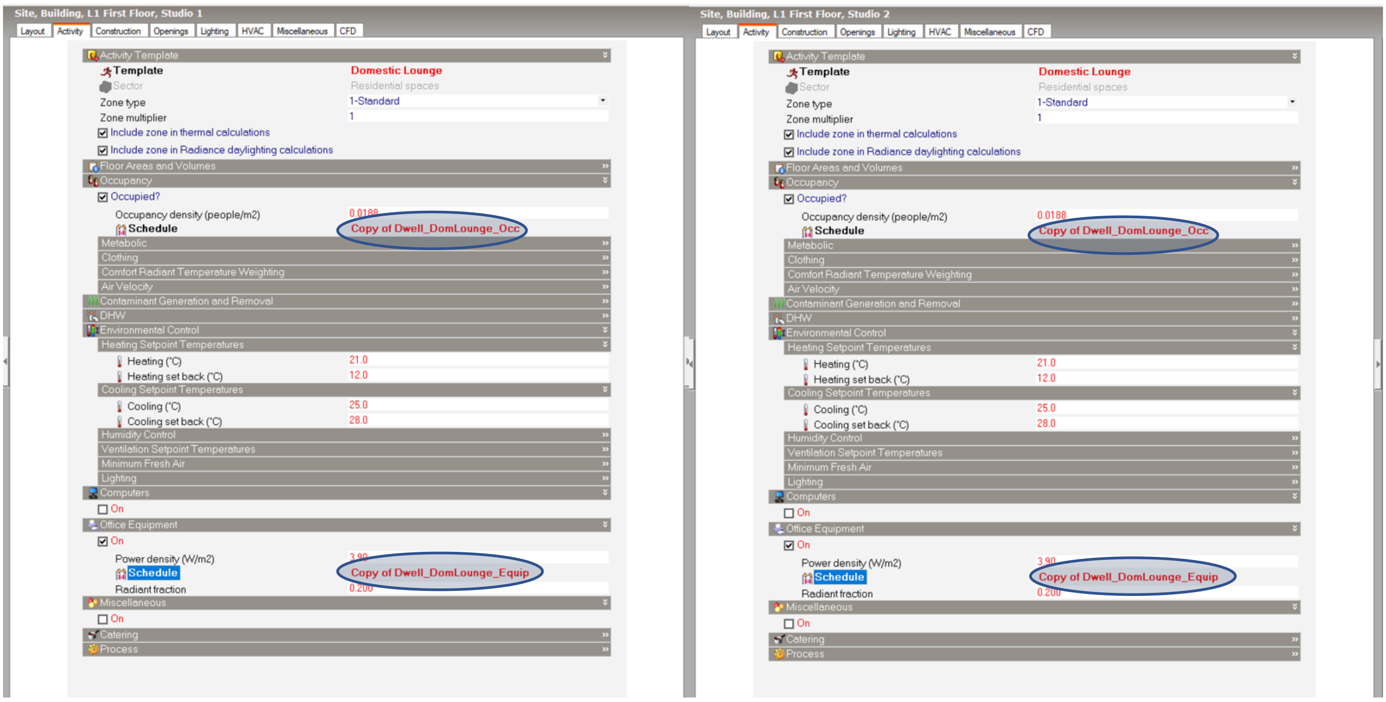


Figure 10. Changed Schedule For Occupation and Equipment for Studio 1 and 2 from the Customized Templates

After turning off the cooling, a simulation of the model is run, and we observe the results for different zones.

OPEN OFFICE N

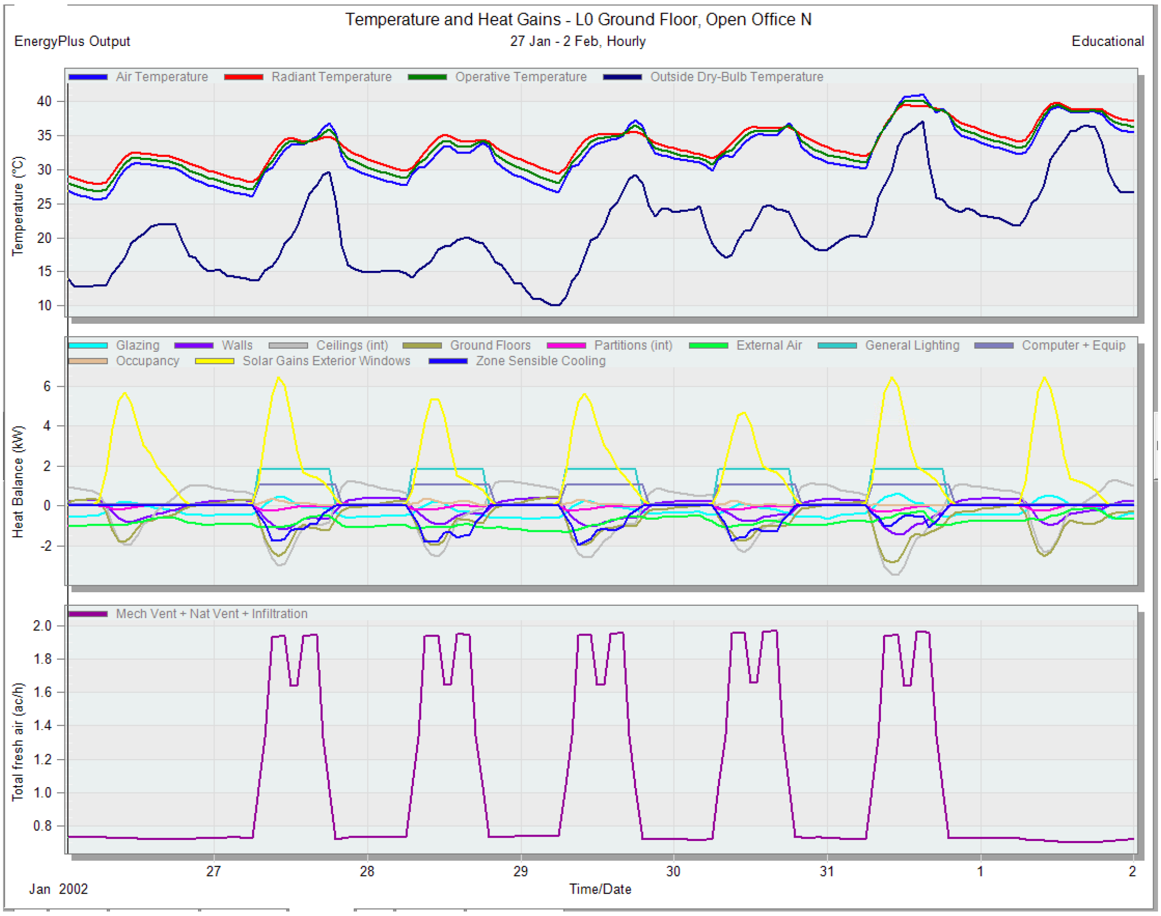


Figure 11. Temperature And Heat Gains Simulation Analysis For Open Office N

Date	Minimum Temperature (°C)	Maximum Temperature (°C)
27 January	25	31
28 January	26	37
29 January	28	34
30 January	27	37
31 January	30	36
1 February	30	41
2 February	33	39

Table 1. Daily Minimum and Maximum Temperatures for Open Office N

The main causes of heat gains identified here are Solar Gains from Exterior windows (average of about 5 kW daily) followed by General Lighting (about 2 kW daily). Other sources of heat gains are computer and equipment, occupancy, and ceilings. It is noteworthy that most zone sensible cooling is used in this zone compared to others as it has the most solar heat gains.

BED 1

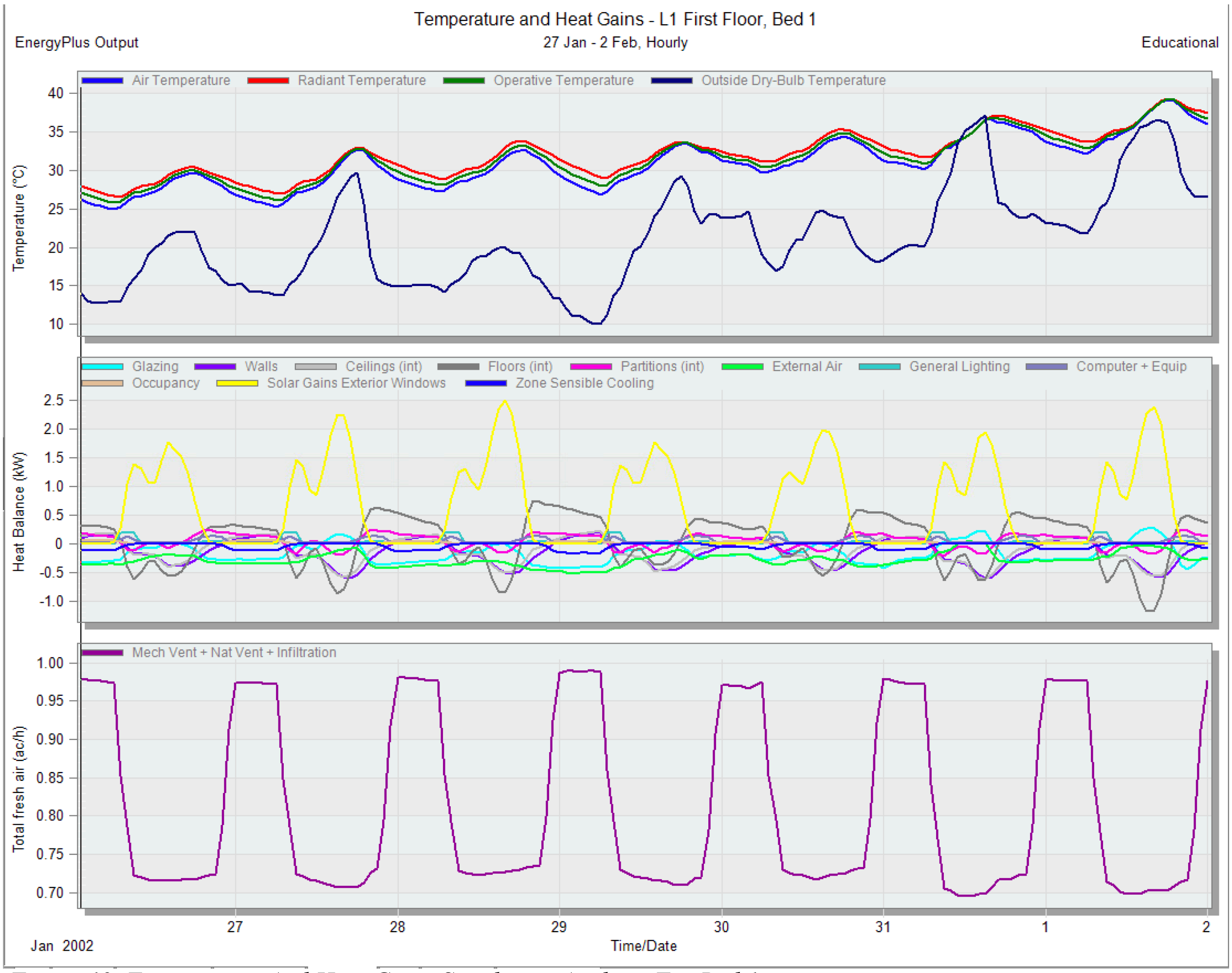


Figure 12. Temperature And Heat Gains Simulation Analysis For Bed 1

Date	Minimum Temperature (°C)	Maximum Temperature (°C)
27 January	25	29
28 January	25	33
29 January	26	31
30 January	26	34
31 January	30	35
1 February	30	36
2 February	33	39

Table 2. Daily Minimum and Maximum Temperatures for Bed 1

The main causes of heat gains identified here are Solar Gains from Exterior windows (average of about 2 kW daily) followed by General Lighting (about 0.2 kW daily). Other sources of heat gains are computer and equipment and occupancy. It is noteworthy that least zone sensible cooling is used in this zone compared to others as it has the least solar heat gains.

LIVING 1

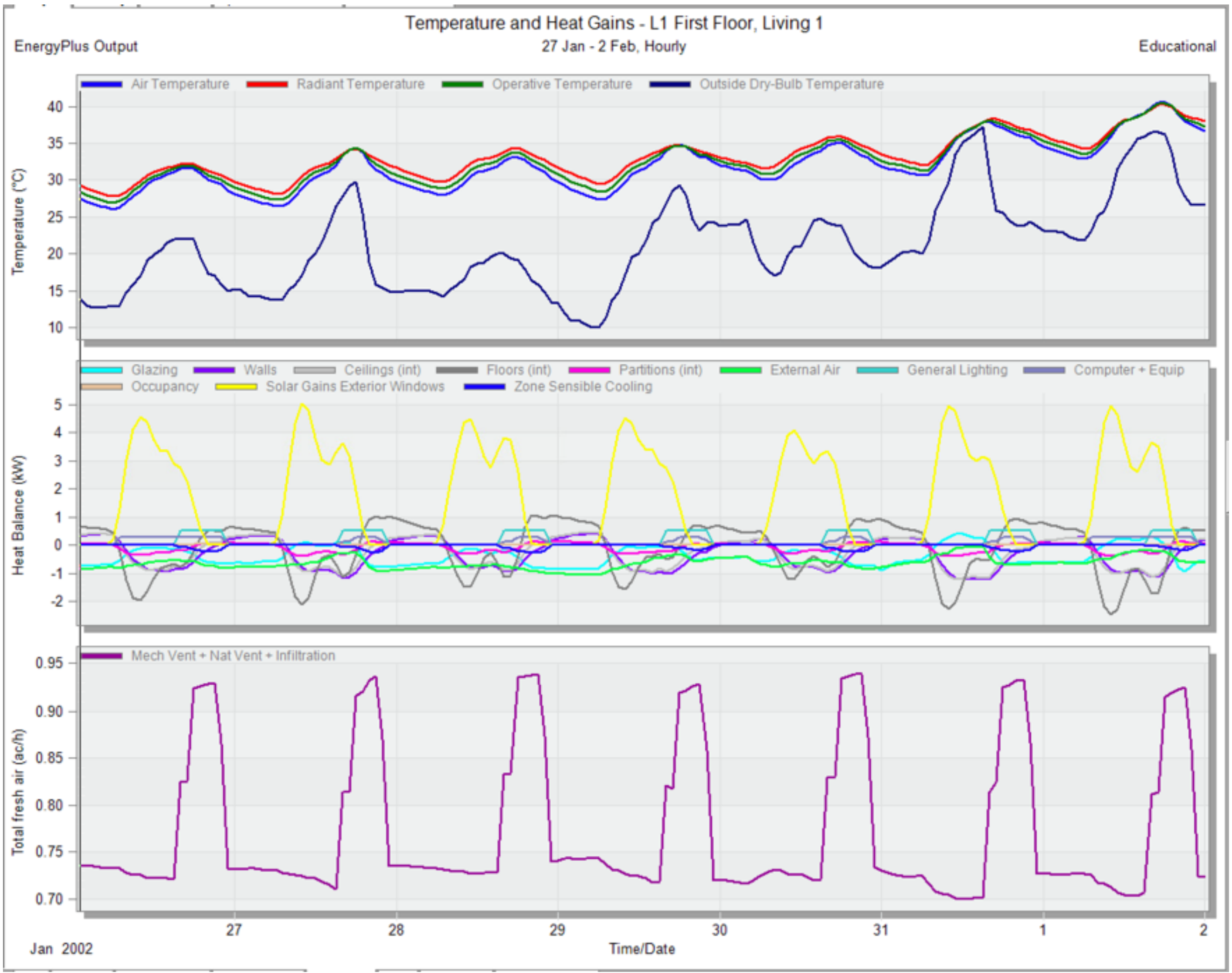


Figure 13. Temperature And Heat Gains Simulation Analysis For Living 1

Date	Minimum Temperature (°C)	Maximum Temperature (°C)
27 January	26	31
28 January	26	34
29 January	26	33
30 January	26	35
31 January	30	35
1 February	31	37
2 February	33	40

Table 3. Daily Minimum and Maximum Temperatures for Living 1

The main causes of heat gains identified here are Solar Gains from Exterior windows (average of about 4.5 kW daily) followed by General Lighting (about 0.5 kW daily). Other sources of heat gains are computer and equipment and occupancy.

STUDIO 1

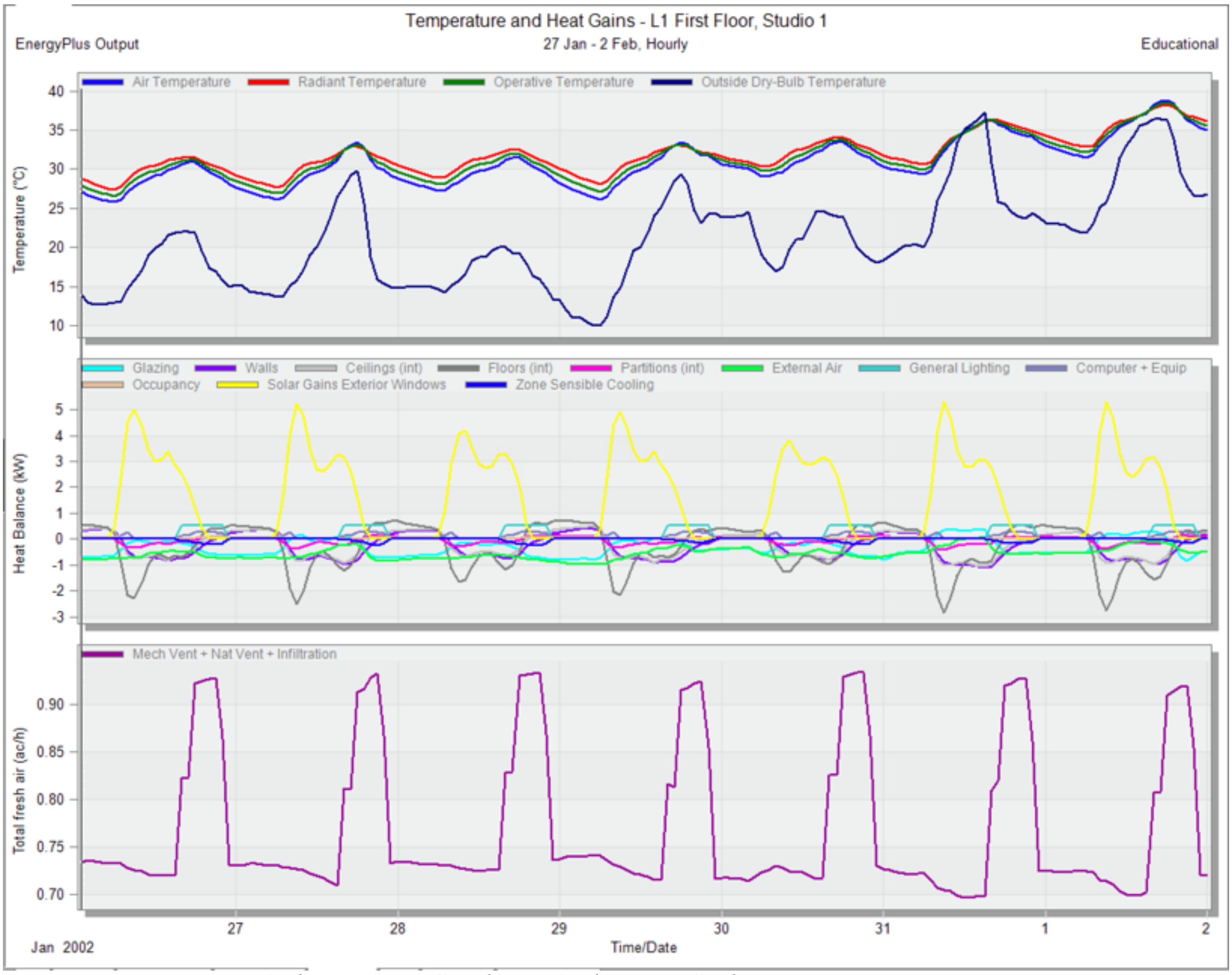


Figure 14. Temperature And Heat Gains Simulation Analysis For Studio 1

Date	Minimum Temperature (°C)	Maximum Temperature (°C)
27 January	26	31
28 January	26	33
29 January	27	31
30 January	26	34
31 January	29	34
1 February	29	36
2 February	32	38

Table 4. Daily Minimum and Maximum Temperatures for Studio 1

The main causes of heat gains identified here are Solar Gains from Exterior windows (average of about 4.5 kW daily) followed by General Lighting (about 0.5 kW daily). Other sources of heat gains are computer and equipment and occupancy.

The construction of L1 External Wall is customized to make it a lightweight wall and is visualized.

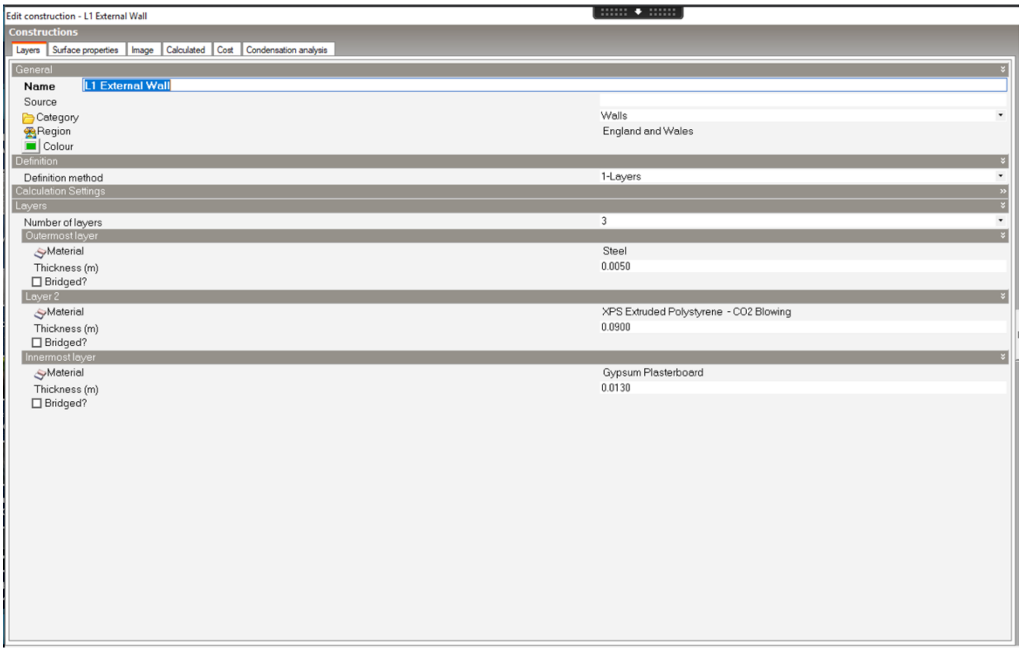


Figure 15. Screenshot showing customization of the L1 External Wall

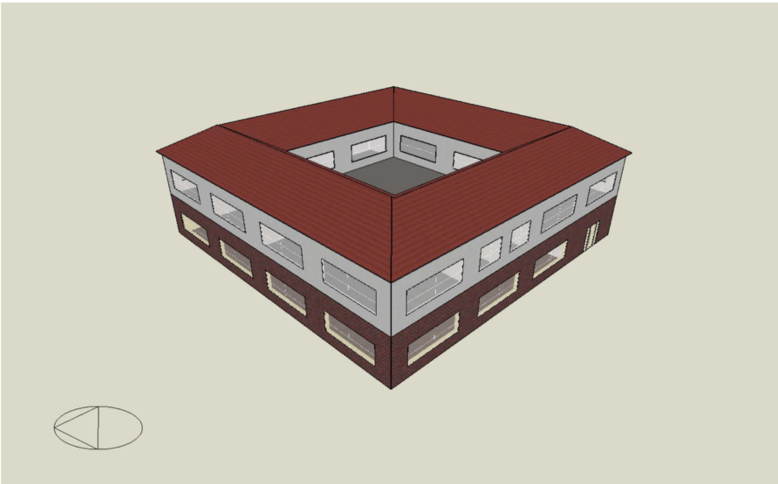


Figure 16. Axonometric View of the Building Model showing changed materials of External Wall on First Floor

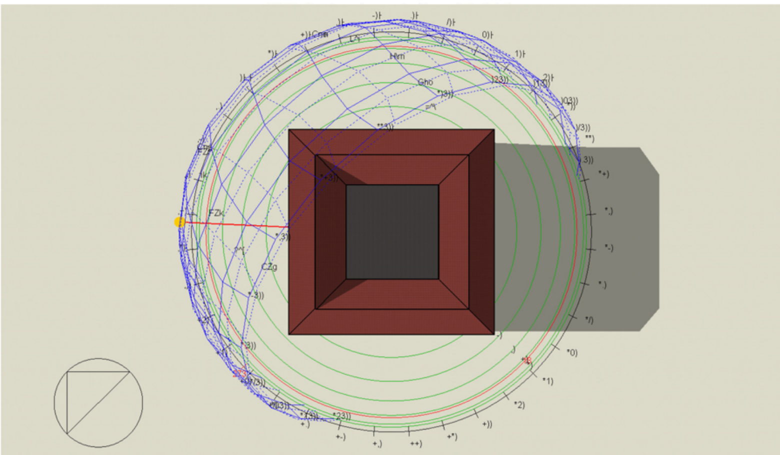


Figure 17. Plan View of the Building Model showing Sun Path Diagrams and Shadows

A simulation is run to observe the impact of the change in construction on the building's parameters.

OPEN OFFICE N

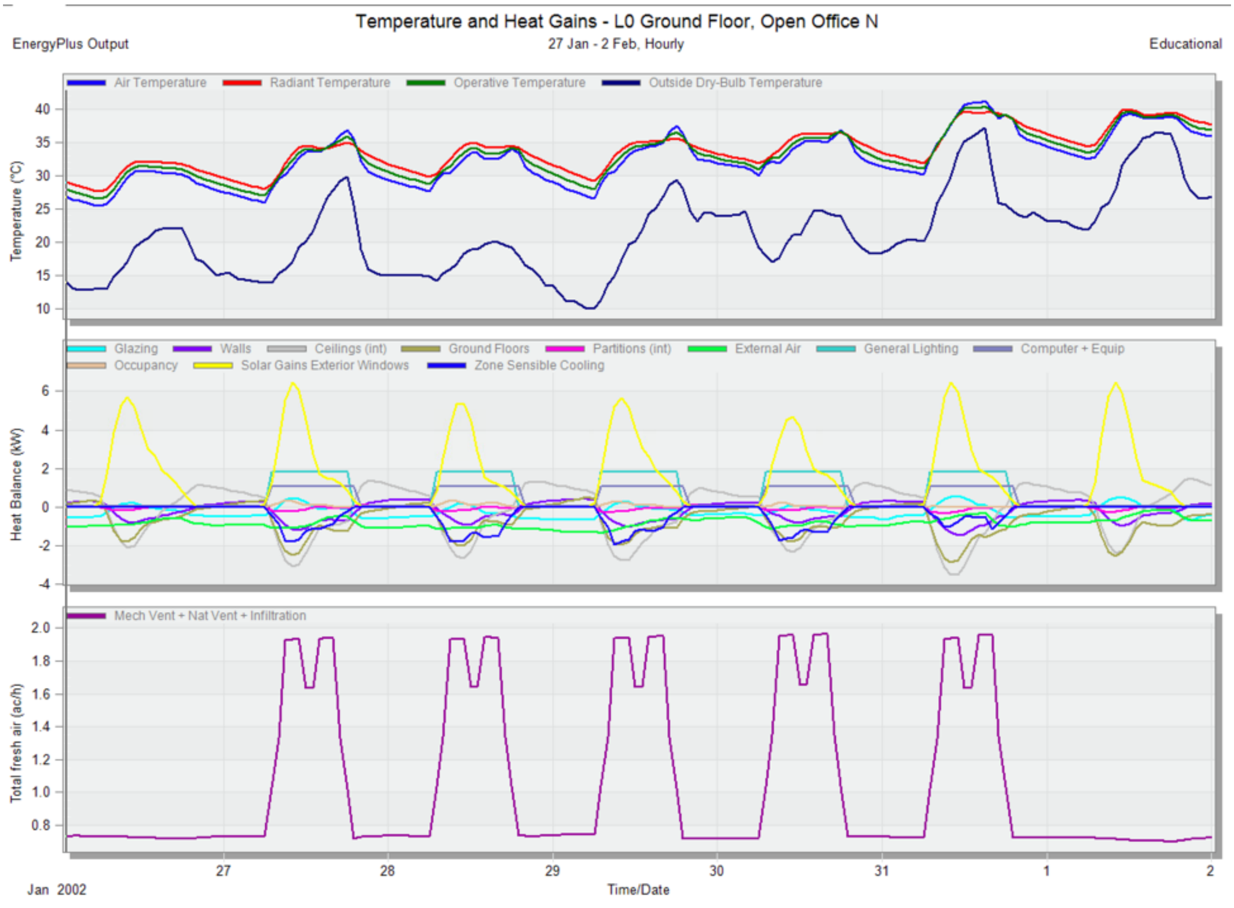


Figure 18. Temperature And Heat Gains Simulation Analysis For Open Office N after changing L1 External Wall

Date	Minimum Temperature (°C)	Maximum Temperature (°C)
27 January	25	30
28 January	26	33
29 January	27	34
30 January	26	36
31 January	30	36
1 February	30	41
2 February	33	38

Table 5. Daily Minimum and Maximum Temperatures for Light Weight Open Office N

The heat balance observed from the walls fluctuates but is mainly negative. The floors and ceilings also yield a negative heat balance peaking to about -2 kW daily. The partitions remain somewhat constant at 0 kW.

BED 1

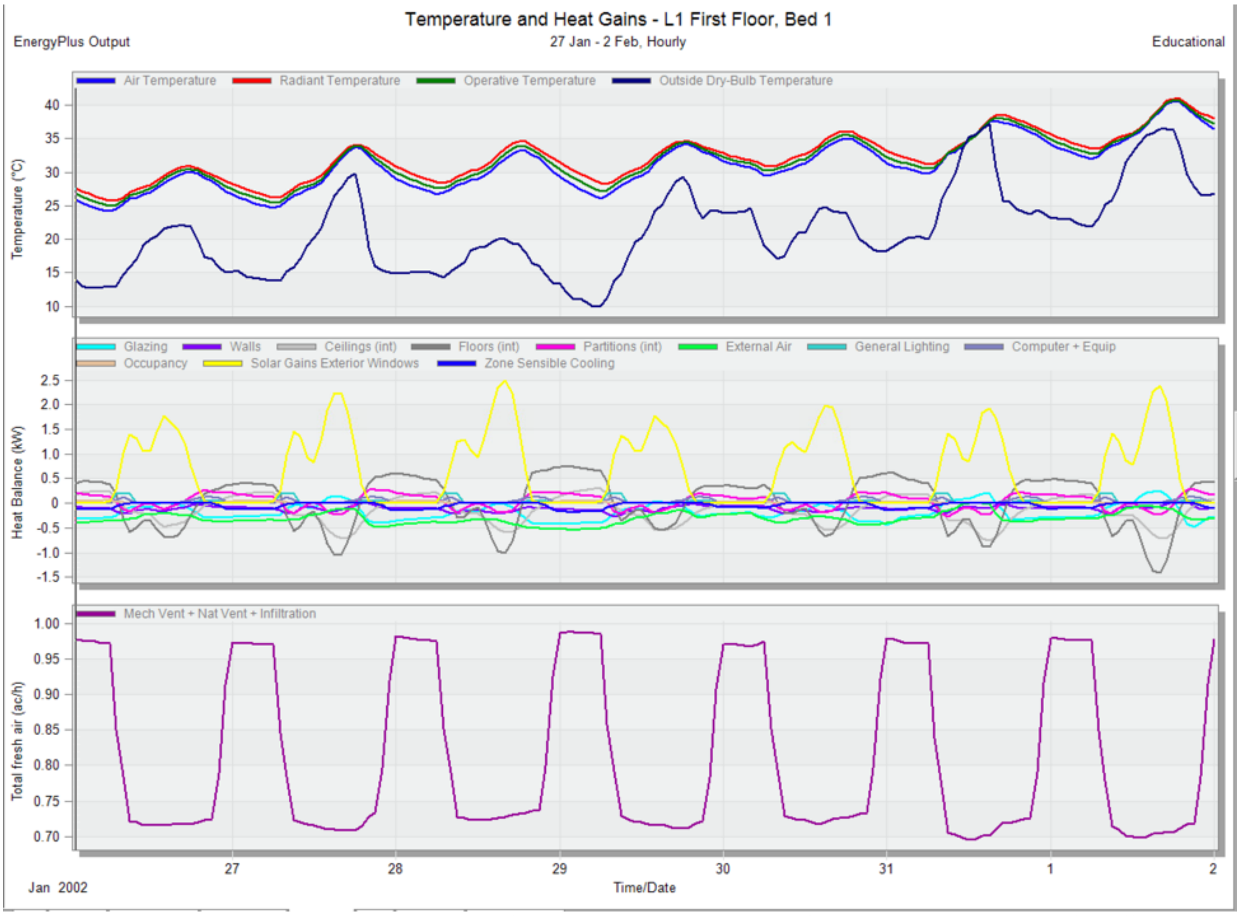


Figure 19. Temperature And Heat Gains Simulation Analysis For Bed 1 after changing L1 External Wall

Date	Minimum Temperature (°C)	Maximum Temperature (°C)
27 January	25	30
28 January	25	34
29 January	26	34
30 January	26	34
31 January	30	35
1 February	30	37
2 February	33	41

Table 6. Daily Minimum and Maximum Temperatures for Light Weight Bed 1

There is very little fluctuation in heat balance from the walls and the floors and ceilings yield a negative heat balance peaking to almost -1 kW daily. There is a fluctuation in the heat balance of the partitions between 0.2 kW and -0.2 kW daily.

LIVING 1

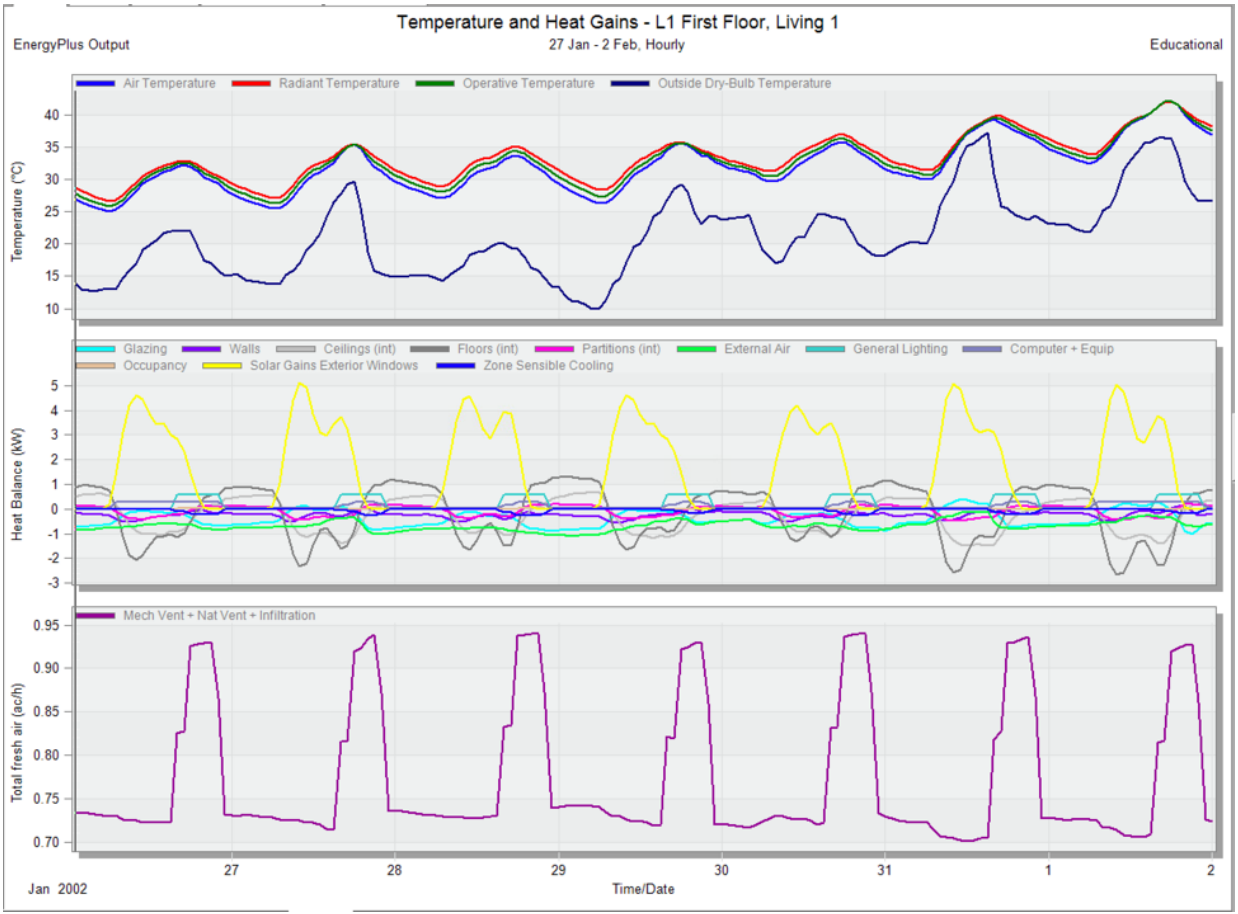


Figure 20. Temperature And Heat Gains Simulation Analysis For Living 1 after changing L1 External Wall

Date	Minimum Temperature (°C)	Maximum Temperature (°C)
27 January	25	32
28 January	25	35
29 January	26	34
30 January	26	35
31 January	30	35
1 February	30	39
2 February	33	42

Table 7. Daily Minimum and Maximum Temperatures for Light Weight Living 1

There is a small negative Heat Balance from the walls and partitions. The Heat Balance from the floor and ceilings fluctuates between 1 kW to -2.5 kW daily and 0.5 kW to -1 kW daily respectively.

STUDIO 1

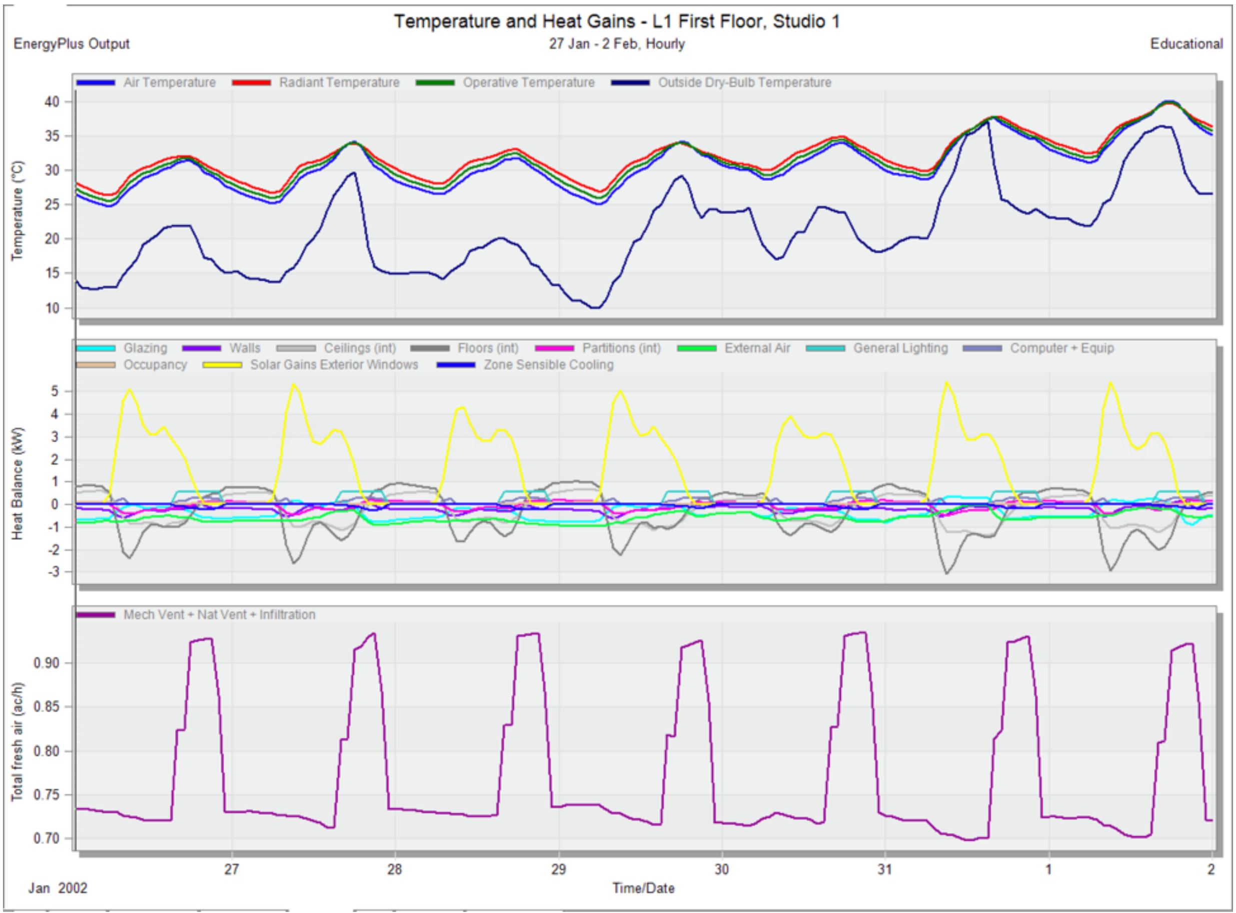


Figure 21. Temperature And Heat Gains Simulation Analysis For Studio 1 after changing L1 External Wall

Date	Minimum Temperature (°C)	Maximum Temperature (°C)
27 January	25	31
28 January	25	34
29 January	26	32
30 January	25	34
31 January	29	34
1 February	29	37
2 February	31	40

Table 8. Daily Minimum and Maximum Temperatures for Light Weight Studio 1

There is a small negative Heat Balance from the walls and partitions. The Heat Balance from the floor and ceilings fluctuates between 1 kW to -2.5 kW daily and 0.5 kW to -1 kW daily respectively.

ANALYSIS : On changing the construction, the temperature fluctuations intensify but subtly and the overall maximum temperature is higher, and the overall minimum temperature is lower than the values obtained initially. This behavior is explained by the slight decrease in the thermal mass of the construction when changing it to be light weight. It can be observed that after changing the construction to a light weight construction, the heat gain through the fabric (walls, partitions, floor and ceiling) becomes more negative. Hence, this change in construction reduces the fabric gains. This can be explained due to the decrease in the U-Value of the wall to 0.349 W/m^{2}K. As the U-Value decreases, the building fabric becomes more thermally capable to reduce heat gains withing the building.

TUTORIAL 3

Initially, a baseline simulation is run on the tutorial model and zone level results for internal gains and comfort for a specific chosen zone - L0 Open Office N are analyzed.

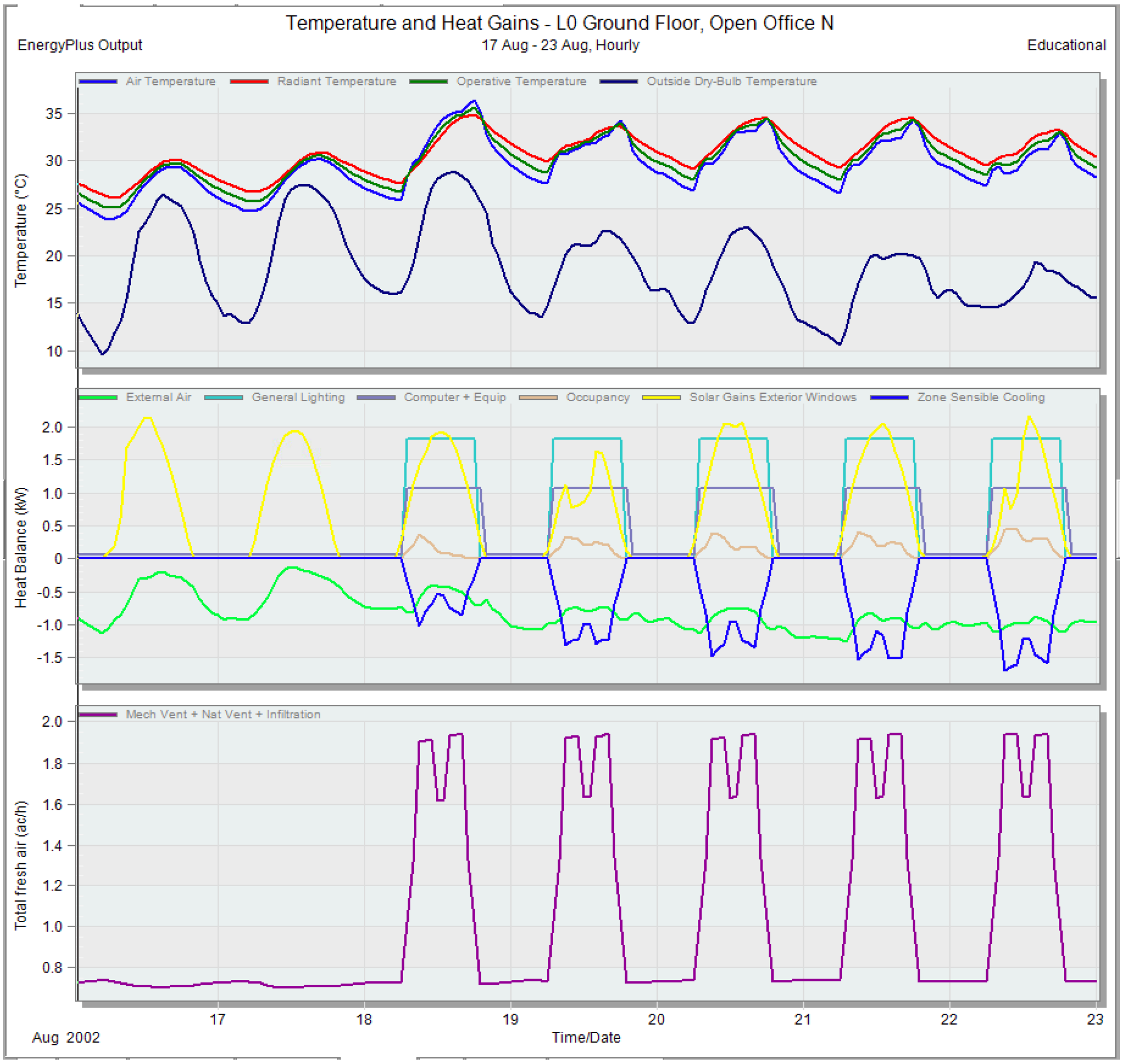


Figure 22. Temperature And Heat Gains from Baseline Simulation Analysis For Open Office N

It can be observed that the indoor temperatures are significantly higher than the outdoor dry bulb temperature with a margin of about 5 °C - 10 °C. The highest indoor temperature is about 36 °C and the lowest is 25 °C.

The main source of heat gains are the Solar Gains that present a daily peak of almost 2 kW. This is followed by General Lighting (1.8 kW daily), Computer and Equipment (1 kW daily) and occupancy. There are heat losses from the Zone Sensible Cooling (1 kW-1.5 kW) and the external air.

The comfort is measured by the air changes per hour of fresh air. The zone receives a maximum of over 1.8 ac/h of fresh air daily.

It can also be observed from these graphs that the zone is not in full use during 17-18 August

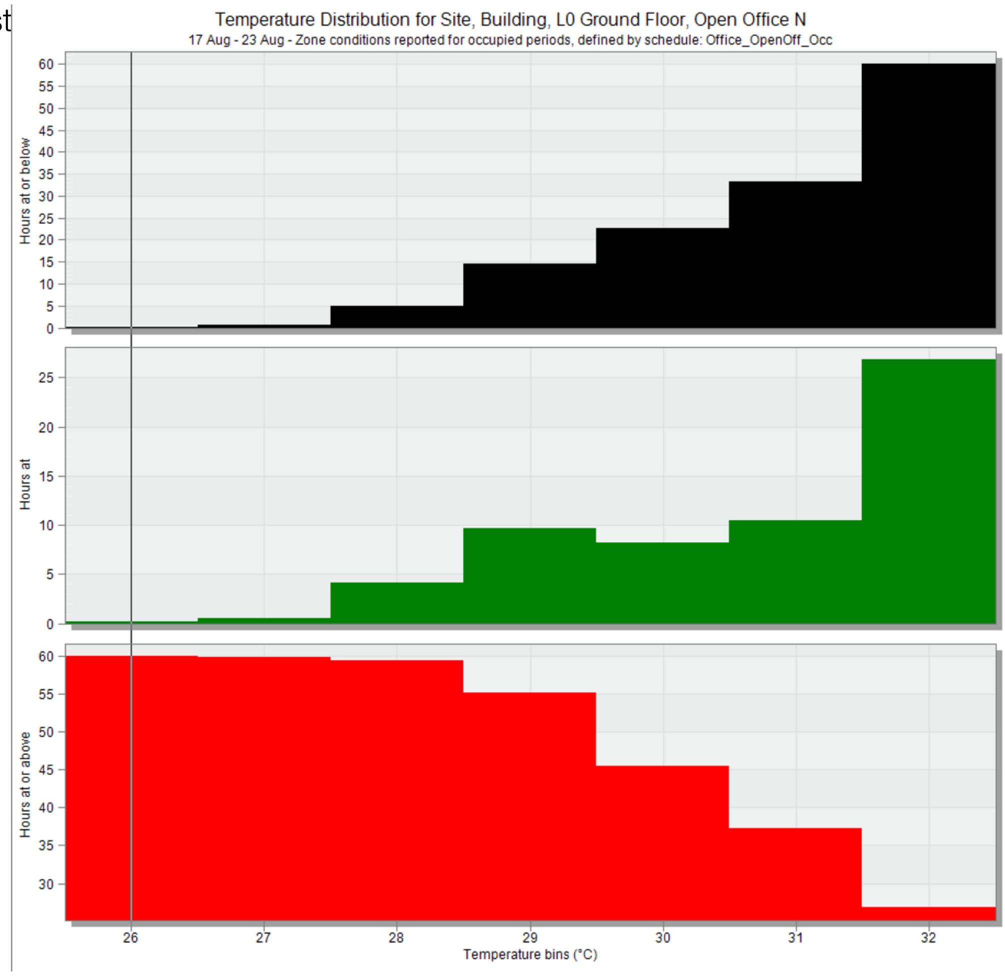


Figure 23. Temperature Distribution Histogram from Baseline Simulation Analysis For Open Office N

The space is said to be overheated if the temperature inside exceeds 28 °C. The histogram generated above can be used to see the overheating by measuring the hours above 28 °C during occupied times. This shows 55 hours at or above 28 °C.

To reduce solar gains, shading is added to the building model and visualized.

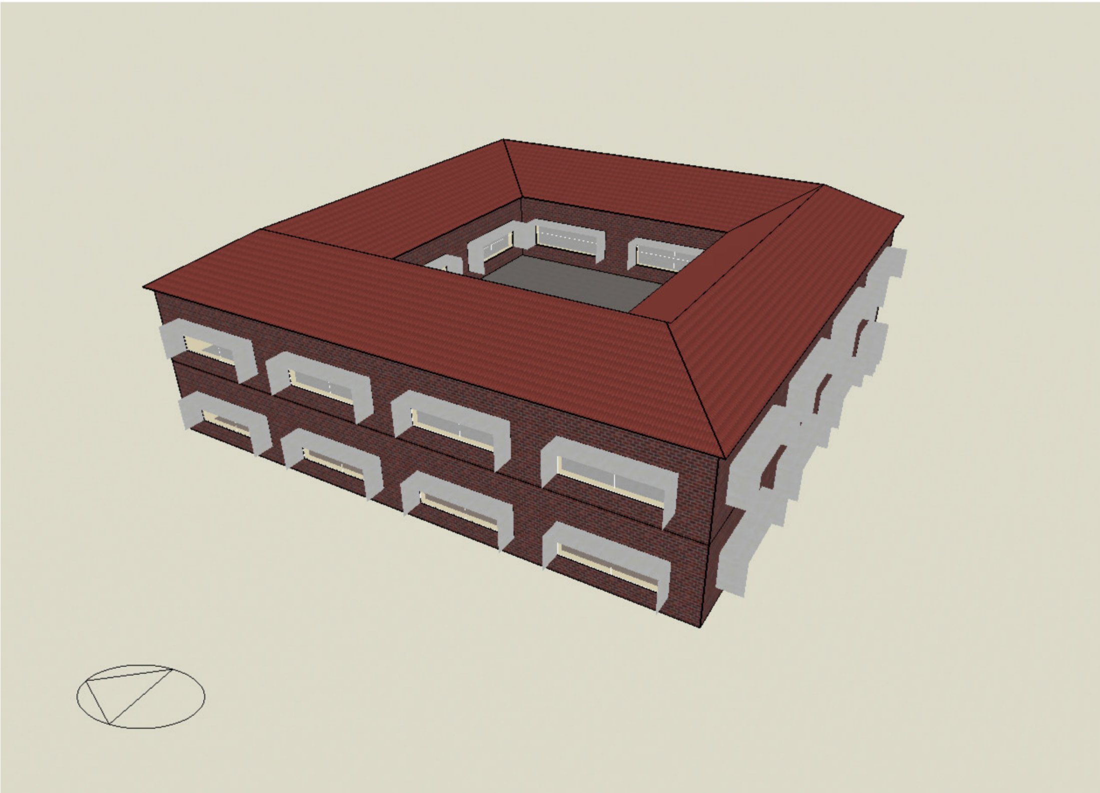


Figure 24. Rendered Axonometric View Of Building Model showing the Shading Device

A baseline with shading simulation is run and compared with the baseline simulation

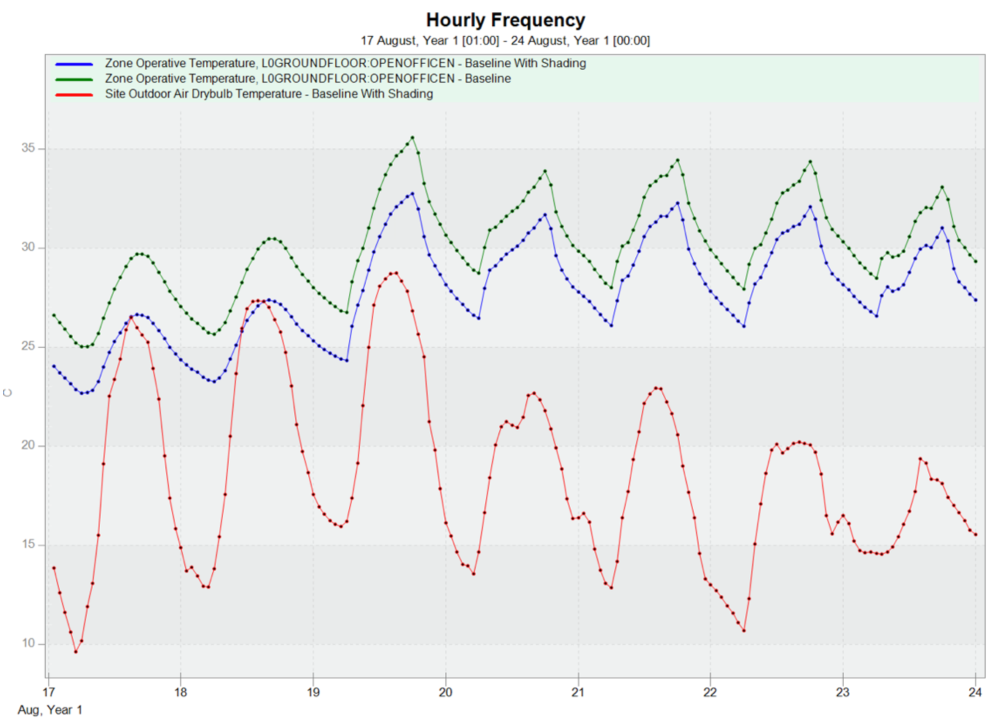


Figure 25. Graph Comparing the Operative Temperature of the same zone with and without shading with the external temperature

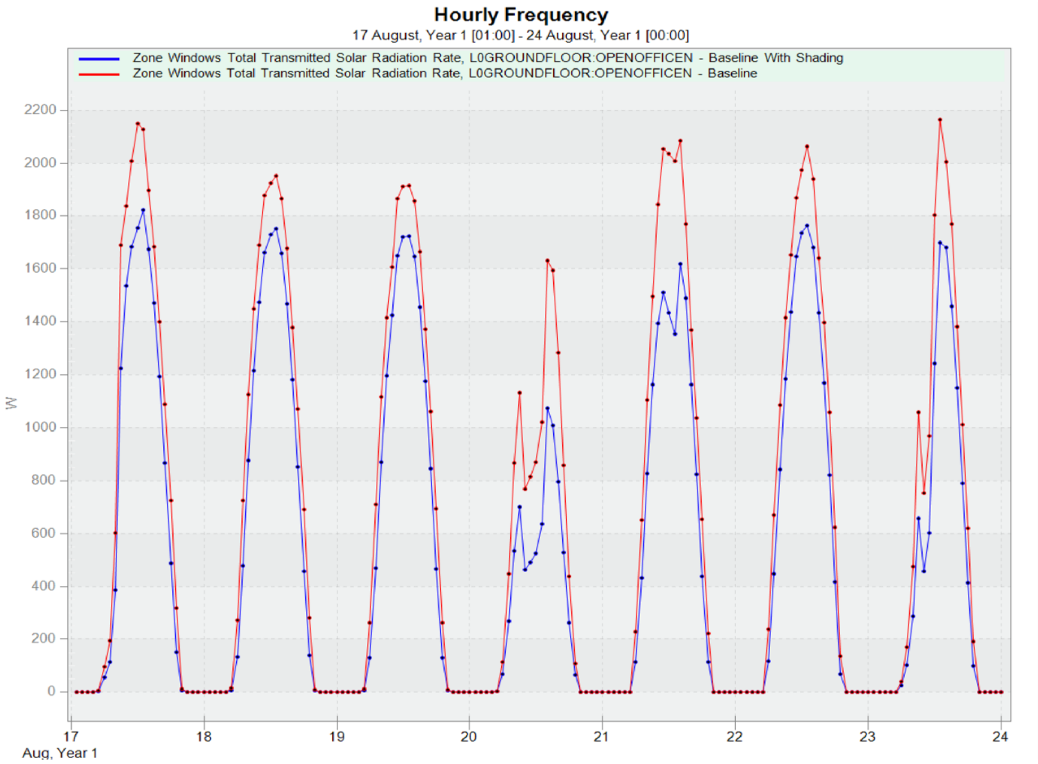


Figure 26. Graph Comparing the Total Transmitted Solar Radiation Rate of the windows of the same zone with and without shading

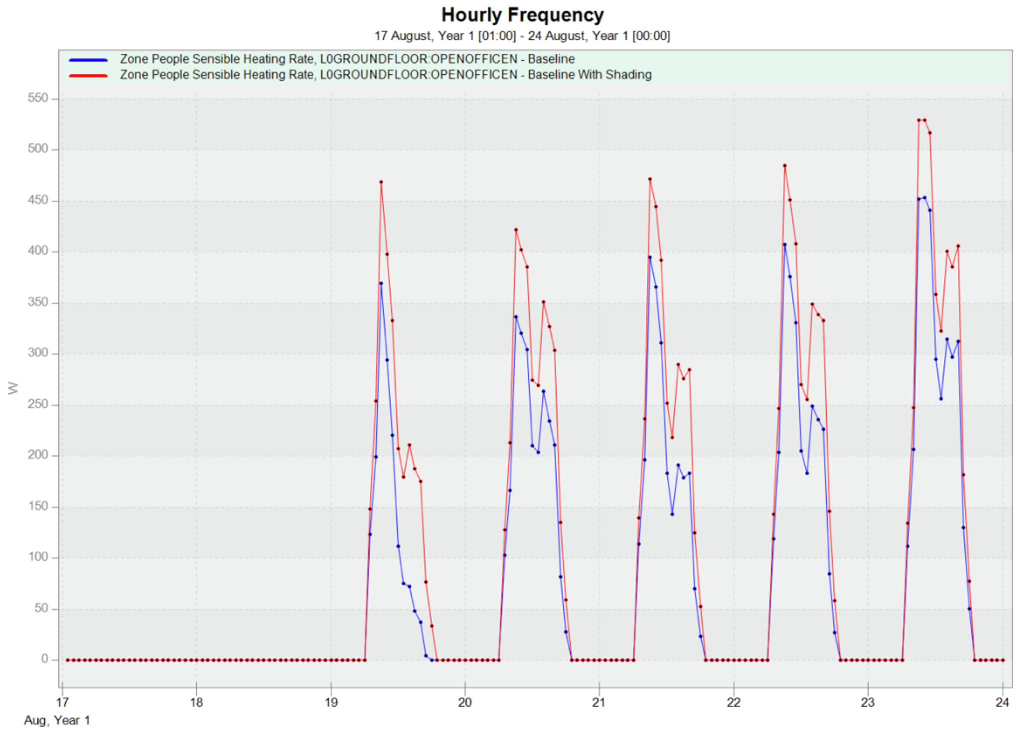


Figure 27. Graph Comparing the People Sensible Heating Rate of the same zone with and without shading

From Fig 25, it can be clearly observed that introducing shading to the building significantly lowers the zone operative temperature by nearly 3°C as it reduces heat gains from solar radiations. The reductions in solar radiations are of about 400 W at the peaks and are clearly visible in Fig 26. It is interesting to note that as shading is introduced the people sensible heating rate within the zone increases (Fig 27).

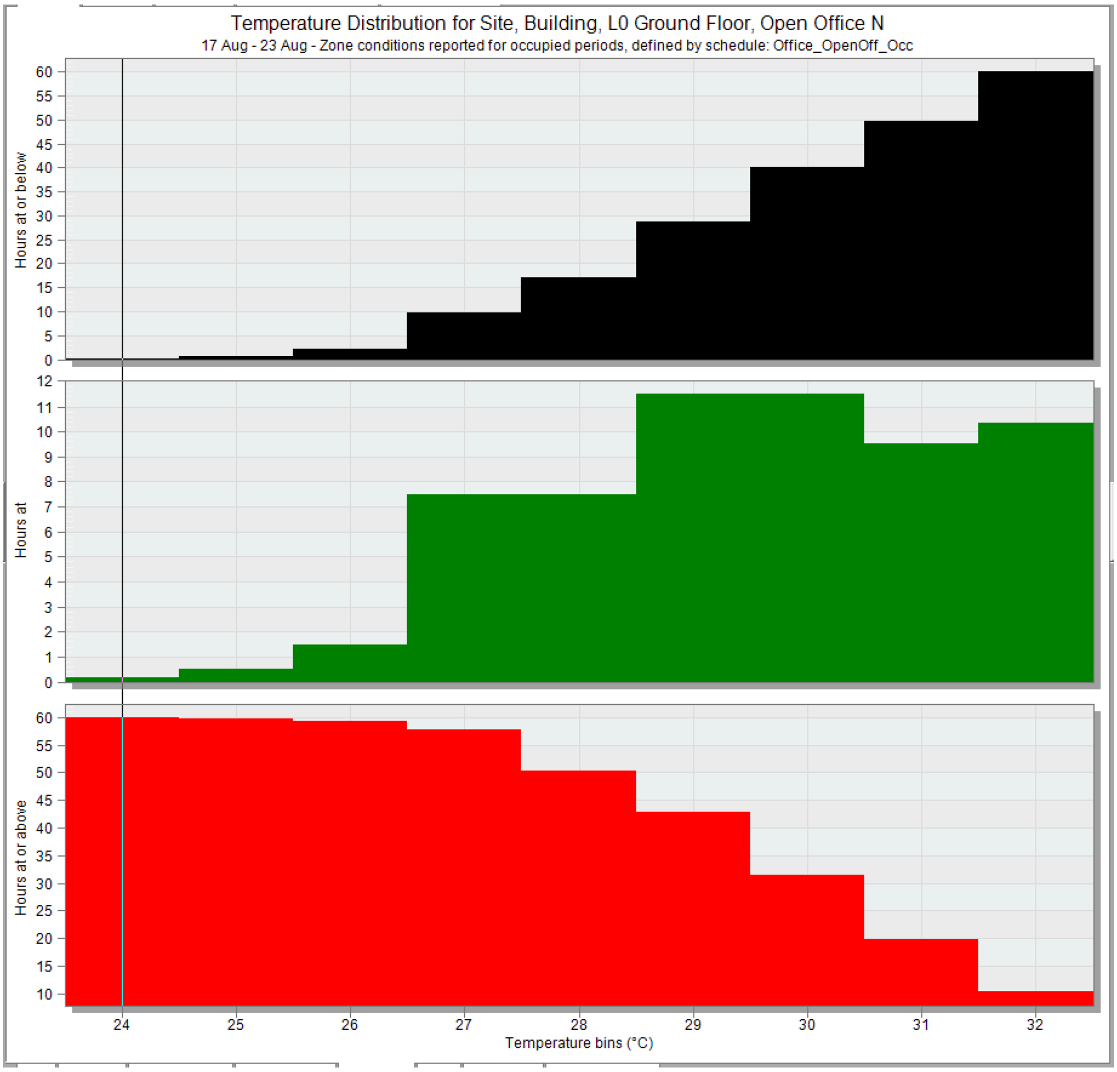


Figure 28. Temperature Distribution Histogram from Baseline Simulation With Shading Analysis For Open Office N

The above histogram shows that on introducing shading the overheating hours, i.e., hours at or above 28 °C decreases from 55 hours (without shading) to 50 hours (with shading).

The internal heat gains can be further reduced by introducing more external air and this is done by apply 24/7 natural ventilation to the building model.

A baseline with shading and natural ventilation simulation is also run and the results are compared alongside the results obtained from the first two simulations performed.

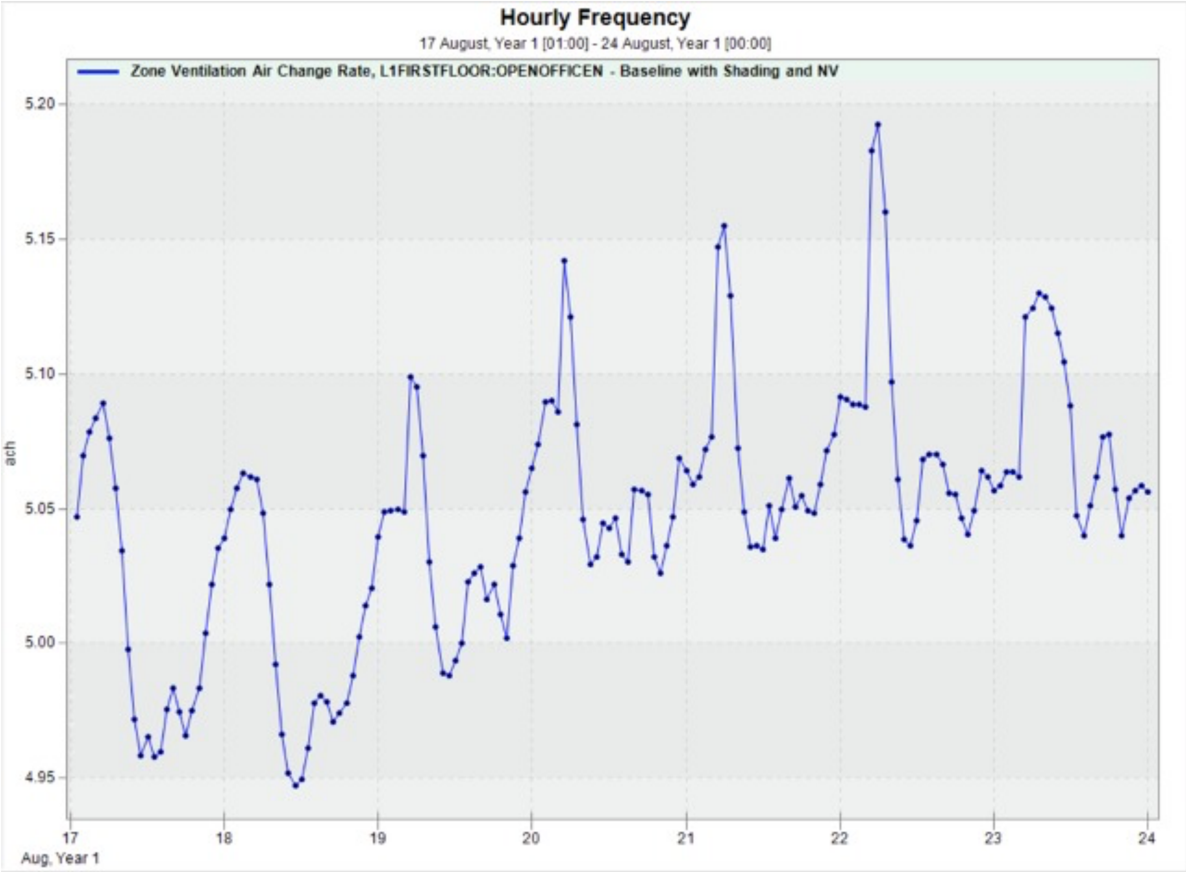


Figure 29. Graph showing the Ventilation Air Change Rate from Baseline with Shading and Natural Ventilation Simulation for Office N

The above graph shows the Ventilation Air Change Rate after enabling Natural Ventilation. The average air change rate from above can be taken as 5 ach.

Air change rate is given by
n = 3600q/V

where q = Flow of Fresh Air(m^3/s), n =air change rate(ach) and V = Volume of Room(m^3)

We have n = 5 ach, V = 318.73 m^3

- ⇨ q = 5 x 318.73 / 3600
- ⇨ q = 0.443 m^3/s

The flow of fresh air is hence ***0.443 m^3/s***

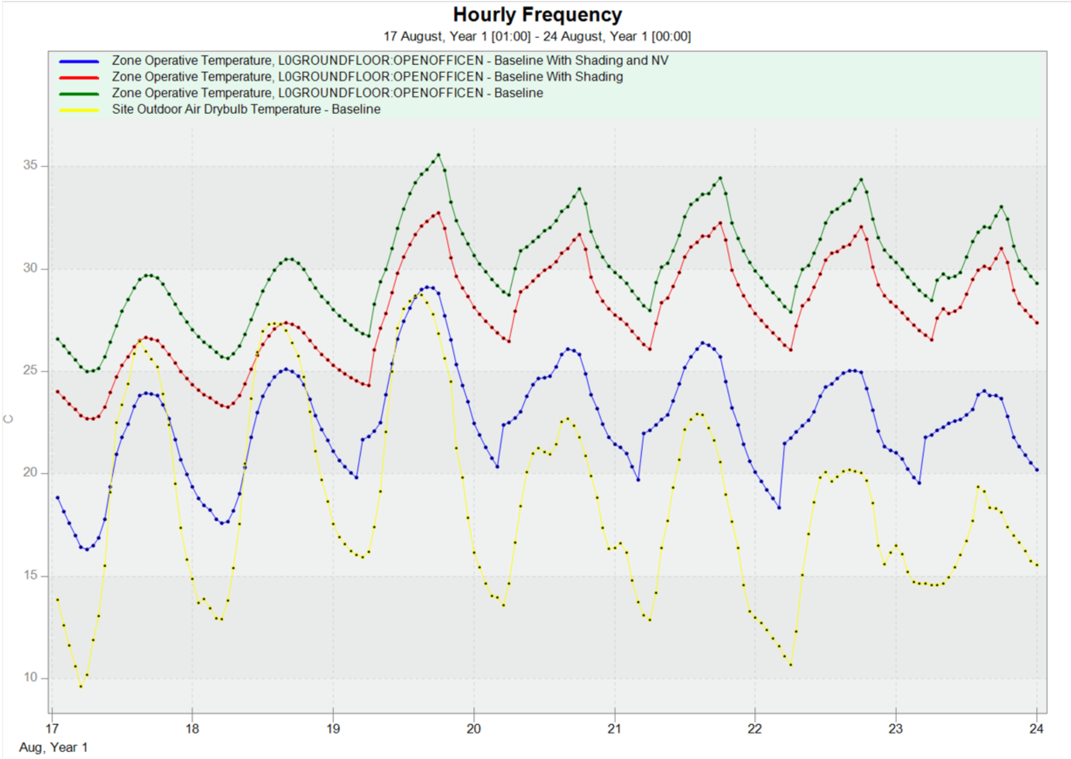


Figure 29. Graph Comparing the Operative Temperature of the same zone without Shading, with Shading and with Shading and Natural Ventilation

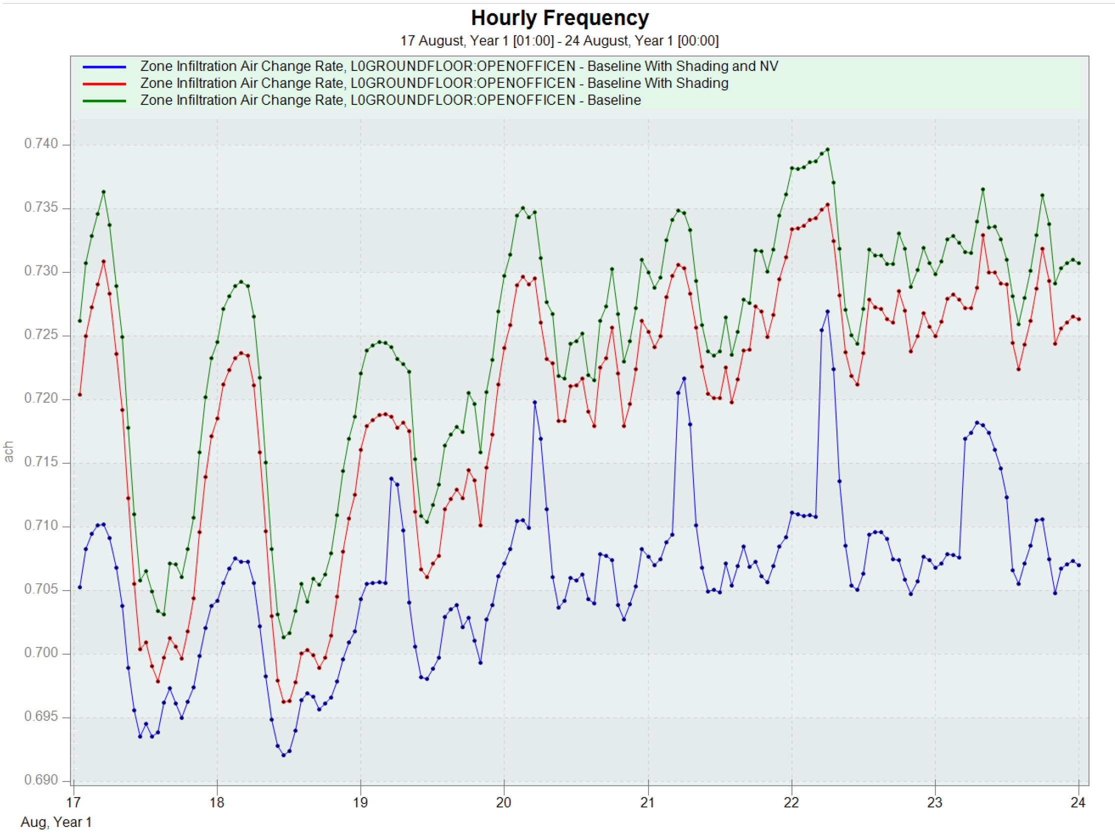


Figure 30. Graph Comparing the Infiltration Air Change Rate of the same zone without Shading, with Shading and with Shading and Natural Ventilation

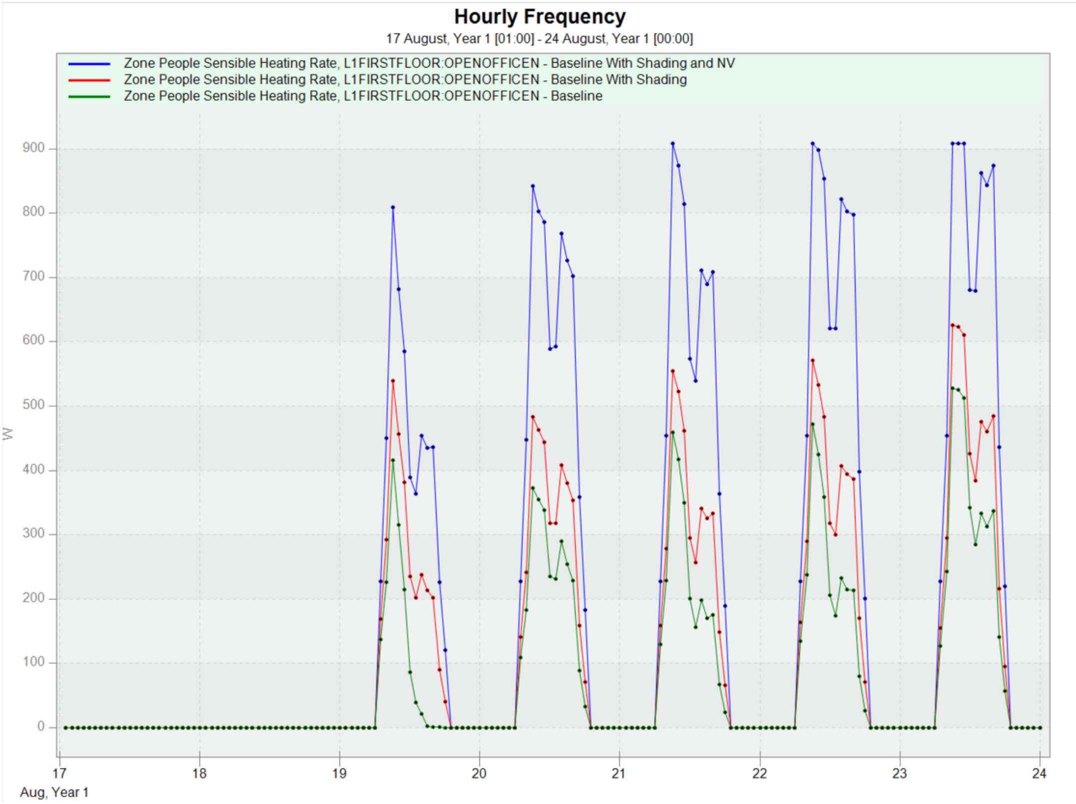


Figure 31. Graph Comparing the People Sensible Heating Rate of the same zone without Shading, with Shading and with Shading and Natural Ventilation

Fig 29 shows that the temperature lowers even more once Natural Ventilation is introduced along with shading. This is because of the introduction of external air. However, at some points, this leads to over cooling of the building wherein the inside temperature drops below the outside temperature creating a potentially undesirable situation.

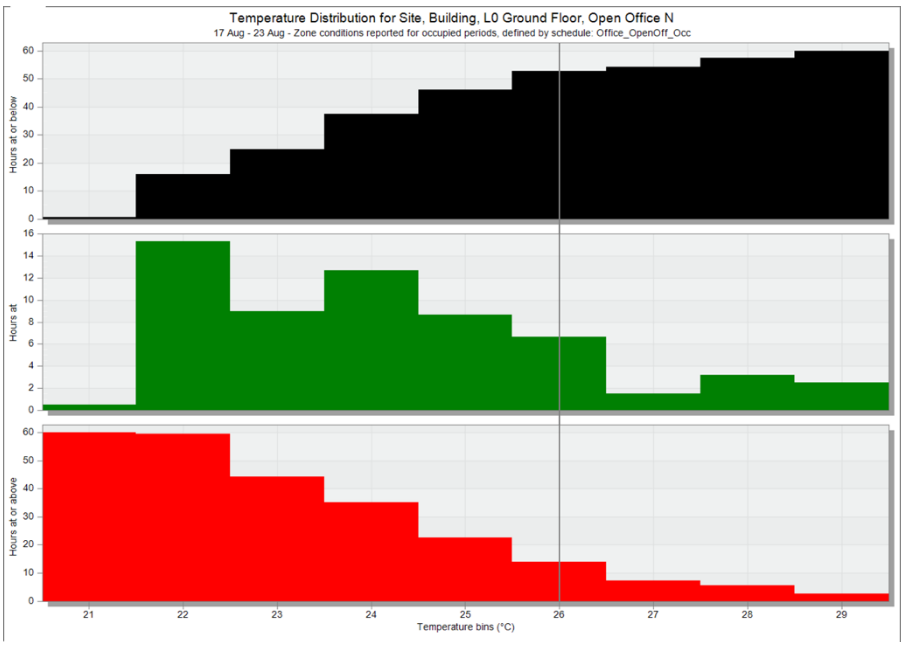


Figure 32. Temperature Distribution Histogram from Baseline Simulation With Shading and Natural Ventilation Analysis For Open Office N

Fig 30 show the zone infiltration air change rates in the three simulations which is interestingly lowest for the building with Natural Ventilation and shading. This shows that as the intentional air flow, i.e., Natural Ventilation is introduced into the building, the unintentional air flow, i.e., Infiltration is decreasing. It is interesting to note that as Natural Ventilation is introduced, the people sensible heating rate increases further (Fig 31).

The above histogram shows that on introducing natural ventilation along with shading, the overheating hours, i.e., hours at or above 28 °C decreases drastically from 55 hours (without shading) and 50 hours (with shading) to 6 hours.

The above-mentioned overcooling from natural ventilation increases the heating demands of the building which can be seen below.

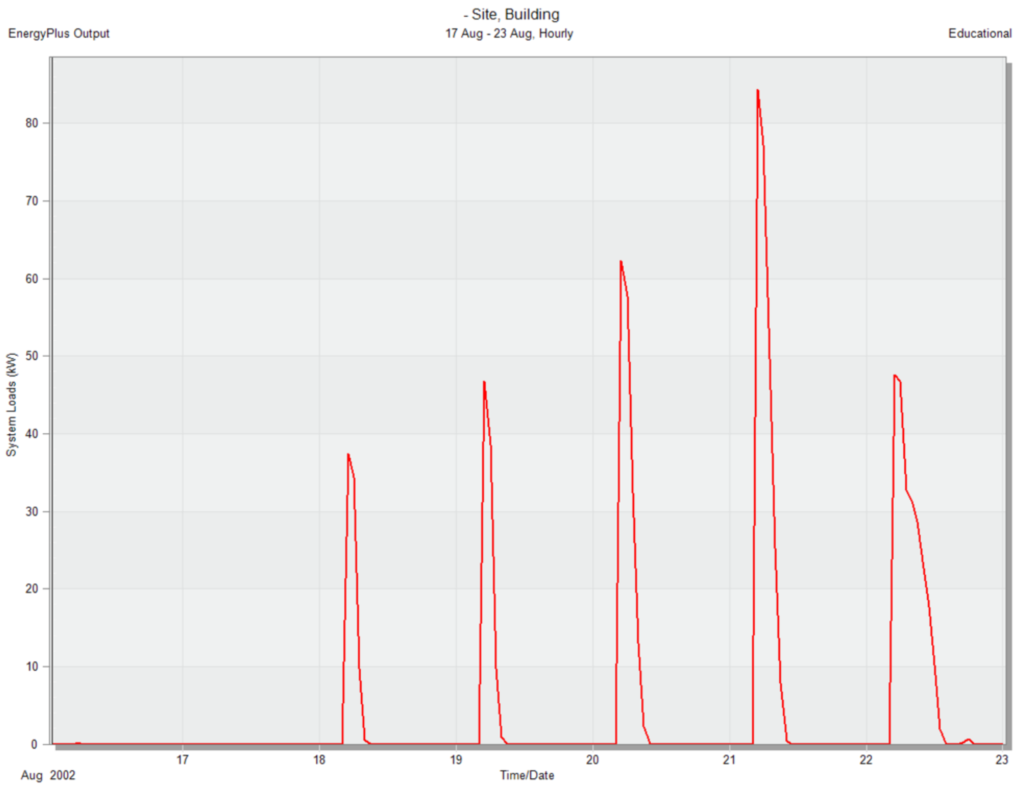


Figure 33. Zone Heating of the Building after applying shading and natural ventilation

To overcome the issue of overcooling, Ventilation Setpoint Temperature's indoor minimum temperature is defined.

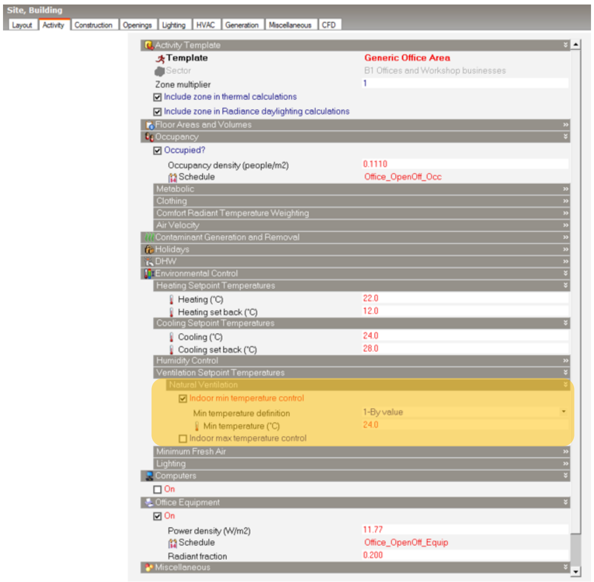


Figure 34. Defining Ventilation Setpoint Temperature's Indoor minimum temperature control to optimize over-cooling of the building due to Natural Ventilation

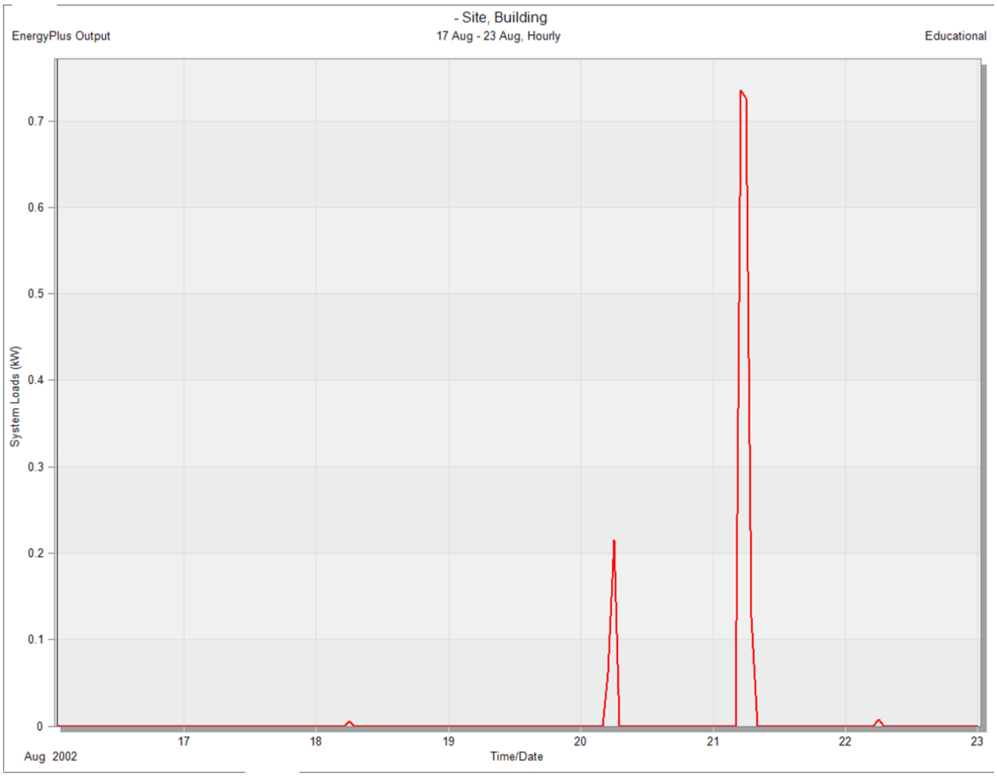


Figure 35. Zone Heating of the Building after defining the Ventilation Setpoint Temperature

The above decrease in zone heating requirement indicates that setting the Ventilation Setpoint Temperature optimized the over-cooling of the building that occurred due to uncontrolled natural ventilation.

Other impacts of this change can be observed graphically.

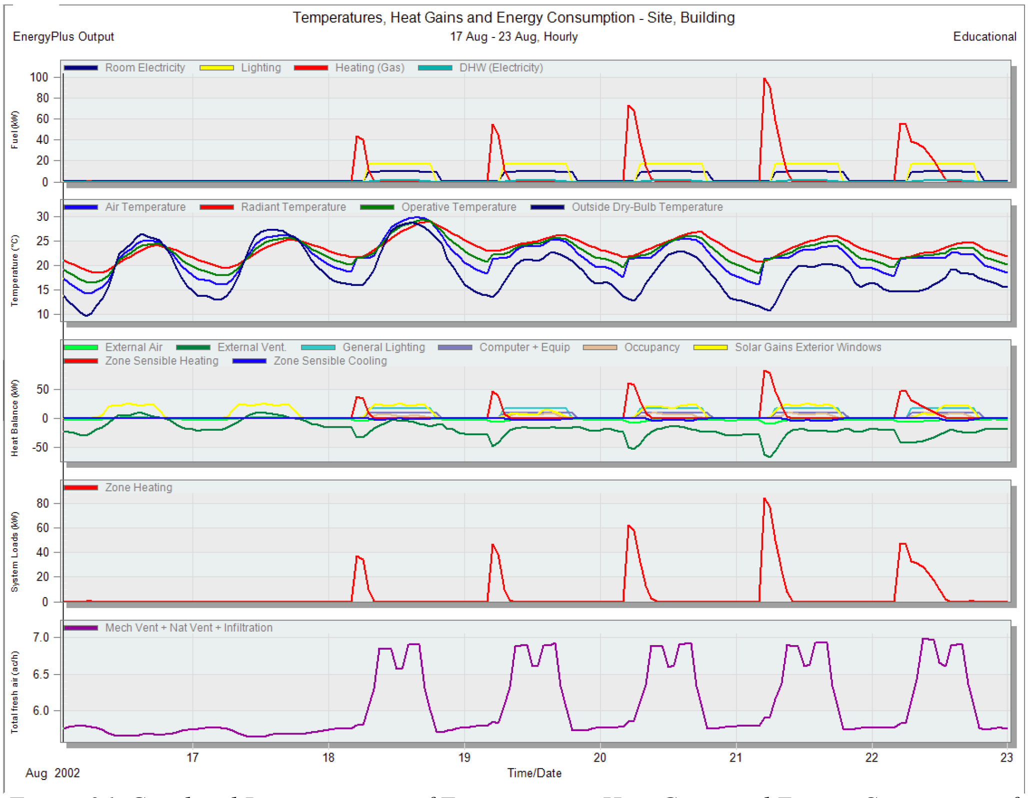


Figure 36. Graphical Representation of Temperatures, Heat Gains and Energy Consumption for the Building before defining the Ventilation Setpoint Temperature

Figure 37. Graphical Representation of Temperatures, Heat Gains and Energy Consumption for the Building after defining the Ventilation Setpoint Temperature

ANALYSIS : It is observed that on defining Ventilation Setpoint, the indoor operative temperature does not drop below the outdoor temperature at any point as it did before. Thus, solving the problem of overcooling. Due to this there is a vast significant decline in the Zone Heating. The change in total fresh air is interesting as there is not a peak increase but there is an overall increase in the distribution of total fresh air through the day and this distribution remains almost uniform through the week.

SUBMISSION 2 : COURSEWORK EXERCISES

STAGE 1: BASELINE RUN

1.1 Location - London-Gatwick

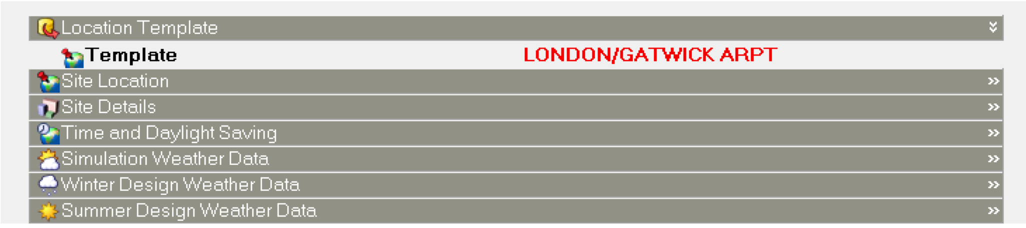


Figure 1. Screenshot showing location template of the building

1.2 Construct a building block - of 30m x 15m and dividing into two equal zones

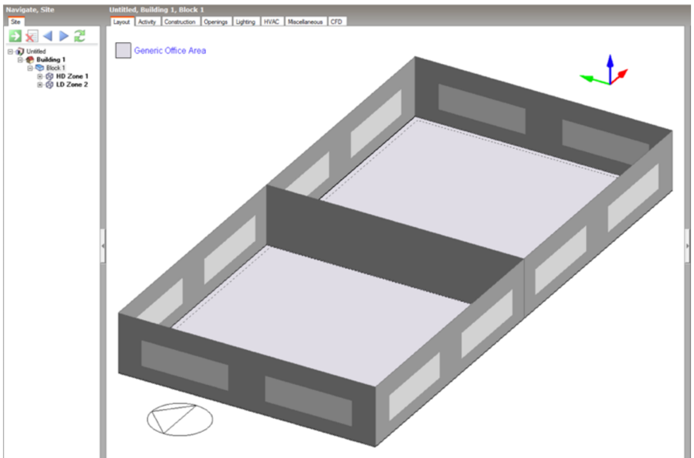


Figure 2. Screenshot showing construction of 30m x 15 m building

1.3 Changing Zone Density - Zone 1 to High Density of Occupants

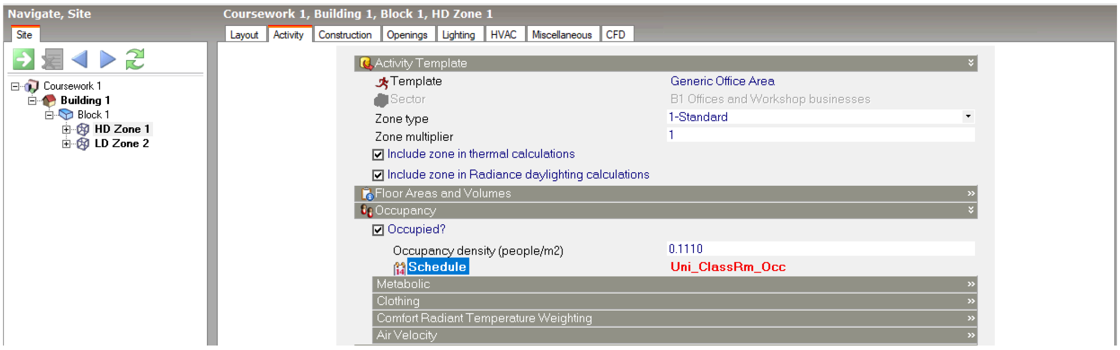


Figure 3. Screenshot showing change of Zone 1 to High Density Occupation Schedule

Zone 2 to have Low Density of Occupants

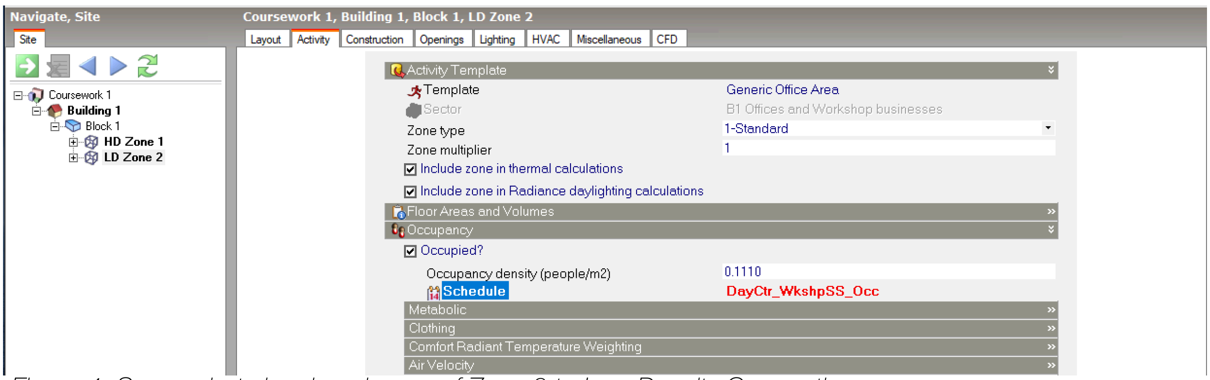


Figure 4. Screenshot showing change of Zone 2 to Low Density Occupation

1.4 Modifying Zone Constructions -

The construction of the Low-Density Zone 2 is edited to Lightweight.

The roof construction is changed to a library data template for Lightweight Flat Roof
The wall construction changed by editing the Project Template to a standard Lightweight Wall Template.[2]

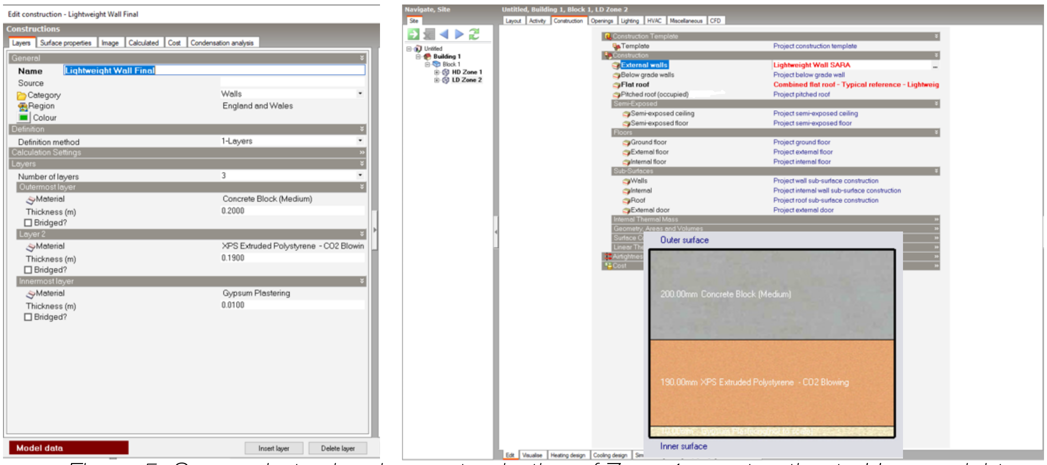


Figure 5. Screenshots showing customization of Zone 1 construction to Heavyweight

The construction of the High-Density Zone 1 is edited to Heavyweight.

The roof construction is changed to a library data template for Heavyweight Flat Roof
The wall construction changed by editing the Project Template to a standard Heavyweight Wall Template.[2]

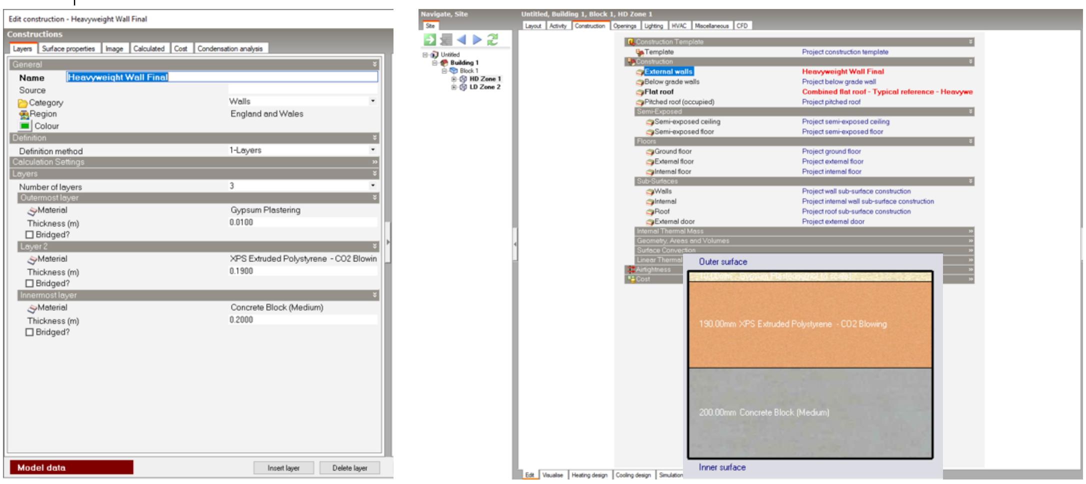


Figure 6. Screenshots showing customization of Zone 2 construction to Lightweight

We can observe the U-Values and Thicknesses of the two zones to be the same, but they have different Internal Heat Capacities

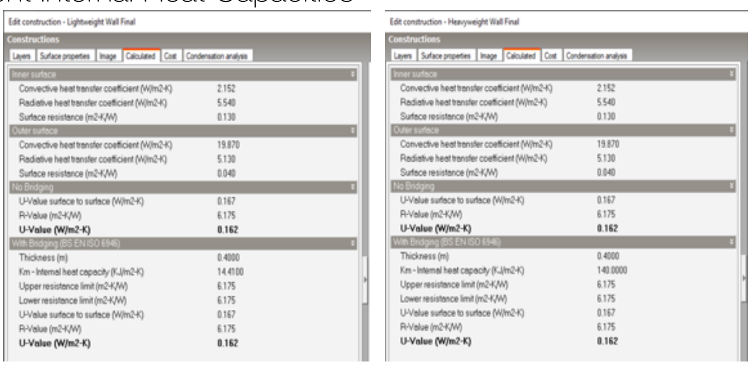


Figure 7. Screenshots showing U-Values and Thicknesses of Zone 1 (right) and Zone 2 (left) constructions

1.5 Openings and Glazing - Desired doors and windows are drawn and the glazing is changed to a double glazing

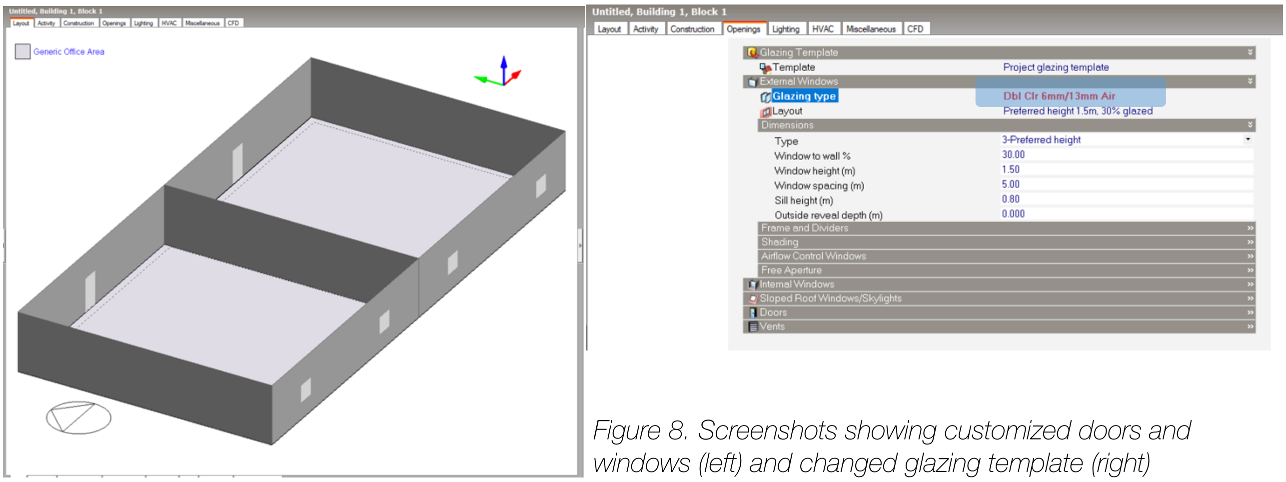


Figure 8. Screenshots showing customized doors and windows (left) and changed glazing template (right)

1.6 Cooling - Turned off cooling in HVAC tab

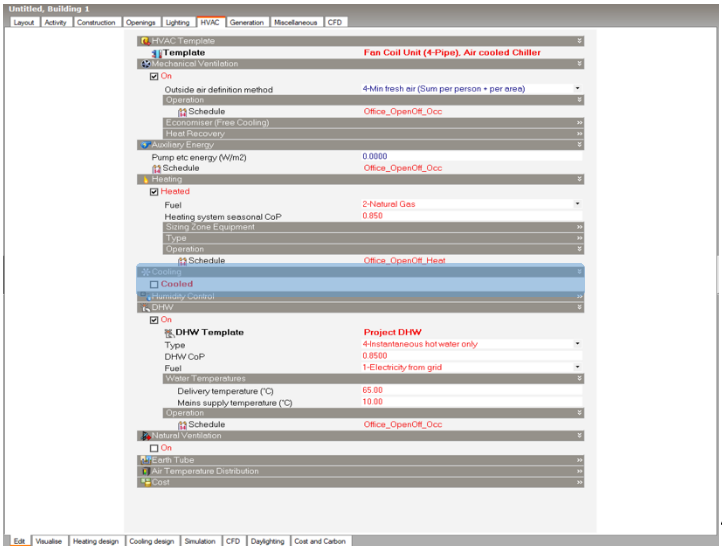


Figure 9. Screenshot showing turned off cooling

1.7 Lighting - Ensuring General Lighting is on then changing the lighting schedule for high- and low-density zones to ensure they correspond the previously assigned occupancy schedule.

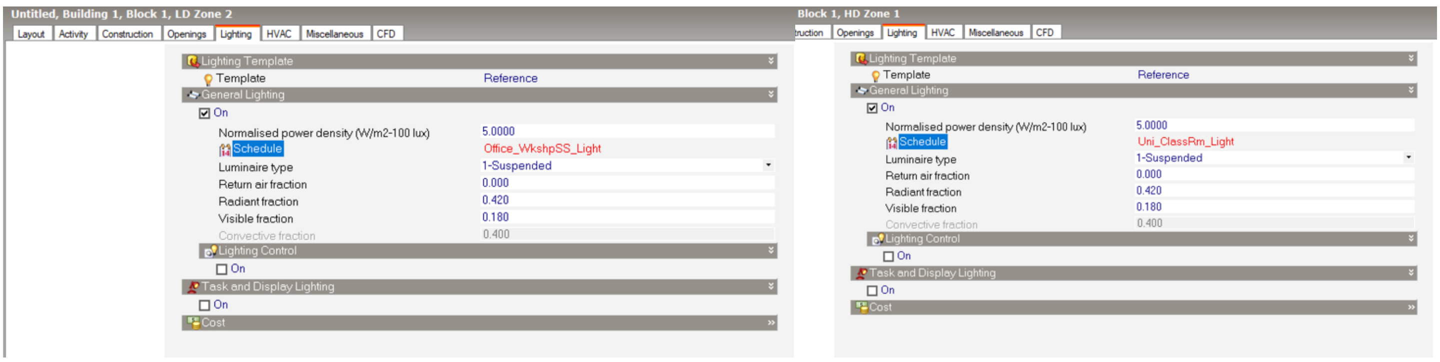


Figure 10. Screenshots showing change in lighting schedule to comply with occupancy

1.8 Temperature Analysis (Summer): It can be observed that the high-density zone (HDZ) with heavy weight construction has an almost constant trend of daily indoor temperatures through the week, oscillating between 22 °C and 32 °C. The low-density zone (LDZ) with light weight construction, shows temperatures below the HDZ for the first two days as it isn't in full operation and for the rest of the days shows similar trends as the HDZ except has more extreme peak temperatures. This can be explained by the construction composition. The lightweight construction, having a lower thermal mass, has higher thermal conductivity, thus it is a better conductor of change in temperature. It is noteworthy that when the LDZ is not in full operation, the indoor temperature also drops below the outside temperature. For all other times, the indoor temperature is well above the outdoor temperature.

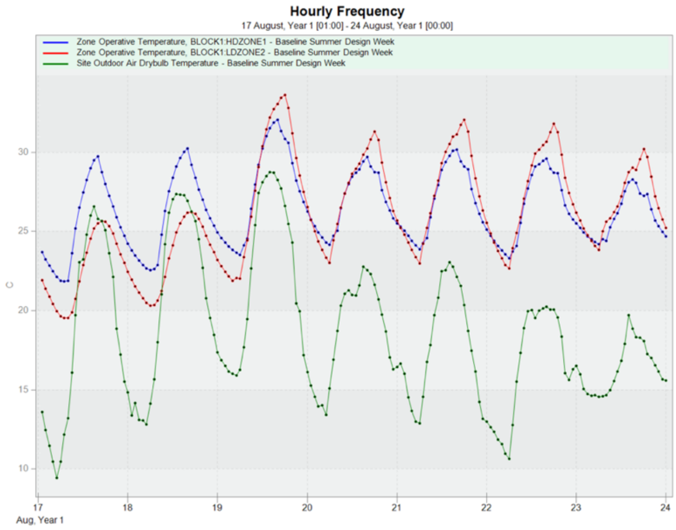


Figure 11. Graph comparing Operative Temperatures of Zone 1 and 2 with the Outdoor Drybulb Temperature during Summer Design week

Temperature Analysis (Winter): It can be observed that the indoor temperature for both zones always remains well above the outdoor temperature, indicating the success of winter heating strategies. The operative temperatures of both zones are similar and follow the same general trend. As observed in summer, the LDZ due to its lightweight construction tends to have more extreme peaks in temperature owing to its lower thermal mass.

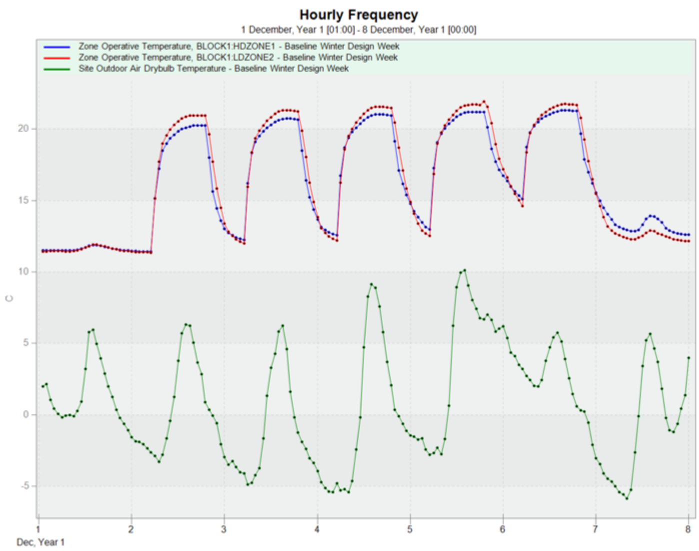


Figure 12. Graph comparing Operative Temperatures of Zone 1 and 2 with the Outdoor Drybulb Temperature during Winter Design week

Internal Heat Gains (Summer): The internal latent gain energy of both zones appears only when the zone is in use and is 0 otherwise. It reaches a peak of over 2300 W for the low-density lightweight zone 2 and just over 2000 W for the high-density heavyweight zone 1. The higher gains in zone 2 are explained by its lightweight construction, which is more susceptible to fluctuations in heat than the heavyweight construction. The people sensible heating rate reaches a sudden peak at the beginning of every day's occupancy period but steadily decreases through the occupied time for both zones. This is an evidence of a successful building cooling strategy. Both zones have similar people sensible heating rates with the low-density zone reducing below the high-density zone towards the end of its occupancy. This is due to the difference in occupancy density of the two zones.

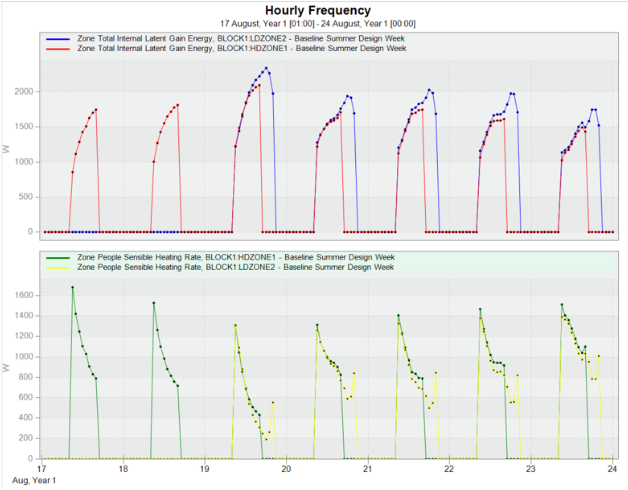


Figure 13. Graph comparing Internal Heat Gains of Zone 1 and 2 during Summer Design week

Internal Heat Gains (Winter): In contrast to the summer, both people sensible heating as well as internal latent heat gain remain largely constant during the occupied periods and through the week. This can be correlated to a relatively steadier trend of indoor temperature during the winter. The total internal latent gain peaks to almost 800 W daily for both zones. However, a slight increase is seen towards the end for the lightweight zone which can be explained by its construction. The people sensible heating rate peaks to about 1800 W for both zones but interestingly the low-density zone shows a peak towards the daily end. Since this can't be explained by the nature of the occupant density it could be due to the nature of the activity (since the low-density zone assigned is a workshop which involves more physical exertion than the high-density zone university). There is also a daily midday dip for the high-density zone to 1300 W.

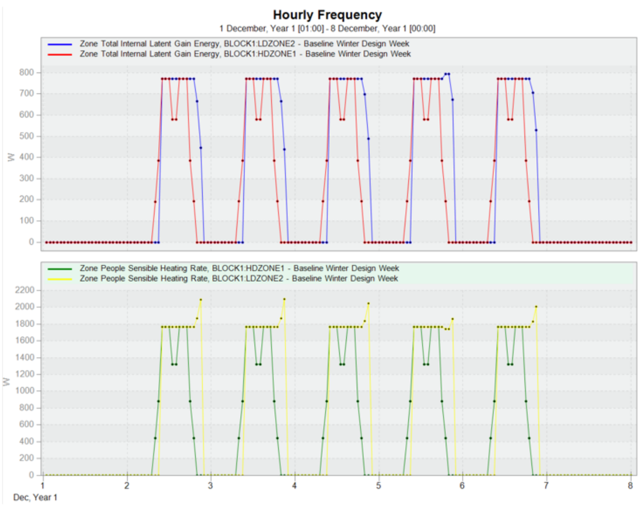


Figure 14. Graph comparing Internal Heat Gains of Zone 1 and 2 during Winter Design week

Surface Transfers: The graphs show a comparison of each correlating surface of both zones during the summer and winter design weeks. In EnergyPlus “Surface Inside Face Conduction Heat Transfer Rate” is defined as “heat flow by conduction right at the inside face of an opaque heat transfer surface. A positive value means that the conduction is from just inside the inside face toward the inside face”. [1]
We observe a general trend that the fluctuations in the inside face conduction heat transfer are visible greater for zone 1 walls with heavyweight construction and it presents higher negative values that the lightweight construction. This is consistent with the high thermal mass of the heavyweight construction. These values are almost the same for the roof, ground, and wall with doors for both the zones. The inside face conduction rate presents higher negative values during the winter simulations in comparison to the summer.

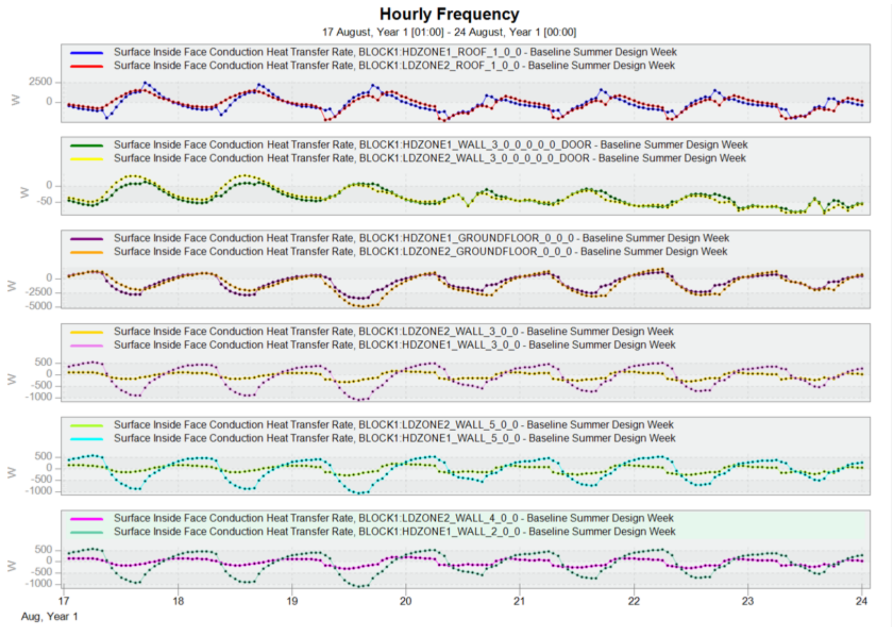


Figure 15. Graph comparing Surface Transfers of Zone 1 and 2 during Summer Design week

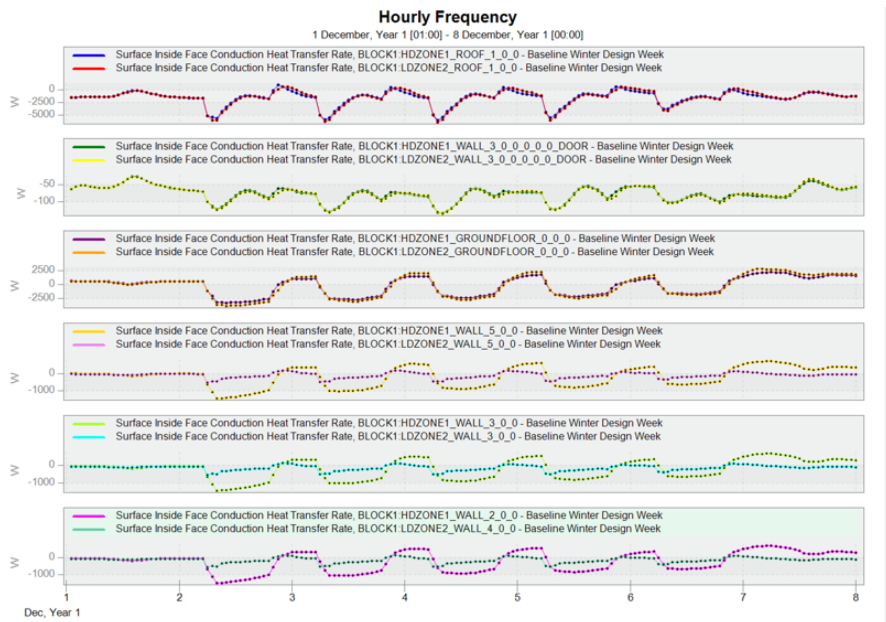


Figure 16. Graph comparing Surface Transfers of Zone 1 and 2 during Winter Design week

Zone Heating Demand (Summer): During the summer simulations, the heavyweight zone 1 does not show any zone heating demands owing to the high thermal mass and consequently high thermal absorption of its construction. However, the lightweight zone 2 with lower thermal absorption is unable to retain heat and hence requires some zone heating at periods sudden outdoor temperature drops.

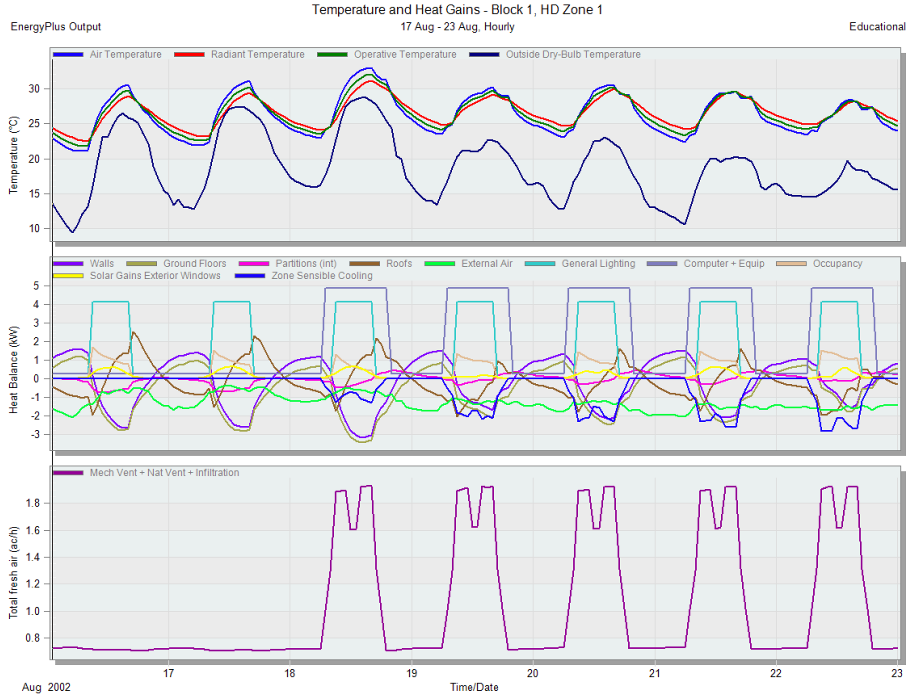


Figure 17. Graph showing Temperature and Heat Gains of Zone 1 during Summer Design Week

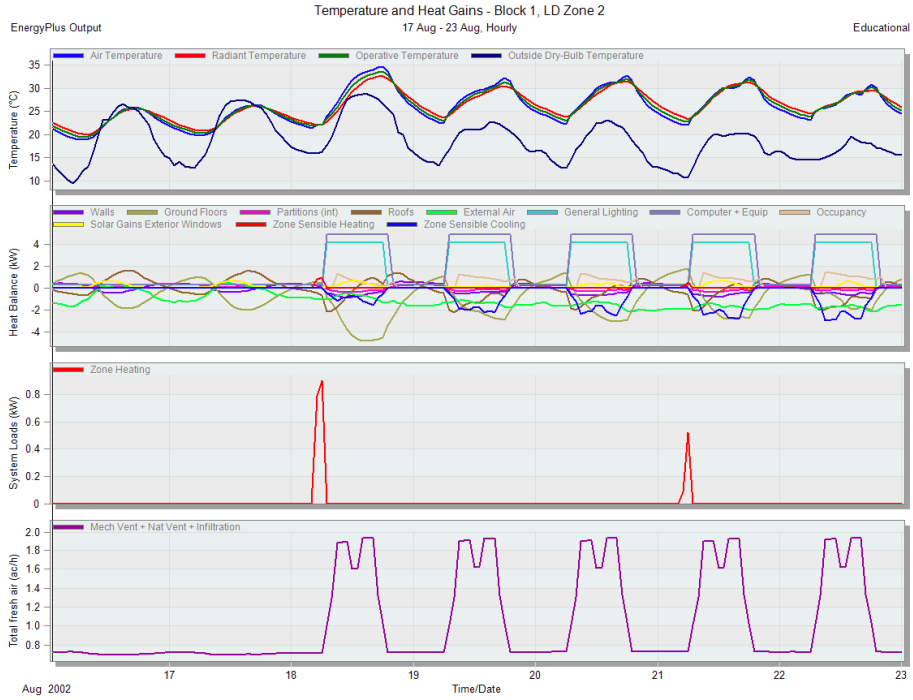


Figure 18. Graph showing Temperature and Heat Gains of Zone 2 during Summer Design Week

Zone Heating Demand (Winter): Both the zones present similar trends in zone sensible heating but on close observation it can be established that the zone heating requirements are slightly greater for the lightweight zone owing to its low thermal mass and poor ability of heat retention. These values present a daily peak of about 15 kW through the simulated week.

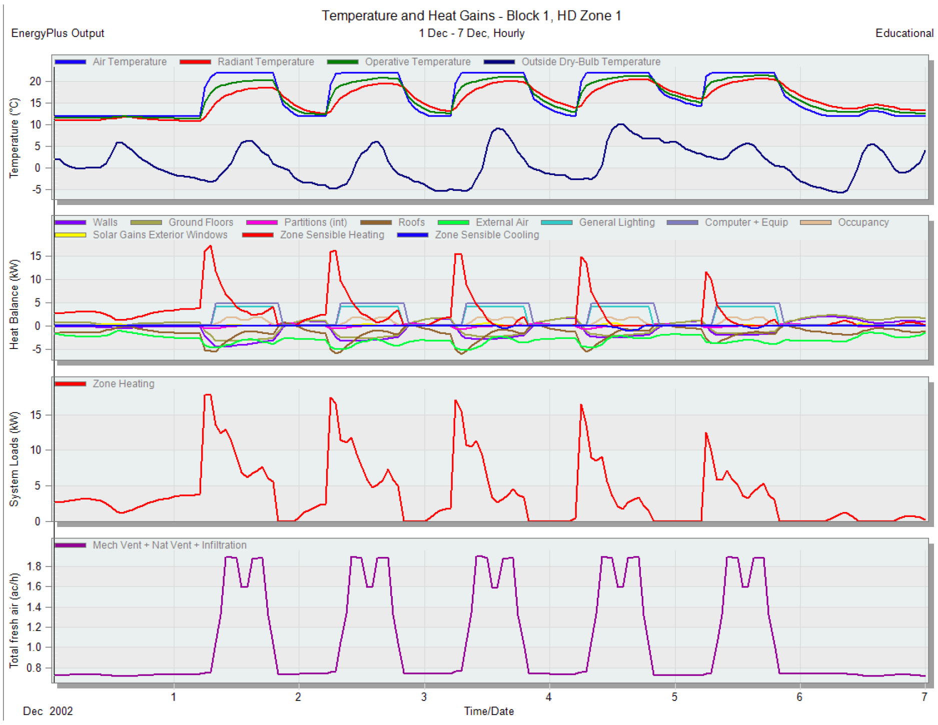


Figure 19. Graph showing Temperature and Heat Gains of Zone 1 during Winter Design Week

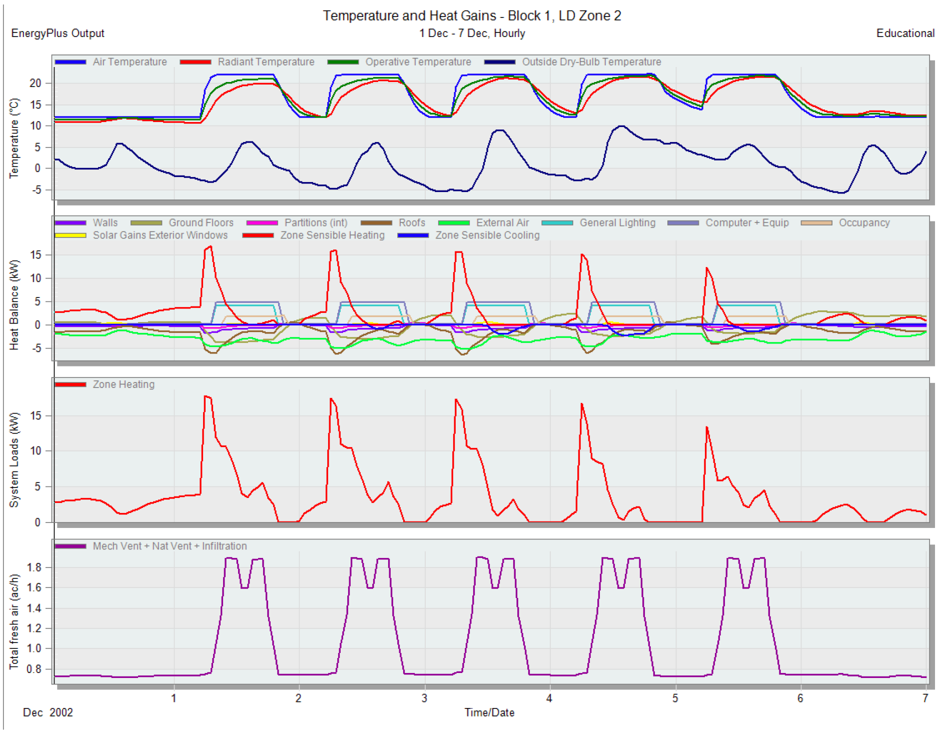


Figure 20. Graph showing Temperature and Heat Gains of Zone 2 during Winter Design Week

1.9 Overheating Analysis

According to the CIBSE TM52 guide[3], the overheating risk assessments of buildings is done using three criterions:

1. Hours of Exceedance
2. Daily Weighted Exceedance
3. Upper Limit Temperature

The building is said to have an overheating risk if it fails in any two of the above three criterion. However, for the sake of simplification, in this coursework the building is assessed using only one of the above criteria, i.e. the Upper Limit Criterion.

This criterion is based upon the comparison of the Operative Temperature to a set Absolute Maximum Value. CIBSE defines the parameter ΔT as the difference between the Operative Temperature and Absolute Maximum Temperature:

$\Delta T = T_{op} - T_{max}$

The difference ΔT should not exceed 4 K, i.e., $|\Delta T| \leq 4$ K.

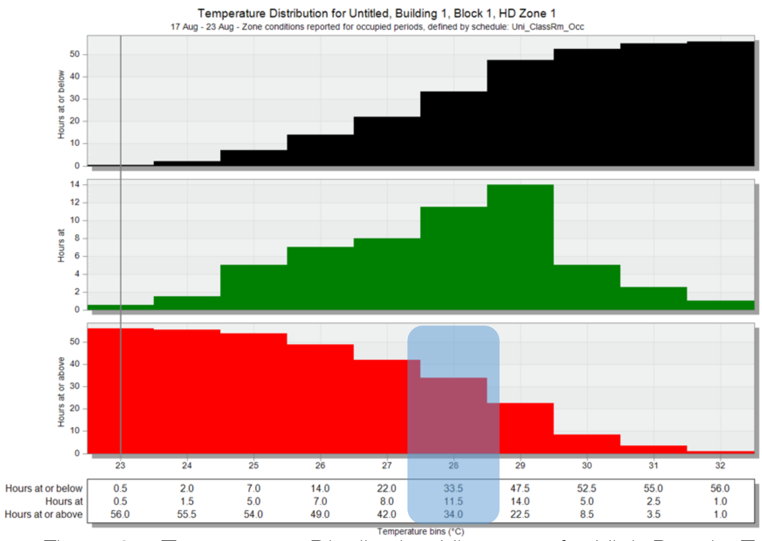
According to the CIBSE Guide A[4], the recommended value for 'Indoor Design Operative Temperature' is 25 °C.

If we take ΔT = - 3 K or 4 °C and T_{op} = 25 °C

- ⇨ $T_{max} = T_{op} - \Delta T$
- ⇨ T_{max} = 25 °C + 3 °C
- ⇨ T_{max} = 28 °C

Hence, the set Absolute Maximum Value of the Temperature is 28 °C

The CIBSE TM52 guide suggests limiting the expected occurrence of operative temperatures above 28 °C to 1% of the annual occupied period, i.e., about 25-30 hours.



	23	24	25	26	27	28	29	30	31	32
Hours at or below	0.5	2.0	7.0	14.0	22.0	33.5	47.5	52.5	55.0	56.0
Hours at	0.5	1.5	5.0	7.0	8.0	11.5	14.0	5.0	2.5	1.0
Hours at or above	56.0	55.5	54.0	49.0	42.0	34.0	22.5	8.5	3.5	1.0

Figure 21. Temperature Distribution Histogram for High Density Zone 1

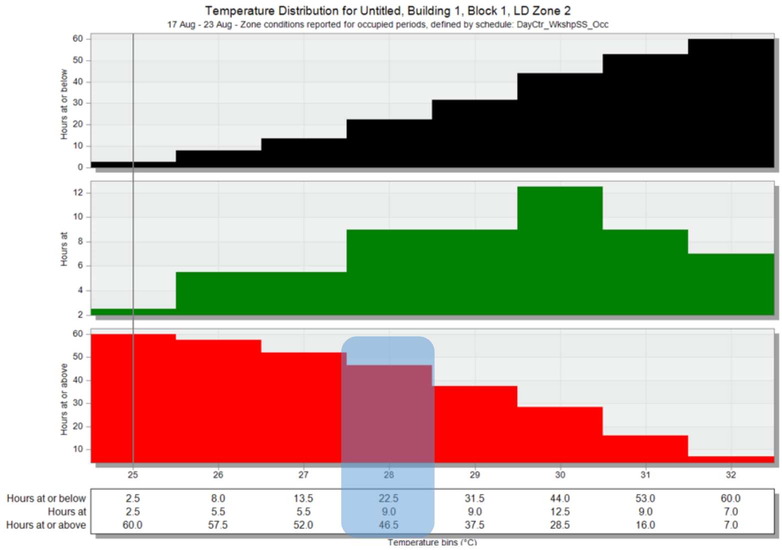


Figure 22. Temperature Distribution Histogram for Low Density Zone 2

It is observed that during the Summer Design Week, the high-density heavyweight Zone 1 overheats for 34 hours, and the low-density lightweight Zone 2 overheats for 46.5 hours.

Calculating the percentage of risk of overheating
P = (hours above 28 °C/ total operating hours) x 100

For high density zone
P_{HDZ} = (34/56) x 100
⇨ ***P_{HDZ} = 60.71 %***

For low density zone
P_{LDZ} = (46.5/60) x 100
⇨ ***P_{LDZ} = 77.5 %***

It is observed that the high-density heavyweight zone presents a lower percentage risk of overheating (60.71 %) in comparison to the low-density lightweight zone (77.5 %). This can be owed to the construction of the zones as a heavyweight construction is more susceptible to resist extreme fluctuations in temperature than lightweight constructions.

STAGE 2 : PERFORMANCE OPTIMIZATION

2.1 Assess the reduction in overheating risk –

A) Natural Ventilation

Natural Ventilation is turned on for both zones for the scheduled occupancy periods and the following results are observed for Summer Design Week Simulations.

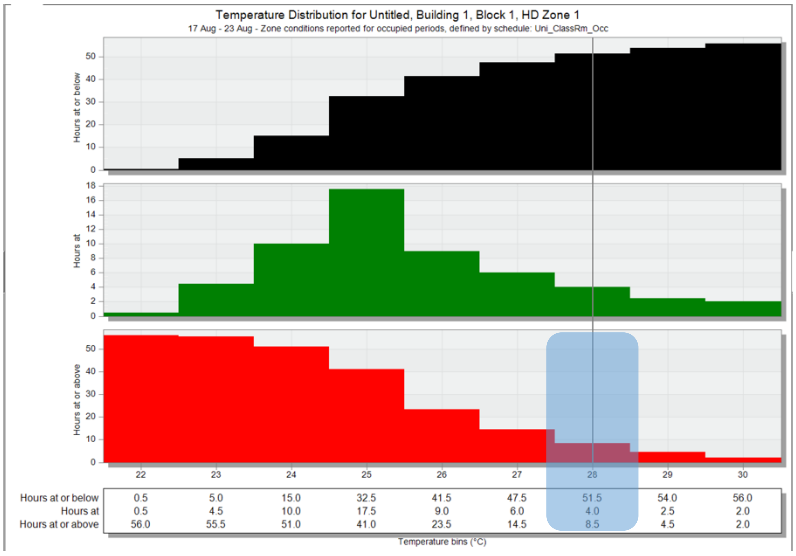


Figure 23. Temperature Distribution Histogram for High Density Zone 1 after adopting Natural Ventilation Strategy

$$P_{HDZ}(NV) = (8.5/56) \times 100$$
$$\Rightarrow \; P_{HDZ}(NV) = 15.18\ \%$$

$$\Delta P_{HDZ}(NV) = P_{HDZ} - P_{HDZ}(NV)$$
$$\Rightarrow \; \Delta P_{HDZ}(NV) = 60.71 - 15.18\ \%$$
$$\Rightarrow \; \Delta P_{HDZ}(NV) = 45.53\ \%$$

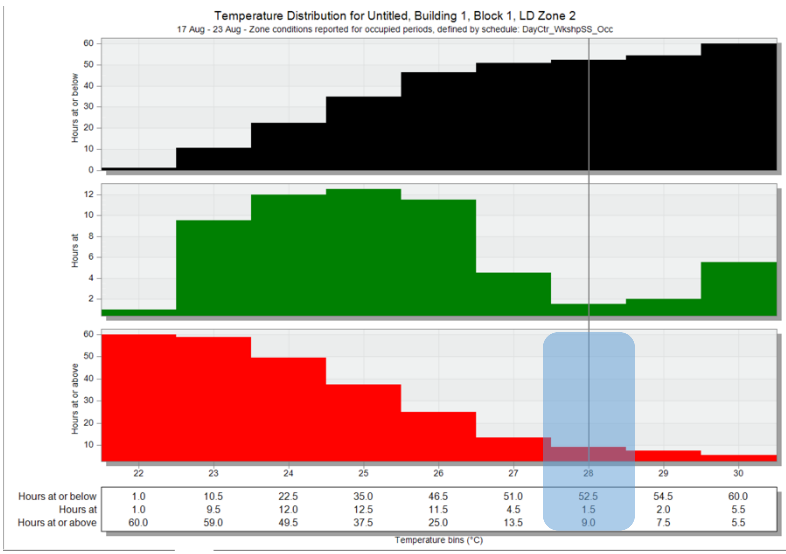


Figure 24. Temperature Distribution Histogram for Low Density Zone 2 after adopting Natural Ventilation Strategy

$$P_{LDZ}(NV) = (9/60) \times 100$$

$$\Rightarrow \; P_{LDZ}(NV) = 15\ \%$$

$$\Delta P_{LDZ}(NV) = P_{LDZ} - P_{LDZ}(NV)$$

$$\Rightarrow \; \Delta P_{LDZ}(NV) = 77.5 - 15\ \%$$

$$\Rightarrow \; \Delta P_{LDZ}(NV) = 62.5\ \%$$

B) Shading

In the openings tab, local shading with the template ' Overhang + Sidefins (1m projection)' are added to both zones in the building model and the following results are observed.

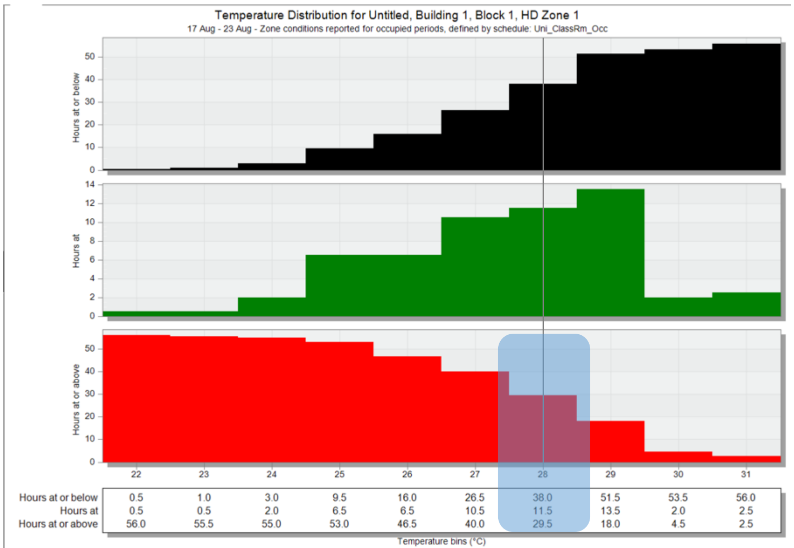


Figure 25. Temperature Distribution Histogram for High Density Zone 1 after adopting Shading Strategy

$$P_{HDZ}(S) = (29.5/56) \times 100$$

$$\Rightarrow \; P_{HDZ}(S) = 52.68\ \%$$

$$\Delta P_{HDZ}(S) = P_{HDZ} - P_{HDZ}(S)$$

$$\Rightarrow \; \Delta P_{HDZ}(S) = 60.71 - 52.68\ \%$$

$$\Rightarrow \; \Delta P_{HDZ}(S) = 8.03\ \%$$

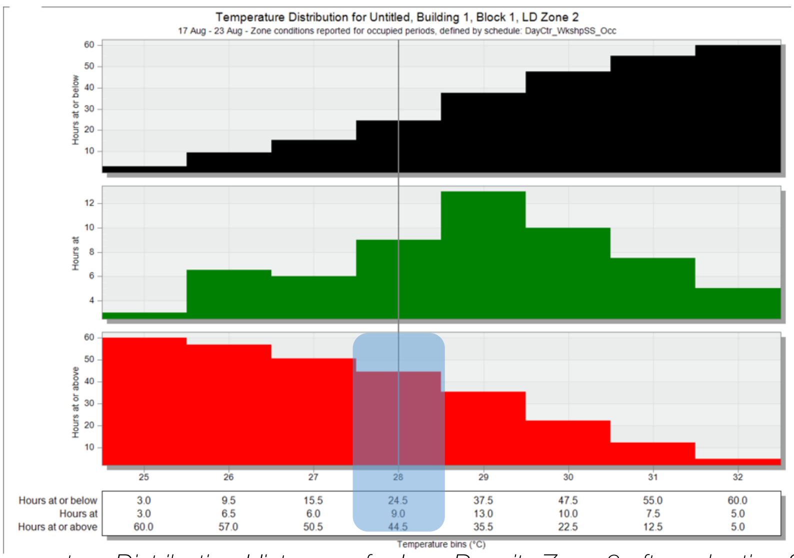


Figure 26. Temperature Distribution Histogram for Low Density Zone 2 after adopting Shading Strategy

$$P_{LDZ}(S) = (44.5/60) \times 100$$

$$\Rightarrow \ P_{LDZ}(S) = 74.17\ \%$$

$$\Delta P_{LDZ}(S) = P_{LDZ} - P_{LDZ}(S)$$

$$\Rightarrow \ \Delta P_{LDZ}(S) = 77.5 - 74.17\ \%$$

$$\Rightarrow \ \Delta P_{LDZ}(S) = 3.33\ \%$$

C) Construction Assemblies Change

The following changes are made to both the zones:
1. Glazing changed to Triple Glazing Template ' Trp Clr 3mm/13mm Air '
2. Shading Template 'Overhang + sidefins (1m projection)'
3. Wall insulation layer (XPS extruded polysterine) thickness changed to 0.3 m

Results from Summer Design Week Simulations are observed.

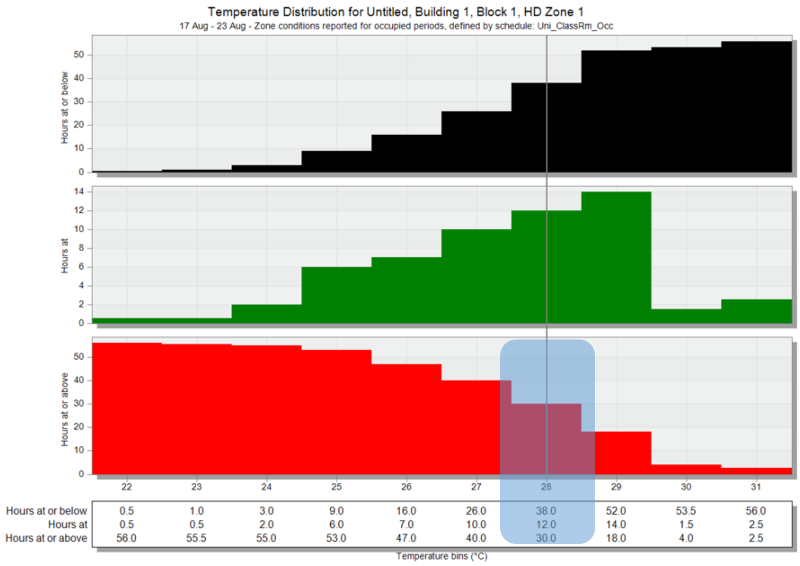


Figure 27. Temperature Distribution Histogram for High Density Zone 1 after adopting Construction Assemblies Change Strategy

$$P_{HDZ}(CA) = (30/56) \times 100$$

$$\Rightarrow \ P_{HDZ}(CA) = 53.57\ \%$$

$$\Delta P_{HDZ}(CA) = P_{HDZ} - P_{HDZ}(CA)$$

$$\Rightarrow \ \Delta P_{HDZ}(CA) = 60.71 - 53.57\ \%$$

$$\Rightarrow \ \Delta P_{HDZ}(CA) = 7.14\ \%$$

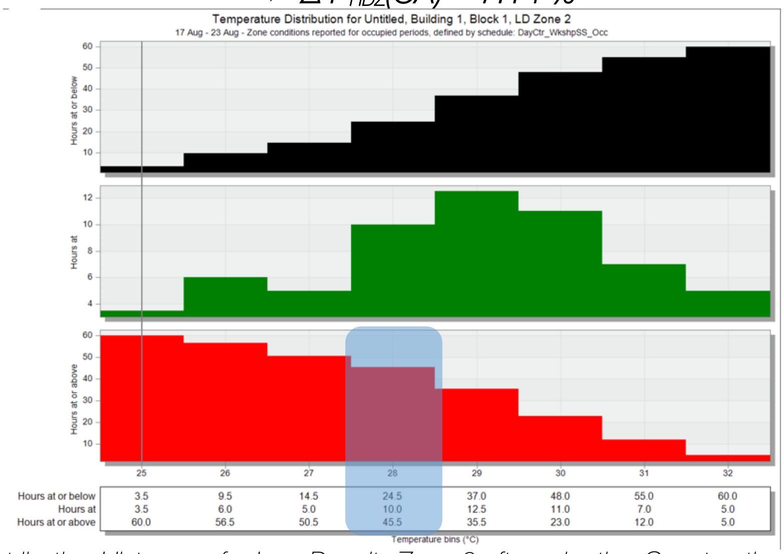


Figure 28. Temperature Distribution Histogram for Low Density Zone 2 after adopting Construction Assemblies Change Strategy

⇨ $P_{LDZ}(S) = 75.83$ %

$\Delta P_{LDZ}(S) = P_{LDZ} - P_{LDZ}(S)$

⇨ $\Delta P_{LDZ}(S) = 77.5 - 75.83$ %

⇨ $\Delta P_{LDZ}(S) = 1.67$ %

STRATEGY	ZONE	% RISK OF OVERHEATING	% RISK REDUCTION DUE TO STRATEGY
Natural Ventilation	Zone 1	15.8 %	45.53 %
	Zone 2	15 %	62.5 %
Shading	Zone 1	52.68 %	8.03 %
	Zone 2	74.17 %	3.33 %
Changing Construction Assemblies	Zone 1	53.57 %	7.14 %
	Zone 2	75.83 %	1.67 %

Table 1. Comparison of reduction in overheating risk from the 3 strategies

It is clearly deducible from the above calculations and comparison that of all the three strategies adopted, the strategy of added natural ventilation is the most effective followed by the addition of shading and the changing of construction assemblies the least effective. It is also noteworthy that natural ventilation is the only strategy that can significantly lower the overheating risk of the lightweight zone 2. This is explained by the simple fact that it works on the principle of introducing new air rather than lowering heat gains from external sources (shading + changing insulation).

2.2 Evaluating Heating Energy Consumption – After determining the reduction in risk due to overheating through different strategies the effect on heating loads must also be assessed.

A) Natural Ventilation : There is a slight increase in the zone heating requirements for the heavyweight zone 1 on application of natural ventilation, however lightweight zone 2 presents a significant change. Initially, zone heating peaked over 15 kW once daily, however, now the heating remains nearly constant at 15 kW through the occupancy period. Hence, there is an overall increase in the buildings heating requirements.

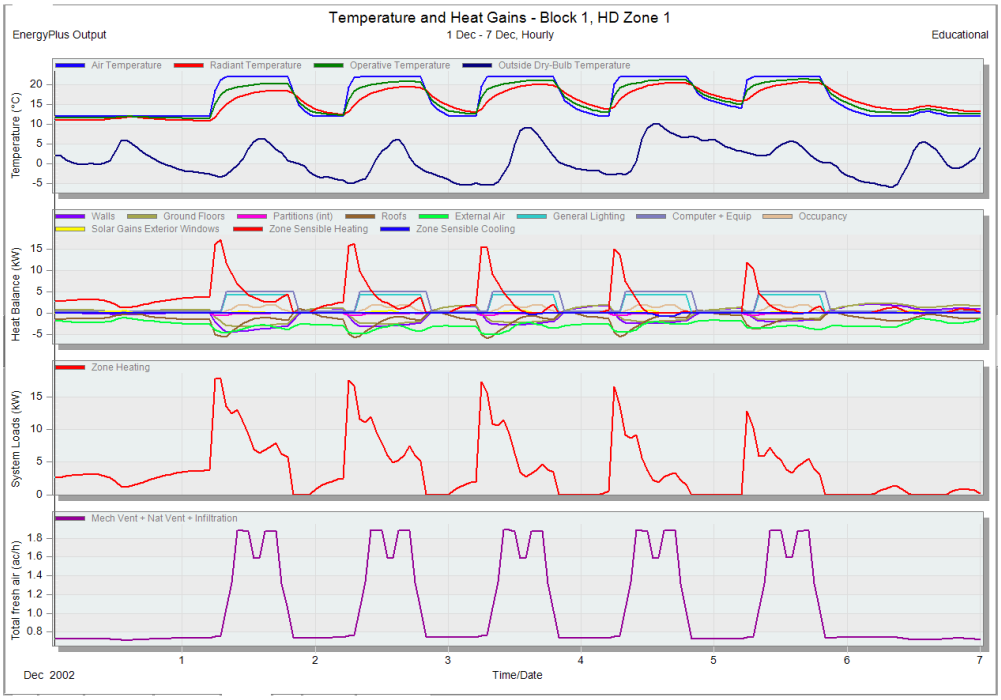


Figure 29. Graph showing Temperature and Heat Gains of Zone 1 with Natural Ventilation during Winter Design Week

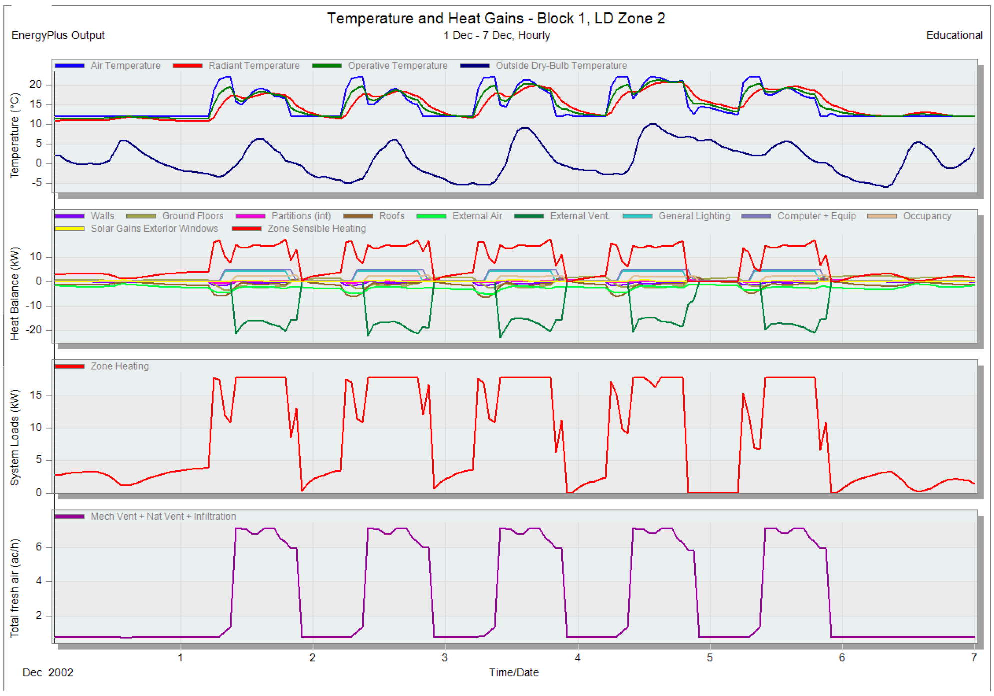


Figure 30. Graph showing Temperature and Heat Gains of Zone 2 with Natural Ventilation during Winter Design Week

B) Shading : The application of shading leads to a very subtle increase in the heating requirements of both zones. This could be explained by the small reduction in solar gains on the addition of shading. The maximum increase observed in both zones is under 0.1 kW

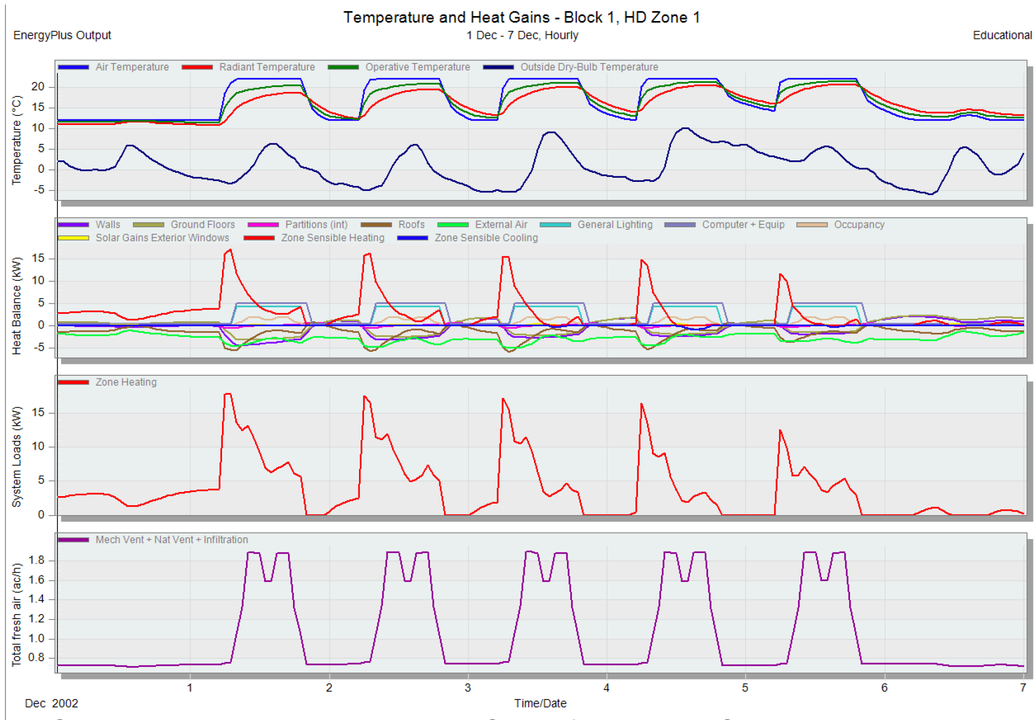


Figure 31. Graph showing Temperature and Heat Gains of Zone 1 with Shading during Winter Design Week

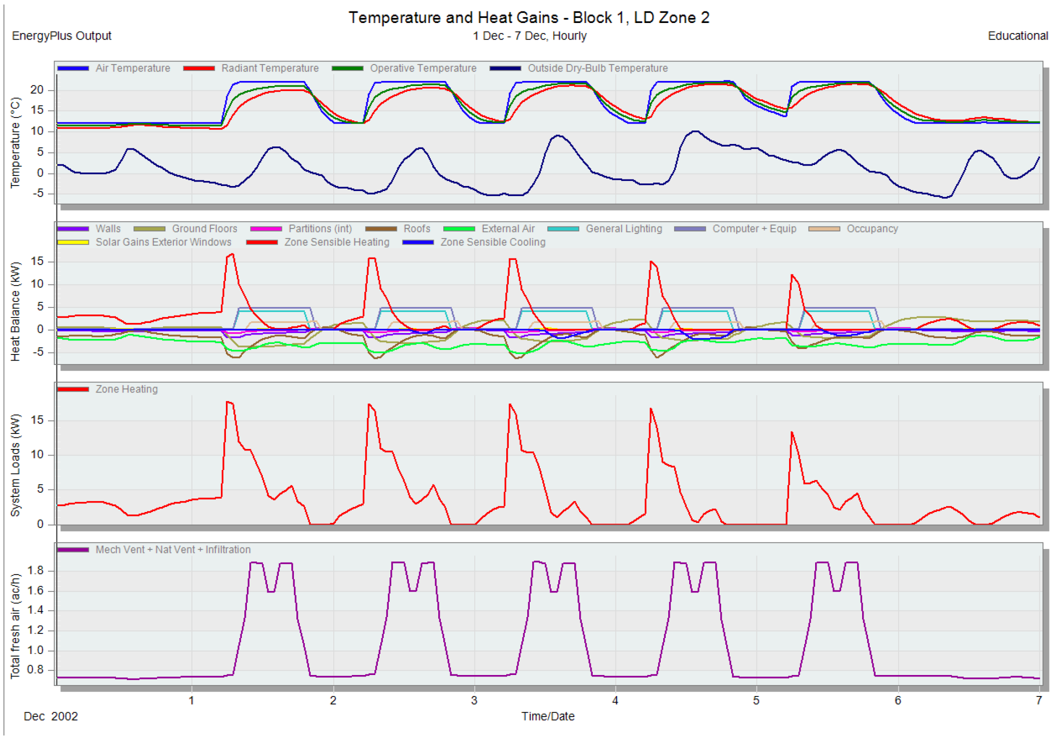


Figure 32. Graph showing Temperature and Heat Gains of Zone 2 with Shading during Winter Design Week

C) Construction Assemblies Change : The application of this strategy, unlike the first two, leads to a subtle decrease in the zone heating demands of both zones. This can be owed to the fact that the increase of insulation improved the heat retaining ability of the walls. The decrease in heating requirements was about 1 kW for zone 1 and under 1 kW for zone 2.

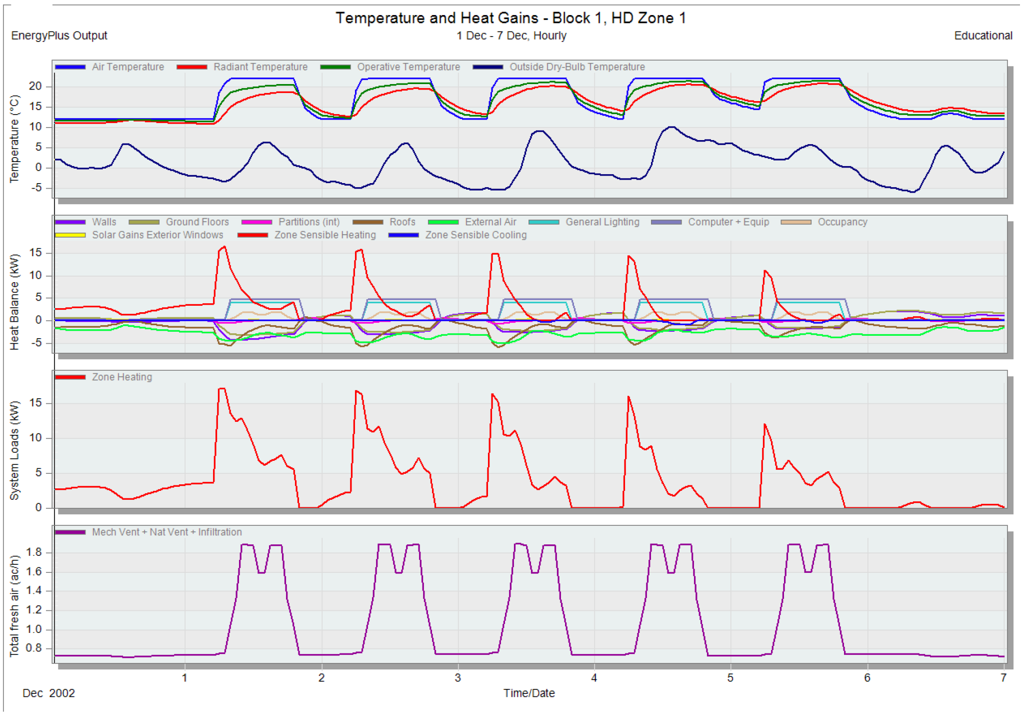


Figure 33. Graph showing Temperature and Heat Gains of Zone 1 with Changed Construction Assemblies during Winter Design Week

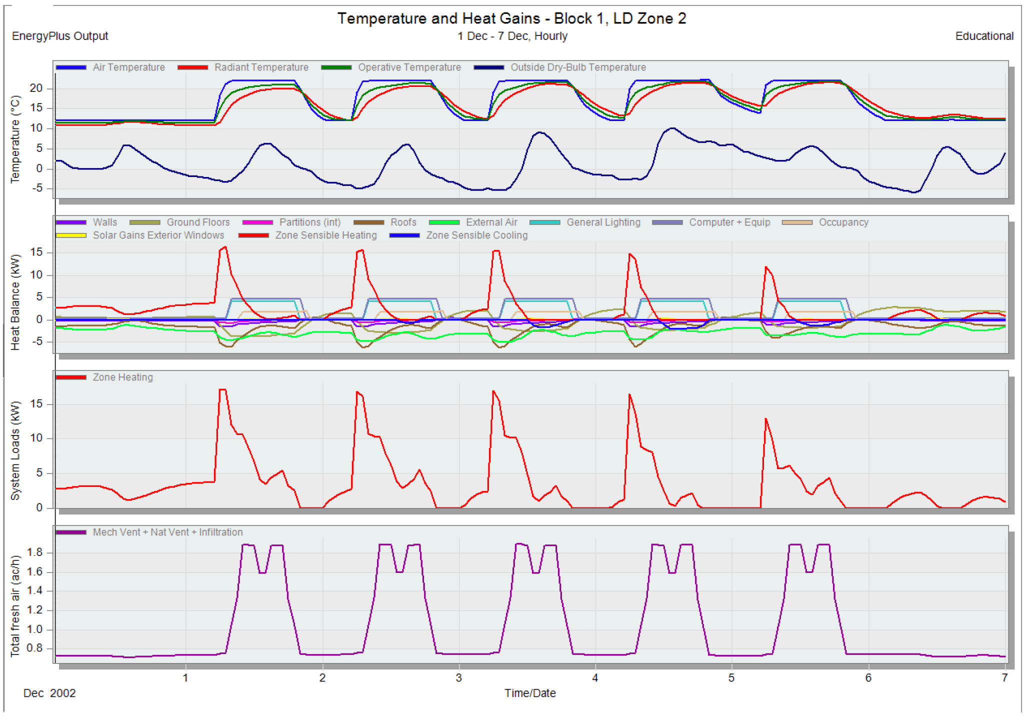


Figure 34. Graph showing Temperature and Heat Gains of Zone 2 with Changed Construction Assemblies during Winter Design Week

2.3 Exploring Strategy – Lighting Controls

It was observed that 'General Lighting was one of the biggest contributer to the internal heat gains and its heat gain reduction would greatly contribute to reducing overheating risks.

To reduce heat gains through 'General Lighting', the lighting controls for the two zones are customized.

The lighting template for Zone 1 from 'Reference' to the suggested ASHRAE 90.1-2016 Template for Schools and Universities 'Building Area Method, School/university, 8.72 W/m^2 at 100 lux'. The lighting template for Zone 2 from 'Reference' to the suggested ASHRAE 90.1-2016 Template for Workshops/Common Spaces 'Common Space, Workshop, 17.11 W/m^2 at 100 lux'.

Thereafter, lighting controls are turned on to optimize general lighting.

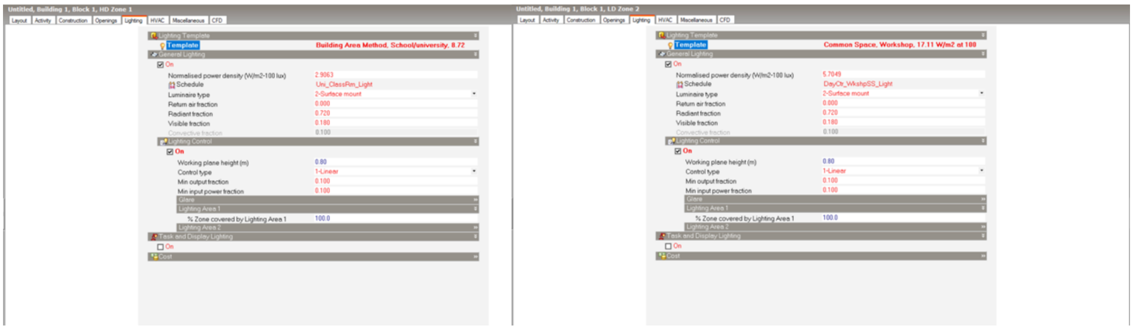


Figure 35. Screenshots showing customization of the lighting template for Zone 1 and Zone 2

Results from Summer Design Week Simulations are observed

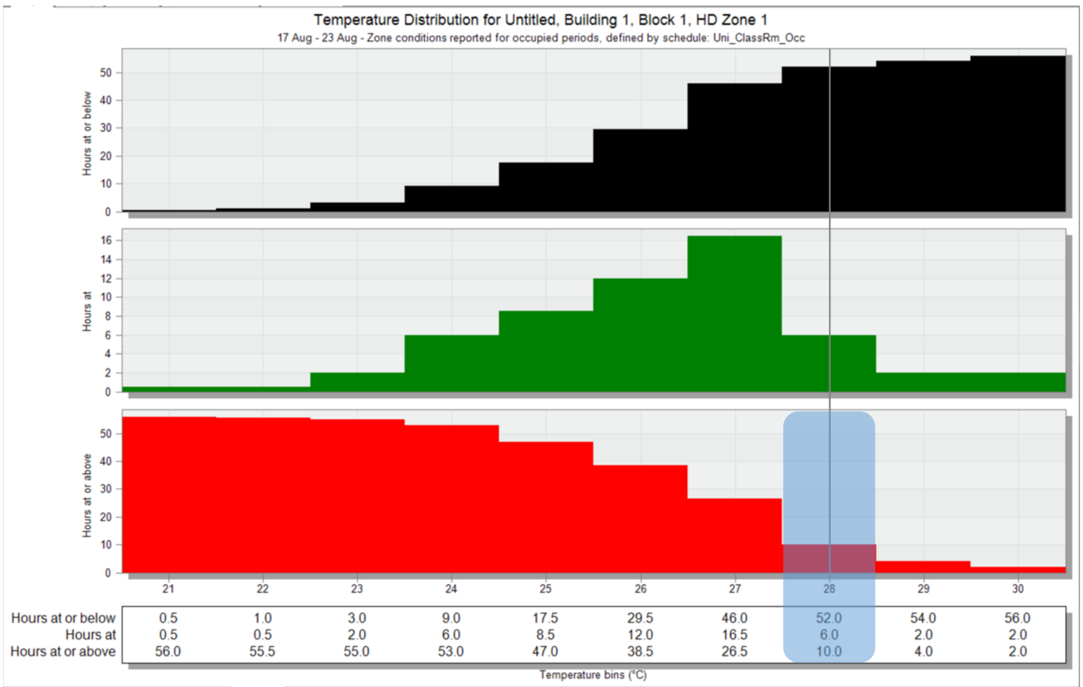


Figure 36. Temperature Distribution Histogram for High Density Zone 1 after adopting Lighting Control Strategy

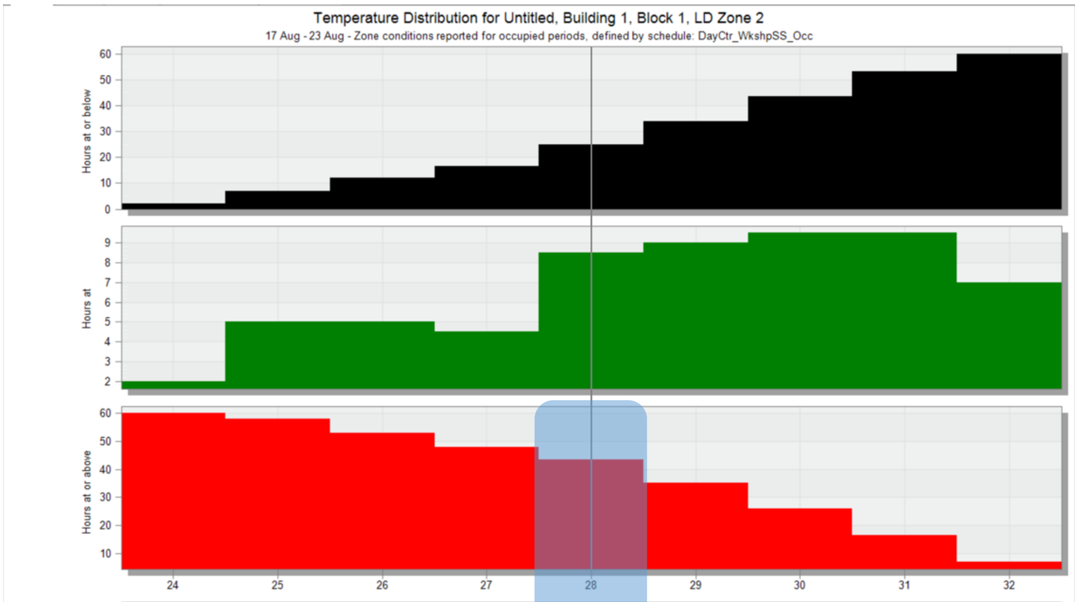
P_{HDZ}(Final) = (10/56) X 100

⇨ *P_{HDZ}(Final) = 17.86 %*

Δ P_{HDZ} (Final) = P_{HDZ} - P_{HDZ}(Final)

⇨ Δ P_{HDZ}(Final) = 60.71 – 17.86 %

⇨ *Δ P_{HDZ}(Final) = 42.85 %*



	24	25	26	27	28	29	30	31	32
Hours at or below	2.0	7.0	12.0	16.5	25.0	34.0	43.5	53.0	60.0
Hours at	2.0	5.0	5.0	4.5	8.5	9.0	9.5	9.5	7.0
Hours at or above	60.0	58.0	53.0	48.0	43.5	35.0	26.0	16.5	7.0

Figure 37. Temperature Distribution Histogram for Low Density Zone 2 after adopting Lighting Control Strategy

P_{LDZ}(Final) = (43.5/60) X 100

⇨ *P_{LDZ}(Final) = 72.5 %*

Δ P_{LDZ}(Final) = P_{LDZ} – P_{LDZ}(Final)

⇨ Δ P_{LDZ}(Final) = 77.5 – 72.5 %

⇨ *Δ P_{LDZ}(Final) = 5 %*

On comparing the outcome of this strategy with the first three, it was observed that it reduces overheating risk more efficiently than applying shading or changing the construction assemblies for both zones, but natural ventilation continues to be the most successful strategy out of the four when it comes to reducing overheating risk. This strategy causes a very slight increase (less than 0.1 kW) in heating demands.

2.4 'Trade-Offs' Encountered

On analyzing all four strategies in summer, it was observed that 'Natural Ventilation' was the most efficient in reducing overheating risks within the building, this was followed by 'Lighting Control' and then 'Shading' and 'Changing Construction Assemblies'. However, the analysis during the winter revealed that 'Natural Ventilation' caused the largest increase in zone heating requirements. It was followed by 'Lighting Control', 'Changing construction Assemblies' and finally 'Shading' which caused reduced zone heating. These can be observed holistically.

STRATEGY	ZONE	% OVERHEATING RISK REDUCTION	APPROX. INCREASE IN ZONE HEATING
Natural Ventilation	Zone 1	45.53 %	10 kW
	Zone 2	62.5 %	15 kW
Shading	Zone 1	8.03 %	0.1 kW
	Zone 2	3.33 %	0.1 kW
Changing Construction Assemblies	Zone 1	7.14 %	- 1 kW
	Zone 2	1.67 %	-1 kW
Lighting Control	Zone 1	42.85 %	0.2 kW
	Zone 2	5 %	0.1 kW

Table 2. Comparison of reduction in overheating risk and increase in zone heating of all the four strategies

The recommendation for the best strategy is the 'Lighting Control' strategy. This strategy causes a significant decrease in risk of overheating without causing a large increase in the zone heating requirements of the building. The Natural Ventilation strategy is rejected due to large increase in zone heating requirements. 'Changing Construction Assemblies' could be a potentially good strategy however, it involves adding a triple glazing, increasing insulation, and adding shading devices which significantly increase production cost. While 'Light Control' strategy also causes an increase in the production cost, 'Changing Construction Assemblies' causes a very small reduction in overheating risk and is hence not feasible.

STAGE 3 : FUTURE CLIMATE ANALYSIS

3.1 Future Simulation

Temperature Analysis:

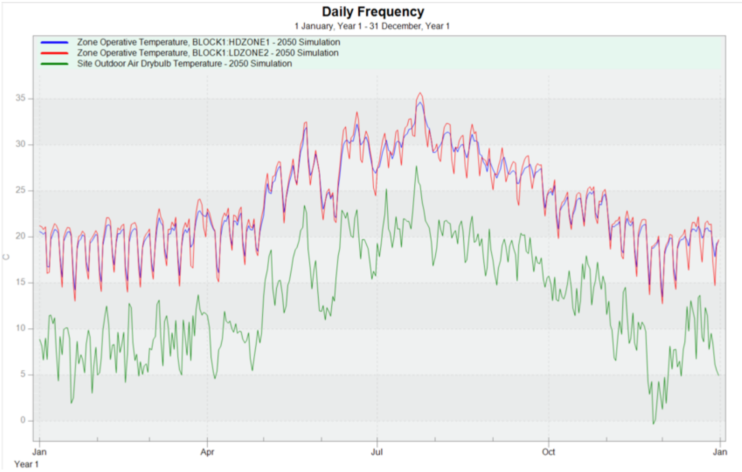


Figure 38. Graph comparing Operative Temperatures of Zone 1 and 2 with the Outdoor Drybulb Temperature for the year 2050

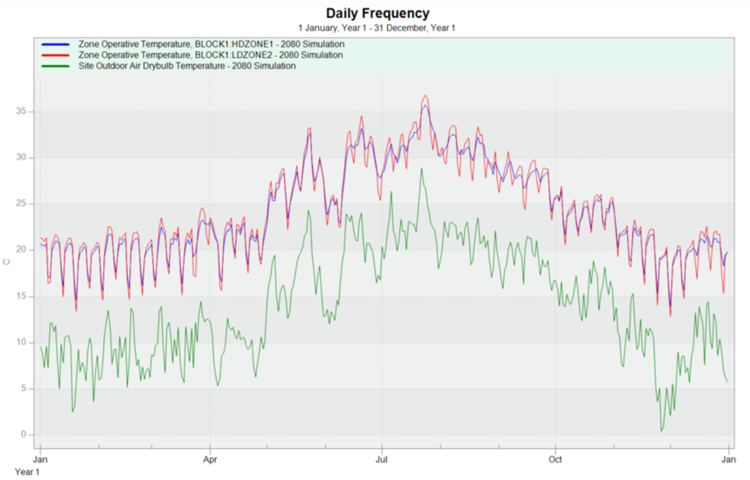


Figure 39. Graph comparing Operative Temperatures of Zone 1 and 2 with the Outdoor Drybulb Temperature for the year 2080

It can be observed that there is a slight increase in the outdoor temperature in 2050 and more in 2080. This change can be attributed to global warming. As before, we observe higher fluctuations in temperatures in the lightweight zone as compared to the heavyweight zone which is due to its low thermal mass and inability to resist changes in temperature. It can be noted that as the outdoor temperature increases from 2050 to 2080, the indoor temperature also increases. This increase is more for the lightweight zone than the heavyweight zone. This reiterates the fact that heavyweight constructions are more capable of resisting change in temperature.

Heat Gain and Comfort:

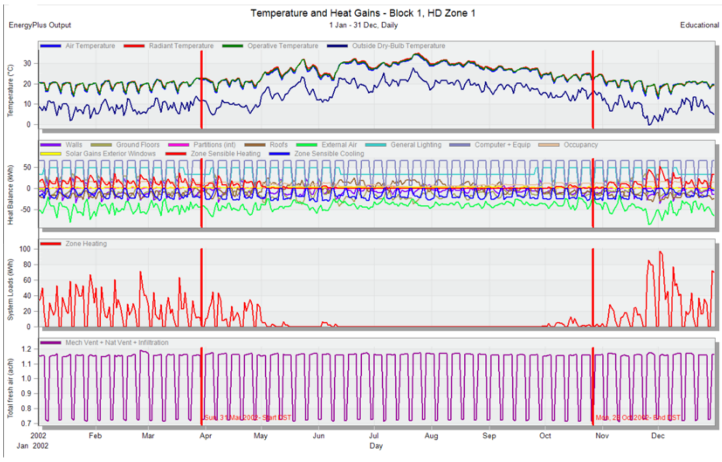


Figure 40. Graph showing Temperature and Heat Gains of Zone 1 in the Year 2050

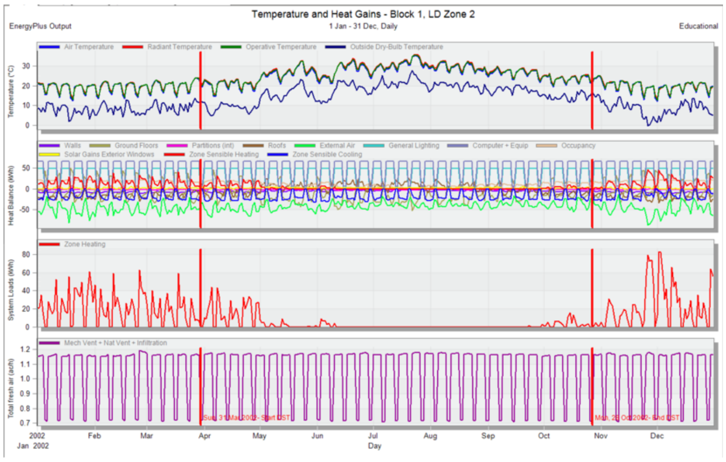


Figure 41. Graph showing Temperature and Heat Gains of Zone 2 in the Year 2050

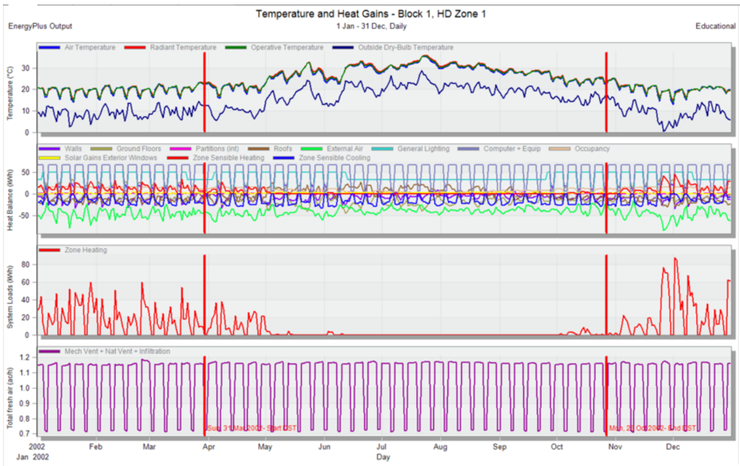


Figure 42. Graph showing Temperature and Heat Gains of Zone 1 in the Year 2080

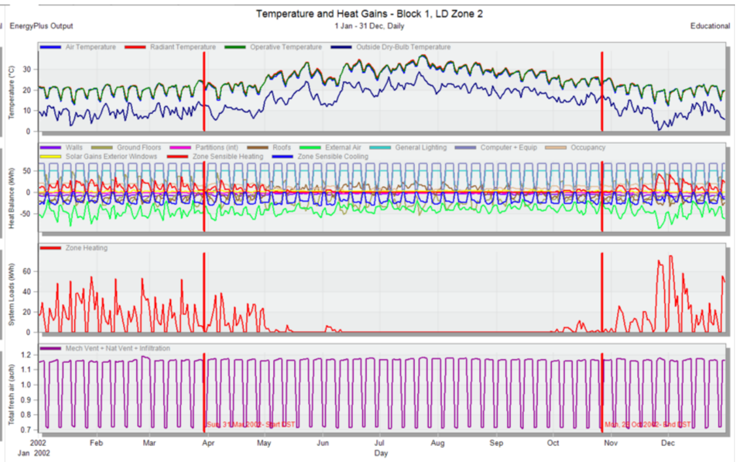


Figure 43. Graph showing Temperature and Heat Gains of Zone 2 in the Year 2080

On observing the zone heating loads, a significant decline in the heating loads can be seen from 2050 to 2080. This can be attributed to the change in temperature. Also, the heating loads are 0 for the summer months (July-Sept). This can be seen in contrast to the past analysis of the building wherein there were heating loads even during the summer.

Overheating:

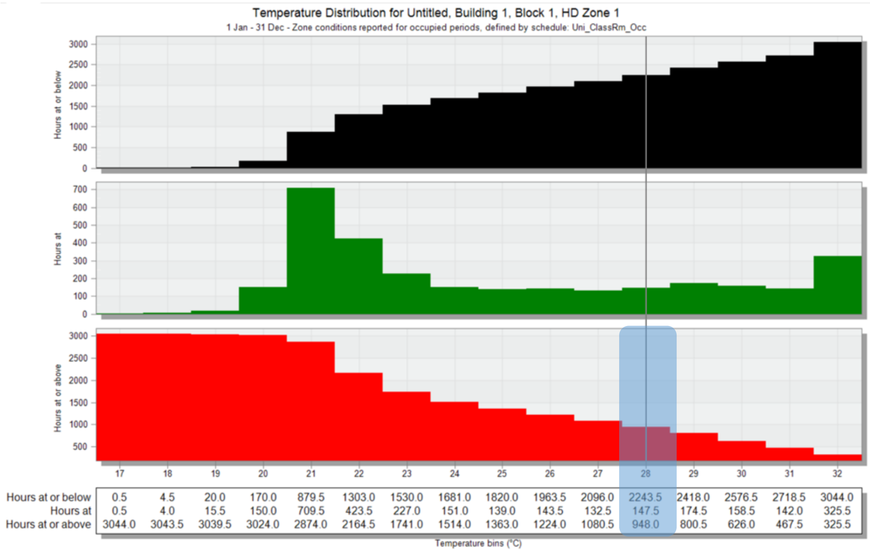


Figure 44. Temperature Distribution Histogram for High Density Zone 1 in the Year 2050

$$P_{HDZ}(2050) = (948/3044) \times 100$$

⇨ $P_{HDZ}(2050) = 31.14\ \%$

$$\Delta P_{HDZ}(2050) = P_{HDZ} - P_{HDZ}(2050)$$

⇨ $\Delta P_{HDZ}(2050) = 60.71 - 31.14\ \%$

⇨ $\Delta P_{HDZ}(2050) = 29.57\ \%$

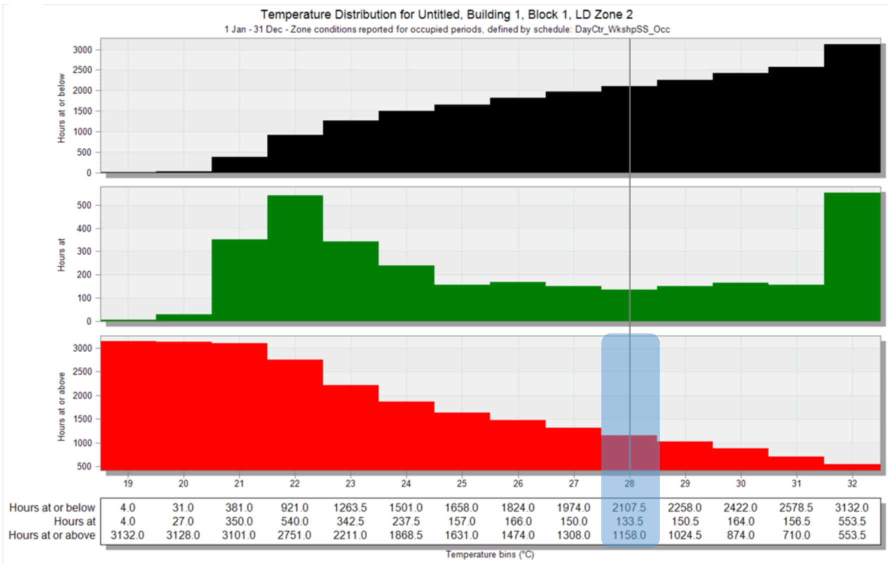


Figure 45. Temperature Distribution Histogram for Low Density Zone 2 in the Year 2050

$$P_{LDZ}(2050) = (1158/3132) \times 100$$

⇨ $P_{LDZ}(2050) = 36.97\ \%$

$$\Delta P_{LDZ}(2050) = P_{LDZ} - P_{LDZ}(2050)$$

⇨ $\Delta P_{LDZ}(2050) = 77.5 - 36.97\ \%$

⇨ $\Delta P_{LDZ}(2050) = 40.53\ \%$

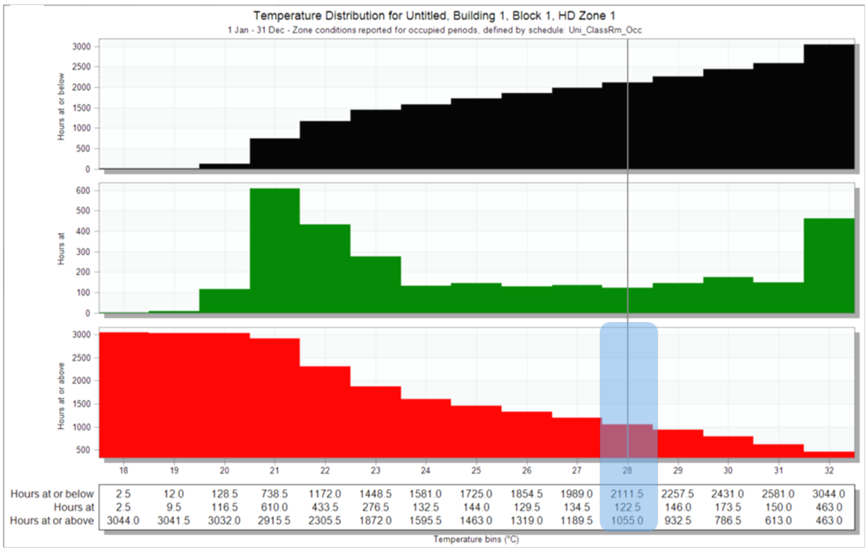


Figure 46. Temperature Distribution Histogram for High Density Zone 1 in the Year 2080

$$P_{HDZ}(2080) = (1055/3044) \times 100$$

⇨ $\mathit{P_{HDZ}(2080) = 34.66\ \%}$

$$\Delta P_{HDZ}(2080) = P_{HDZ} - P_{HDZ}(2080)$$

⇨ $\Delta P_{HDZ}(2080) = 60.71 - 34.66\ \%$

⇨ $\mathit{\Delta P_{HDZ}(2080) = 25.51\ \%}$

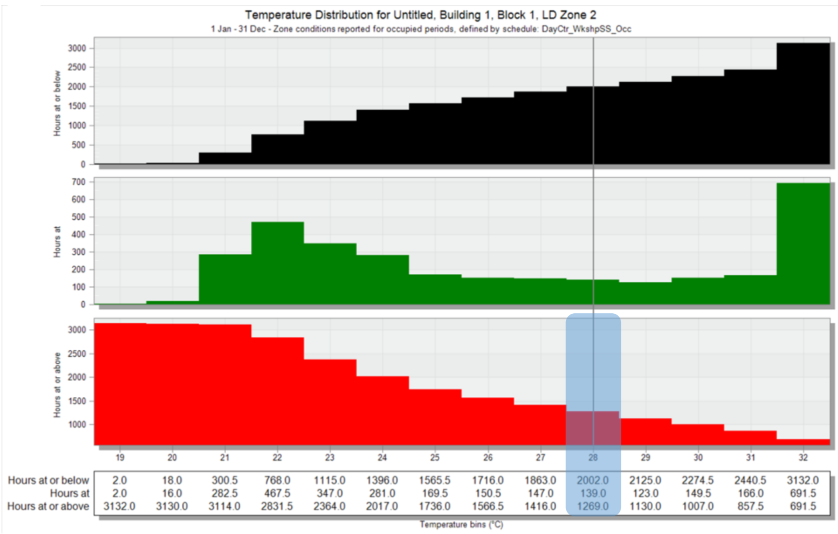


Figure 45. Temperature Distribution Histogram for Low Density Zone 2 in the Year 2080

$$P_{LDZ}(2080) = (1269/3132) \times 100$$

⇨ $\mathit{P_{LDZ}(2080) = 40.52\ \%}$

$$\Delta P_{LDZ}(2080) = P_{LDZ} - P_{LDZ}(2080)$$

⇨ $\Delta P_{LDZ}(2080) = 77.5 - 40.52\ \%$

⇨ $\mathit{\Delta P_{LDZ}(2080) = 36.98\ \%}$

YEAR	ZONE	% RISK OF OVERHEATING	% RISK REDUCTION DUE TO STRATEGY
2050	Zone 1	31.14 %	29.57 %
	Zone 2	36.97 %	40.53 %
2080	Zone 1	34.66 %	25.52 %
	Zone 2	40.52 %	36.98 %

Table 3. Comparison of reduction in overheating risk for Years 2050 and 2080

It is observed that the overheating risk appears to increase with time. This increase reaches far beyond the desired acceptable value which makes it important to re-assess the building strategy to optimize future use of the building.

3.2 Re-evaluation of Building Performance

Due to the rising temperatures, it is important to re-assess the heating strategy of the building to optimize future use. It was observed that in the years 2050 and 2080, the risk of overheating begins to exceed the acceptable amount. To overcome this, a controlled natural ventilation strategy could be introduced into the building design. This would help lower the overheating risk significantly as observed previously. Since in 2050 and 2080, there is a decrease in heating demands, it would overcome the issue of increased heating demand on using Natural Ventilation. To further optimize the Natural Ventilation Strategy, the Natural Ventilation Setpoint temperature could be specified and controlled using sensors. This would prevent overcooling of the building and release the pressure on the zone sensible heating. To further improve the building performance, other strategies such as lighting control and introduction of shading could also be introduced to reduce overheating risks. Another factor to be considered is the temperature fluctuation in the lightweight zone of the building. This could be overcome by making the entire building construction heavyweight. The high thermal mass of heavy weight constructions would evidently increase the building's ability to resist changes in external temperatures through the years.

3.3 Discussing Limitations

In making future predictions of any kind, it is normal to have inconsistencies. Since the data files are predictions based on general trends, they are not completely accurate, and the results can be expected to vary. Another limitation is that the analysis is done on a yearly basis and the daily and hourly trends were not analyzed, hence, the building's reaction could fluctuate more or less than predicted. It is also uncertain whether the function of the building would remain the same through the passage of years. The building could potentially be used differently in the future which would change the occupancy schedule from what it was designed to accommodate. Finally, with the obscure nature of global warming, it can be hard to predict exactly what turn climate change would take in the future and so we cannot ascertain the climate of the future.

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