Assessment of Mitigation Strategies for Urban Heat Island Effect in Open High Rise Residential Areas of Delhi, India

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Abstract: Increasing awareness of the urban heat island (UHI) effect has raised attention about the thermal comfort in cities worldwide. Several studies in the last decades have revealed how critical the UHI effect can be in a cold climate, Mediterranean climate. As a result, there is a need of study for composite climate like Delhi to reduce heat islands in urban areas. A lot of research on mitigation strategy has been done, but most of them considered with one or two variables like mostly are green, blue landscape and widely use of remote sensing data, LCZ -LST relationship. To the best of our knowledge no study has been carried out on the Integrated mitigation approach in composite climate. This study evaluates different UHI mitigation strategies in high rise residential area of Delhi selected according to their building density (LCZ Classification). The effects of cool surfaces (on the roofs, on the facade or as vegetation areas) are evaluated through numerical simulations using the software ENVI-met. Having obtained the surface temperature, potential air temperature, mean radiant temperature, and wind speed, this study compares the mitigation strategies for urban heat island effect and make conclusions about the most effective mitigation strategy.
***Keywords*:** Urban heat island, Envi-met, Integrated approach, LCZ, Delhi, India

1. Introduction

Nowadays, cities are home to more than half of the world's population (Grimm et al. 2008). The underlying surfaces have undergone significant alteration due to concentrated economic and human activity, creating a distinct urban climatic environment (Han et al. 2022). According to Memon et al. (2008), urban heat island effects (UHI), or the phenomena where the air temperature in an urban area is noticeably greater than in a suburban one, have emerged as one of the primary urban environmental issues. The urban heat island effect increases with increasing temperature differences (Oke et al. 2017).According to Ampatzidis and Kershaw (2020), the UHI can be thought of as a heat bubble of air over a city that decreases air movement vertically and traps warm air and pollutants at street level. The effects of the UHI can be more pronounced during heat waves (Gunawardena et al. 2017; Ao et al. 2019; Hidalgo 2022; Founda and Santamouris 2017). The research indicates that during heat waves, sensible and anthropogenic heat fluxes at the urban site increase while latent heat fluxes are slightly reduced. This exacerbates the urban heat island intensity (UHII), as noted by Li and Bou-Zeid (2013). In Beijing, it was discovered that the UHI intensity could reach as high as 8 °C during a heat wave (An et al. 2020).The presence of UHI has a negative impact on inhabitants' thermal comfort as well as their physical and mental health (Liu 2010; Amorim et al. 2021; Garcia and Diaz 2021). It also causes an extra rise in energy and resource consumption (Li et al. 2014, 2015). Therefore, in order to maintain inhabitants' quality of life and accomplish the city's sustainable development, thermal mitigation measures are crucial.

The heat island effect has been greatly lowered because in large part to urban planning. The local climatic zones hypothesis (LCZs) was introduced by Stewart and Oke (2012). Based on factors such building height, density, greening, etc., the urban surface was categorized into 17 categories (ten built-up environment types (LCZ1-LCZ10) and seven natural coverage types (LCZ A-LCZ G). The surface cover, composition, materials, and human activities of each form of LCZ are comparable. The worldwide urban heat island effect has been studied more and urban planning now has a stronger scientific foundation due to LCZ theory. Instead of focusing on the analysis of temperature differences between urban and rural sites, it was advised to concentrate on the investigation of temperature differences inside urban areas, between zones with varied urban structure (Martilli et al. 2020).

2. Need of the Study

Currently, there is a dearth of observation and research in the vertical spaces, with the majority of UHI studies taking place in the horizontal spaces. However, large cities exhibit a three-dimensional development trend of densely populated, tall buildings as a result of ongoing urbanization (Hong et al. 2022a, b). For instance, the proportion of low-rise building types in Delhi's central metropolitan region declined dramatically between 2010 and 2019, whereas the land used for compact high-rise structures showed an increasing tendency. Over half of the buildings in Delhi's central metropolitan region are high-rise and medium-rise structures. According to Sheng et al. (2013), the height of the urban canopy has greatly expanded, and the thermal and humid environment in the three-dimensional urban canopy exhibits complex traits when compared to the horizontal level. Therefore, more research on the UHI and an assessment of the effectiveness of current heat mitigation strategies in three-dimensional spaces within urban canopies with compact high-rise structures are required to give a scientific foundation for urban design. This will include some original thinking and methodologies.

3. Research Background

3.1 Research Objectives

To find out the best mitigation strategy for the selected site.

To evaluate integrated approach weather, it could reduce UHIE on the Built type of Open High Rise under Local Climate Zones in Delhi.

3.2 Limitations of the Study

In this paper we will only discuss month of May & September as May has high temperature and September has higher relative humidity.

3.3 Research Methodology

The Research Methodology is illustrated in Figure 1.

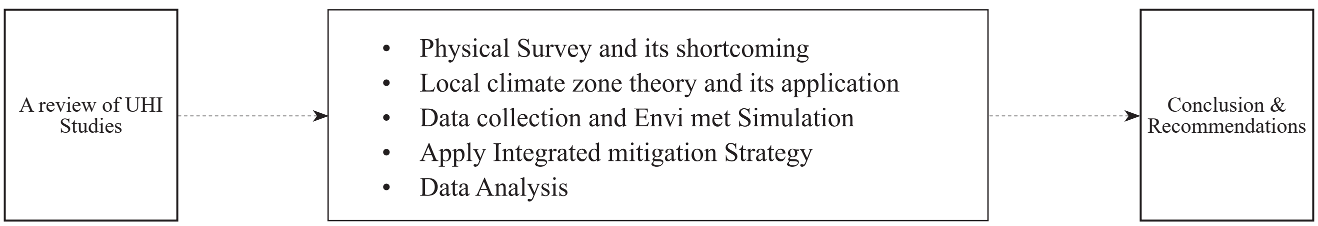

Figure 1. Graphical representation of the research methodology.

4. Delhi: The Study Context

4.1 Chronological Development of Delhi

The research region is the National Capital Territory (NCT) of Delhi, which is also one of India's megacities and the country's capital. Delhi is situated between 28.33 and 29.0 N latitude and 76.83 and 77.33 E longitude and covers an area of about 1500 km2. Delhi has a population of about 11 million people overall, and between 1991 and 2001; it grew at an annual rate of 3.9 percent, which is twice the national average. Large tracts of agricultural land have been lost as a result of Delhi's rapid urban growth, which has a detrimental effect on the sustainability of the city. As a result, one of Delhi's most pressing problems is the issue of urban growth demonstrates the study area's location.

The built-up area increased significantly between 1989 and 2020, from 195.30 sq. km to 435.12 sq. km, according to the results. The built-up area was 195.30 sq. km in 1989, rose to 268.11 sq. km (17.73%) in 2000, then to 351.21 sq. km in 2010, and ultimately to 435.12 sq. km in 2020, as indicated by the periodic observation. From 130.56 sq. km in 1989 to 127.03 sq. km in 2000, 120.92 sq. km in 2010, and 111.39 sq. km in 2020, the vegetation area has gradually shrunk. Furthermore, from 14.34 square kilometers in 1989 to 13.84 square kilometers in 2000, then to 13.59 square kilometers in 2010, then somewhat expanded to 14.11 sq. km in 2020. From 1171.90 sq. km in 1989 to 1103.12 sq. km in 2000, 1026.37 sq. km in 2010, and ultimately 951.48 sq. km in 2020, the LUC category of "others" saw a decline. Figures 2 depict the variations in LUC from 1989 to 2020.

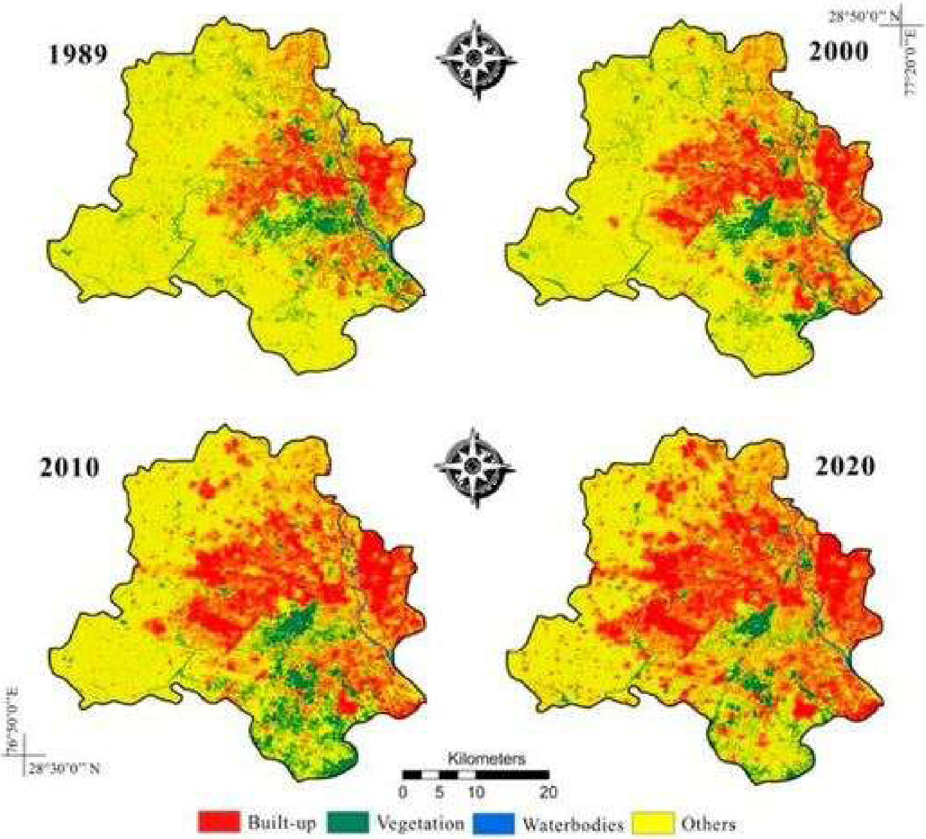

Figure 2. Land use/cover dynamics from 1989 to 2020.

4.2 Climatic Data of Delhi

The climatic Data of Delhi is given in Figure 3.

WEATHER DATA SUMMARY

LOCATION: New Delhi, Delhi, IND
Latitude/Longitude: 28.58° North, 77.2° East, **Time Zone from Greenwich** 5
Data Source: ISHRAE 421820 WMO Station Number, **Elevation** 216 m

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	312	336	454	547	490	492	435	391	398	380	370	319	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	390	323	465	579	400	388	277	213	278	360	496	444	Wh/sq.m
Diffuse Radiation (Avg Hourly)	105	147	141	135	190	200	229	237	207	158	95	94	Wh/sq.m
Global Horiz Radiation (Max Hourly)	775	833	994	1102	1162	1168	1038	947	902	905	902	727	Wh/sq.m
Direct Normal Radiation (Max Hourly)	1217	1148	1249	1239	1352	1365	1137	869	1077	1284	1404	1214	Wh/sq.m
Diffuse Radiation (Max Hourly)	279	355	429	480	499	505	502	493	462	401	316	260	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	3245	3678	5386	6958	6605	6785	5924	5097	4838	4279	3921	3258	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	4059	3528	5500	7362	5396	5349	3779	2778	3361	4040	5263	4540	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	1099	1620	1684	1728	2562	2763	3116	3082	2529	1802	1012	965	Wh/sq.m
Global Horiz Illumination (Avg Hourly)													lux
Direct Normal Illumination (Avg Hourly)													lux
Dry Bulb Temperature (Avg Monthly)	14	16	21	28	31	33	31	29	29	25	19	14	degrees C
Dew Point Temperature (Avg Monthly)	8	10	11	11	19	21	23	24	22	17	10	8	degrees C
Relative Humidity (Avg Monthly)	74	72	56	38	50	54	65	73	68	65	62	67	percent
Wind Direction (Monthly Mode)	290	320	320	320	90	290	110	90	320	110	320	0	degrees
Wind Speed (Avg Monthly)	1	1	1	1	1	2	2	1	1	1	0	1	m/s
Ground Temperature (Avg Monthly of 3 Depths)	18	18	20	22	26	29	30	30	28	24	21	19	degrees C

Figure 3. Climatic Data of Delhi.

5. High Rise Density Area of Delhi, India

Open high-rise development consists of towering structures with greater distances between them. This kind of construction creates an air of openness and frequently includes parks or green areas in between the buildings. Residents enjoy expansive views of the city due to the open plan, which also helps to preserve a visual link to the surrounding environment. Additionally, it is typically associated with congested urban environments. The DLF midtown, Moti Nagar, commonwealth game village, Unity One Karol Bagh, M2k Victoria Azadpur etc. is examples of this category. In this paper we will discuss about M2K Victoria Garden at Azadpur, New Delhi.

5.1 Case Study: The M2k Victoria Garden, Azadpur, New Delhi.

Figure 4. shows the location of the selected site of the M2k Victoria Garden. Figure 5 shows the site plan of the M2k Victoria Garden at Azadpur, New Delhi.

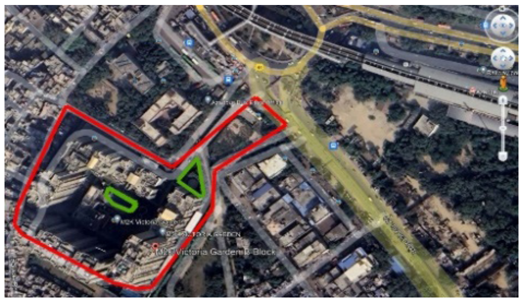

Figure 4. Satellite image of the selected site at Azadpur, New Delhi.

Figure 5. Site Plan of the M2k Victoria Garden at Azadpur, New Delhi.

5.2 Physical Survey of M2k Victoria Garden at Azadpur, New Delhi

Figure 6 shows the physical visual survey of M2K Victoria Garden at Azadpur, New Delhi.

Figure 6. Physical visual survey of M2K Victoria Garden at Azadpur, New Delhi.

Building material - concrete, paint, soil ground for open parking

Windows - normal glass

Green area- presence
Floors- g+19
Water body- yes

5.3 Data Collection

Step 1: Sketchup Modelling

Figure 8 shows the sketchup modelling of of M2K Victoria Garden at Azadpur, New Delhi.

Figure 8. Sketchup modelling of of M2K Victoria Garden at Azadpur, New Delhi.

Step 2: Detailing will be followed up by Envi met 5.6.1. Figure 9 shows the plan and 3D in Envi-met.

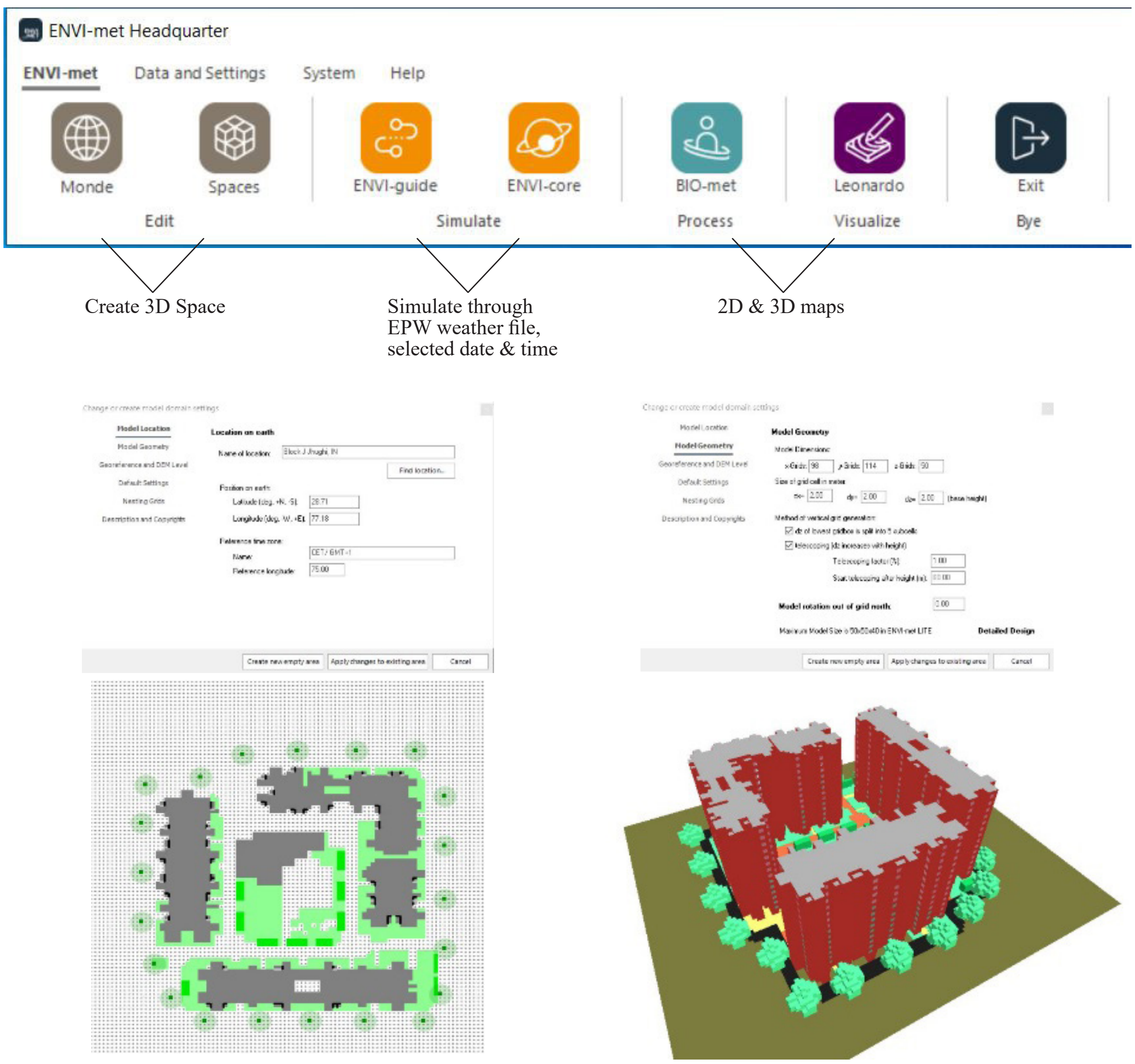

Figure 9. Plan and 3D visualization in Envi-met.

Step 3: For accuracy we adopt full force simulation and select the equinox, solstice and extreme weather day from month of April-September and December 2022 and time is from 12pm-2am (15hr).

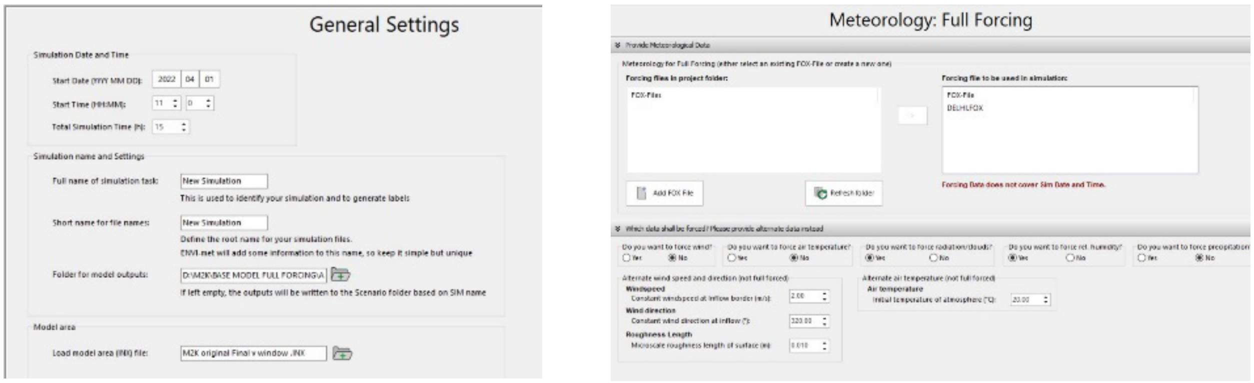

Figure 10. Plan and 3D visualization in Envi-met.

Step 4: Visualize variable parameters in 2D and 3D at different 3 levels of building like bottom, middle and roof of it.

6. Simulation Results

6.1 Potential Air Temperature at K-6 Level during May (12pm-2am)(Bottom)

Figure 11 shows the potential air temperature at K-6 level during May at the bottom of the building.

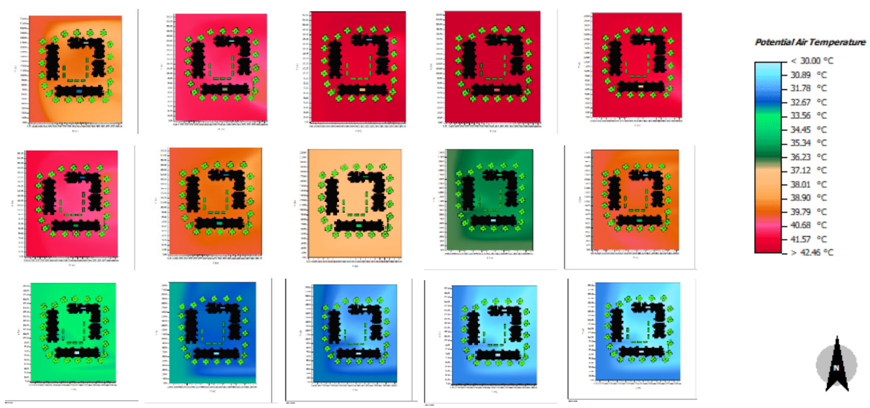

Figure 11. Potential air temperature at K-6 level during May at the bottom of the building.

6.2 Potential Air Temperature at K-19 Level May (12pm-2am)(middle)

Figure 12 shows the potential air temperature at K-19 level during May at the middle of the building.

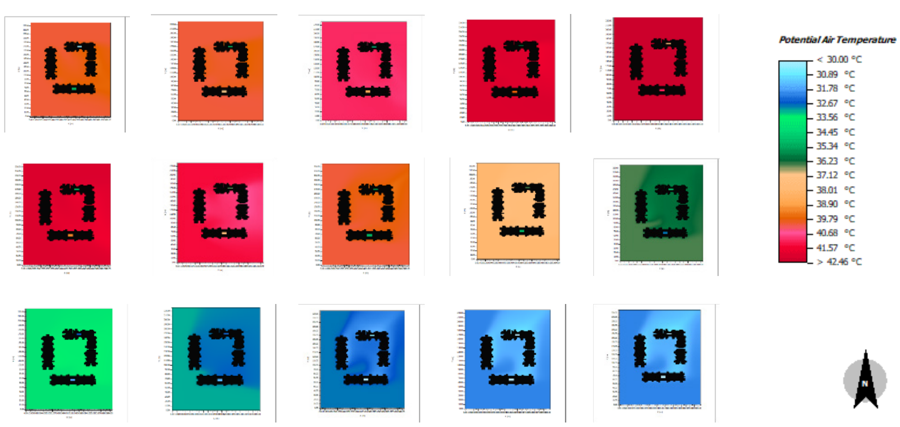

Figure 12. Potential air temperature at K-19 level during May at the middle of the building.

6.3 Potential Air Temperature at K-34 level May (12pm-2am)(Top)

Figure 13 shows the Potential air temperature at K-34 level during May at the top of the building.

Figure 13. Potential air temperature at K-34 level during May at the top of the building.

6.4 Wind Speed Temperature at K-6 Level during May (12pm-2am)(Bottom)

Figure 14. shows the wind speed temperature at k-6 level during May at the bottom of the building (12pm-2am).

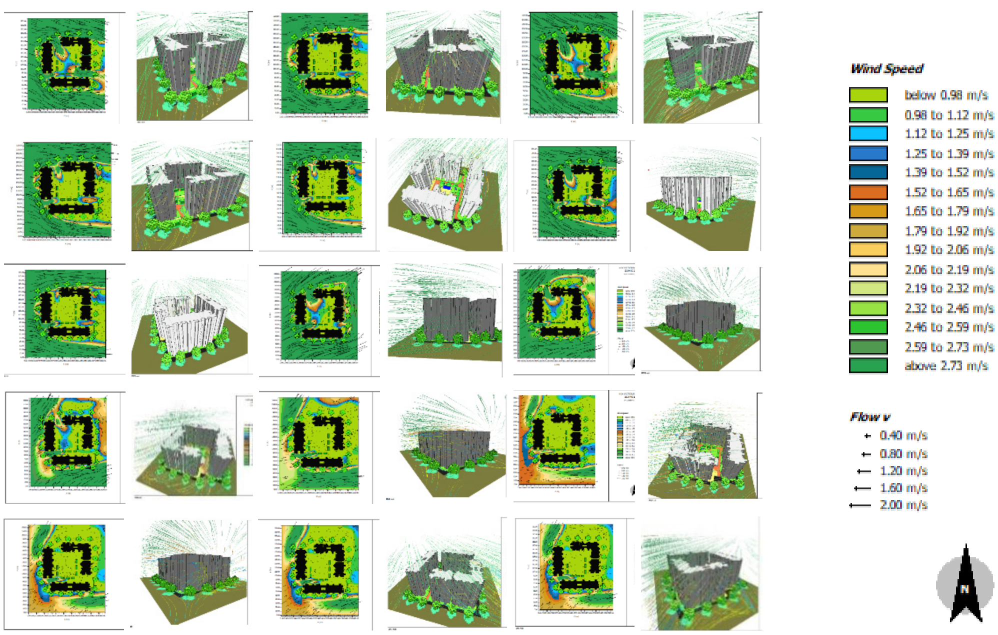

Figure 14. Wind speed temperature at k-6 level during May at the bottom of the building.

6.5 Wind Speed Temperature at K-19 Level during May (12pm-2am)(Middle)

Figure 15 shows the wind speed temperature at k-19 levelduring May at the middle of the building (12pm-2am).

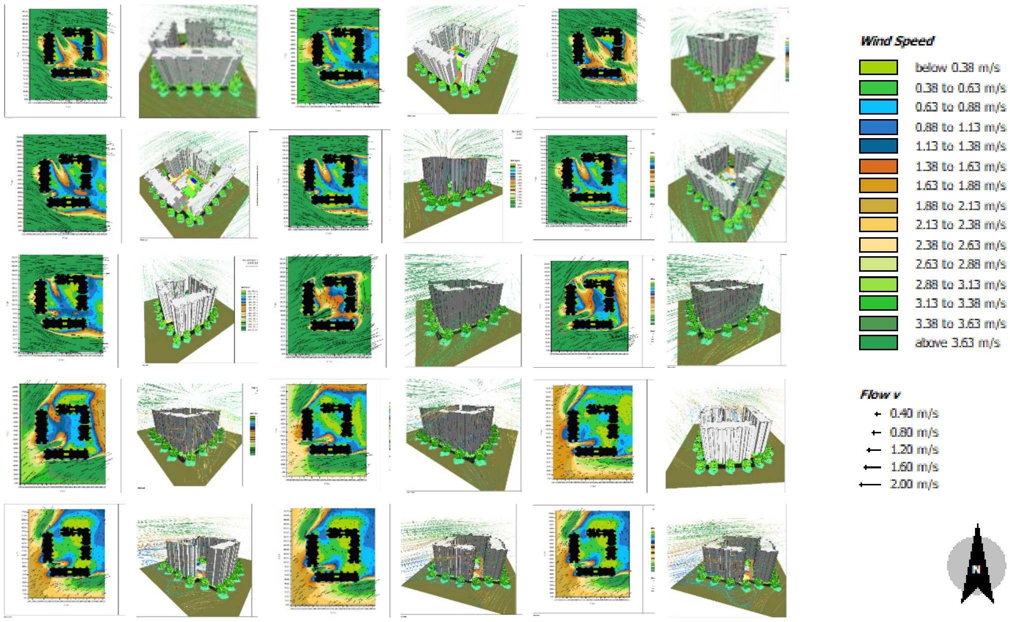

Figure 15. Wind speed temperature at k-19 level during May at the middle of the building.

6.6 Wind Speed Temperature at K-34 Level during May (12pm-2am)(Top)

Figure 16 shows the wind speed temperature at k-34 level during May at the middle of the building (12pm-2am).

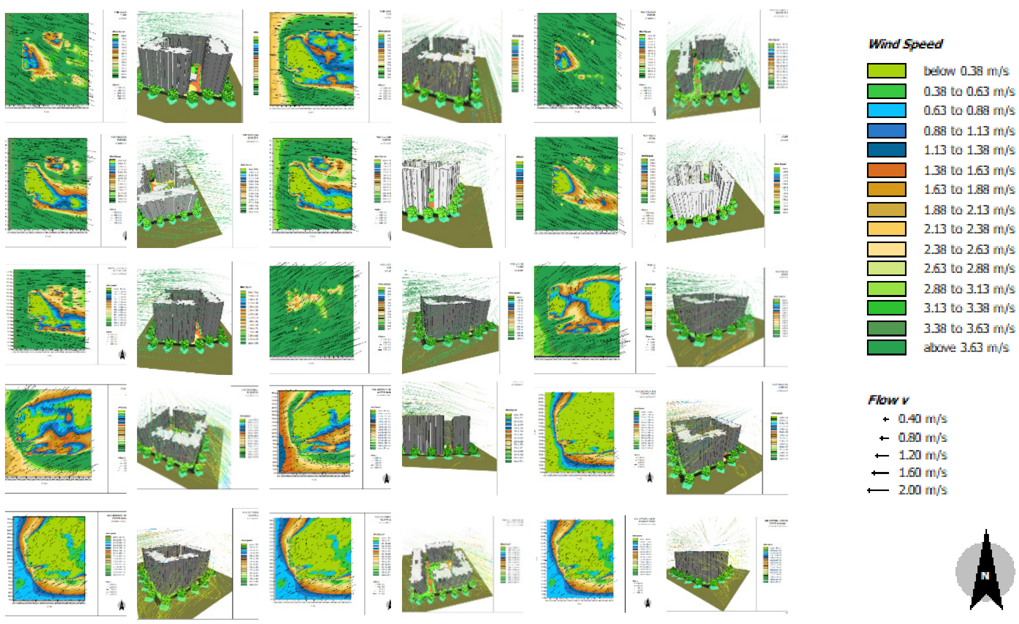

Figure 16. Wind speed temperature at k-34 level during May

6.7 Ground surface temperature during May (12pm-2am)

Figure 17 shows the ground surface temperature during May (12pm-2am).

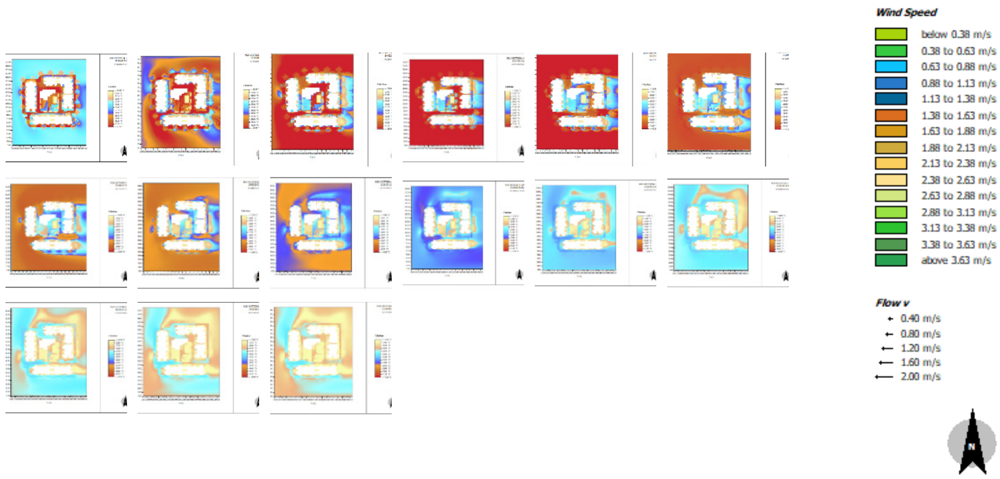

Figure 17. Ground surface temperature during May (12pm-2am)

6.8 Outside Wall Node Surface Temperature during May (12pm-2am)

Figure 18 shows the outside wall node surface temperature during May (12pm-2am)

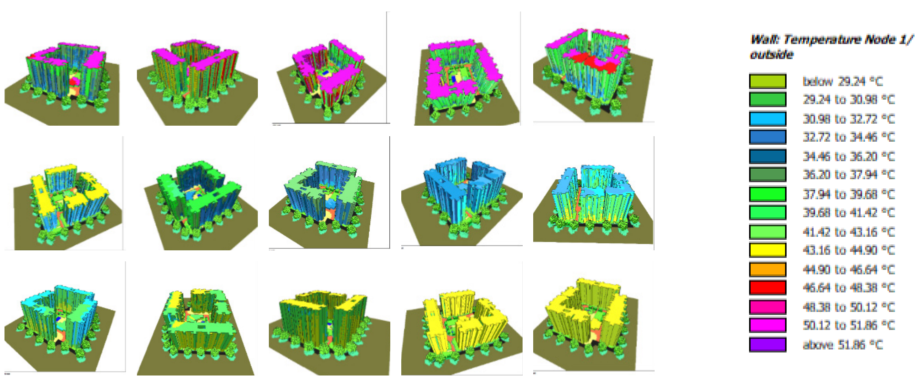

Figure 18. Outside wall node surface temperature during May

6.9 Longwave Radiation Emitted Temperature during May (12pm-2am)

Figure 19 shows the longwave radiation emitted temperature may (12pm-2am)

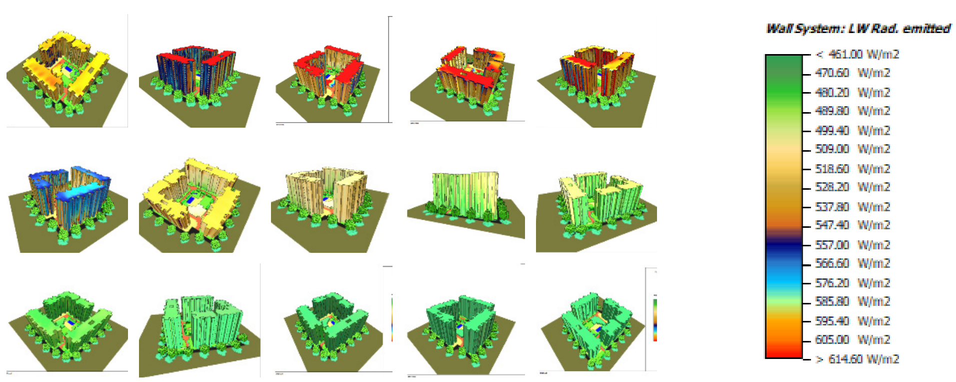

Figure 19. Longwave radiation emitted temperature during May

6.10 Potential Air Temperature at K-6 Level during September (12pm-2am)(Bottom)

Figure 20 shows the Potential air temperature at k-6 level sep (12pm-2am)(bottom)

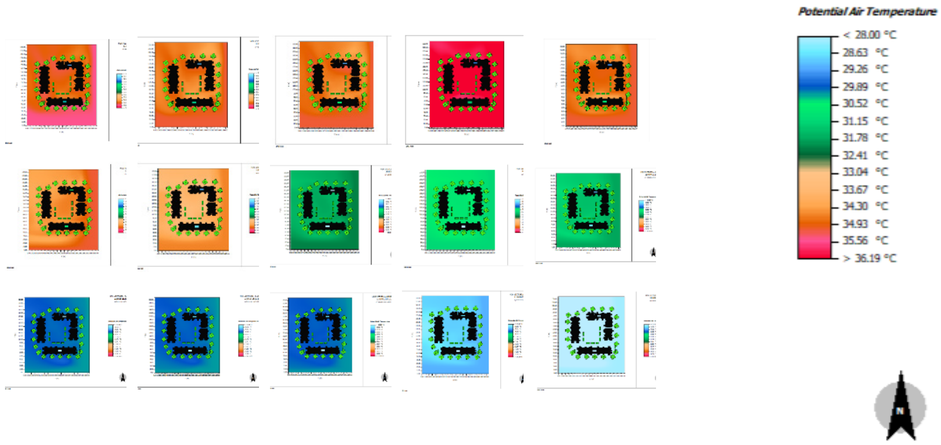

Figure 20. Potential air temperature at k-6 level during September at the bottom of the building.

6.11 Potential Air Temperature at K-19 Level during September (12pm-2am)(Middle)

Figure 21 shows the Potential Air Temperature at K-19 Level during September (12pm-2am)(Middle)

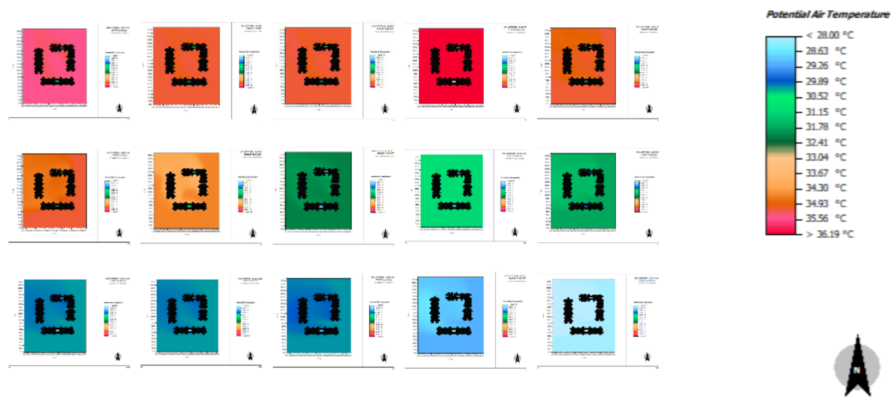

Figure 21. Potential Air Temperature at K-19 level during September at the middle of building.

6.12 Potential Air Temperature at K-34 Level September (12pm-2am)(Top)

Figure 22 shows the Potential Air Temperature at K-34 Level during September (12pm-2am)(Top)

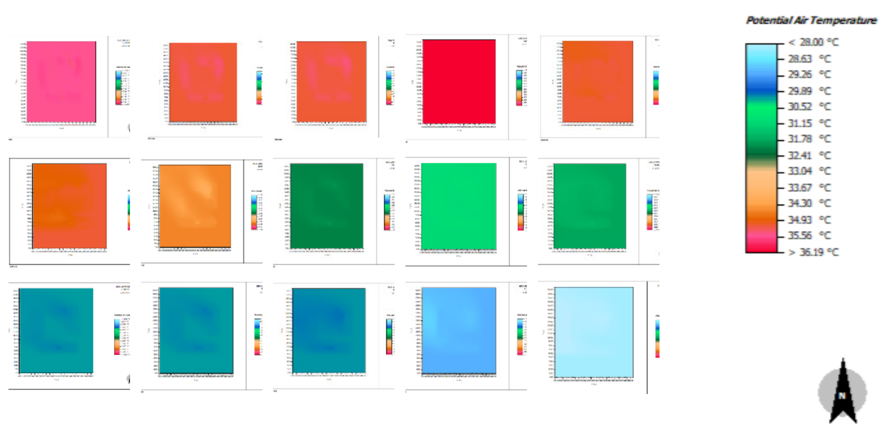

Figure 22. Potential air temperature at K-34 level during September at the top of building.

6.13 Wind Speed Temperature at K-6 Level during September (12pm-2am)(Bottom)

Figure 23 shows the Potential Air Temperature at K-6 Level during September at the bottom of the building (12pm-2am)

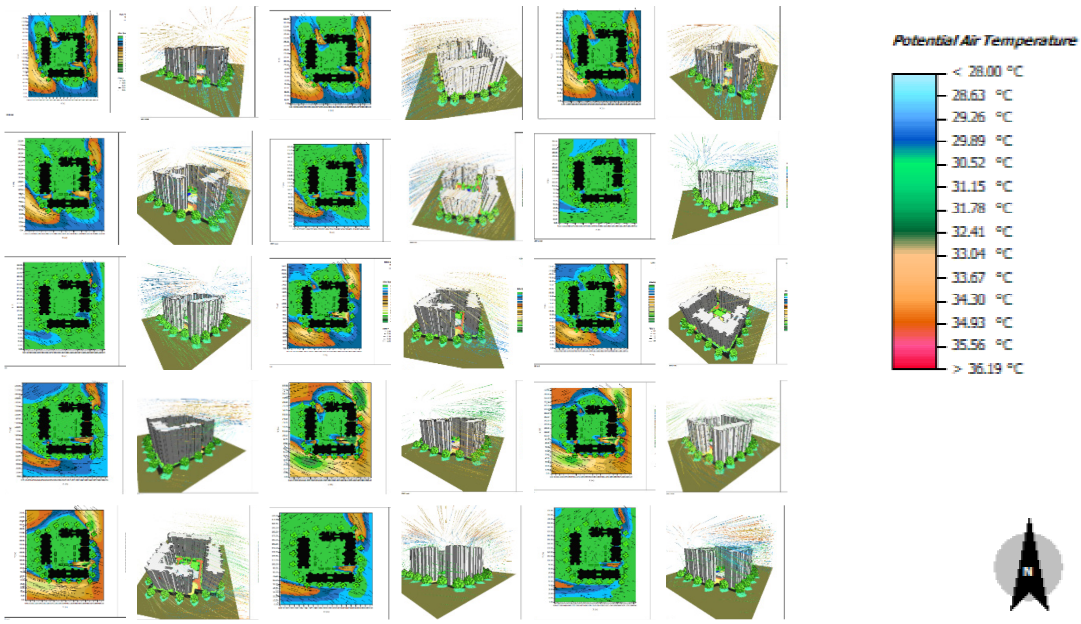

Figure 23. Potential air temperature at K-6 level during September at the bottom of building.

6.14 Wind Speed Temperature at K-19 Level during September (12pm-2am)(Middle)

Figure 24 shows the Potential Air Temperature at K-19 Level during September at the middle of the building (12pm-2am).

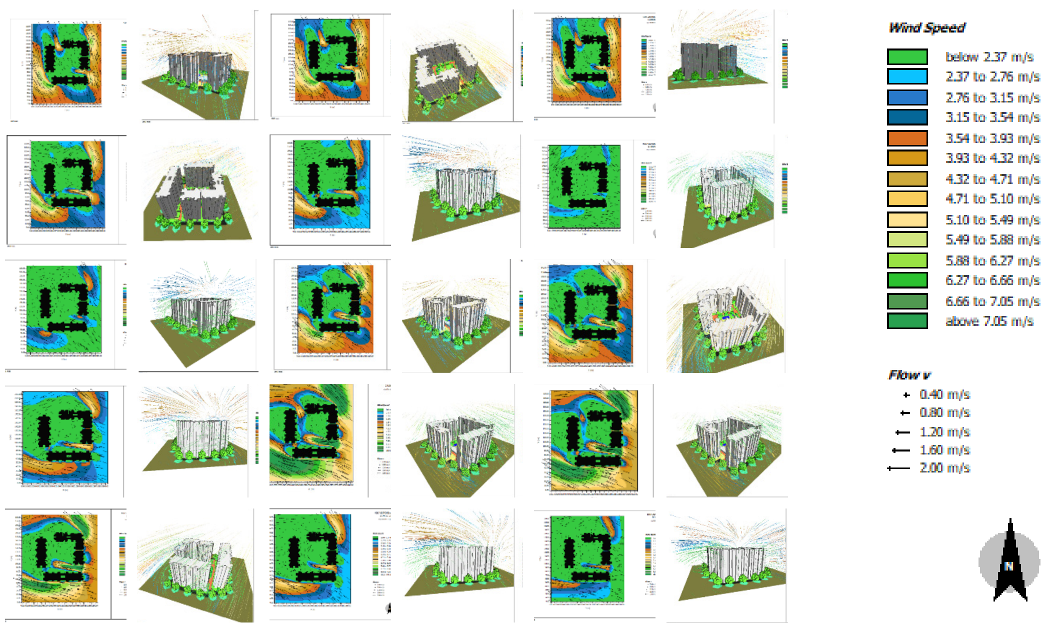

Figure 24. Potential air temperature at K-19 level during September at the middle of building.

6.15 Wind Speed Temperature at K-34 Level in September (12pm-2am)(Top)

Figure 25 shows the Potential Air Temperature at K-34 Level during September at the top of the building (12pm-2am).

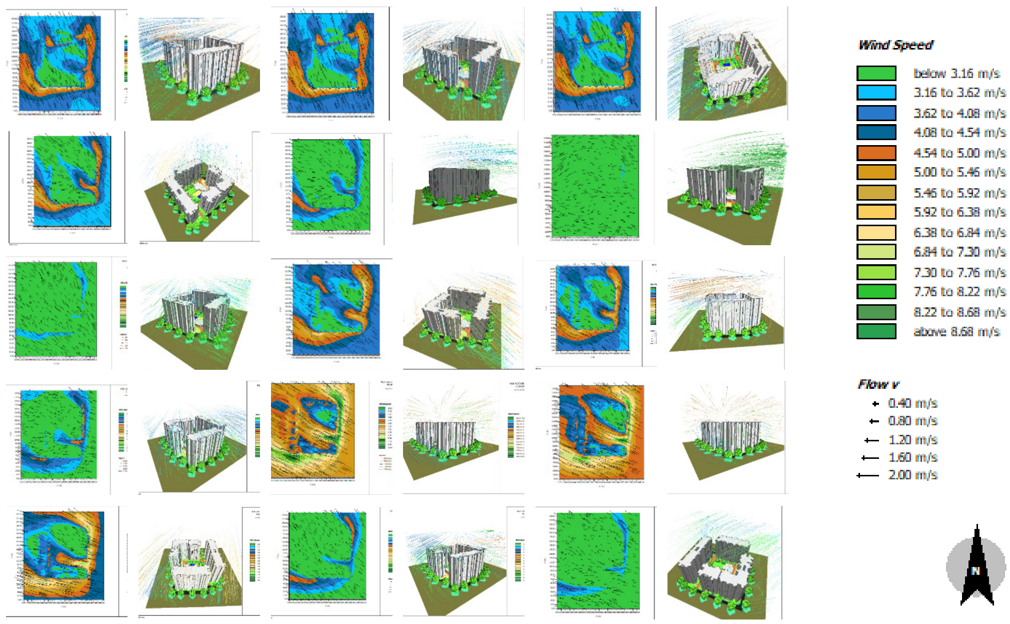

Figure 25. Potential air temperature at K-34 Level during September at the middle of building.

6.16 Ground Surface Temperature during September (12pm-2am)

Figure 26 shows the Potential Air Temperature during September (12pm-2am)

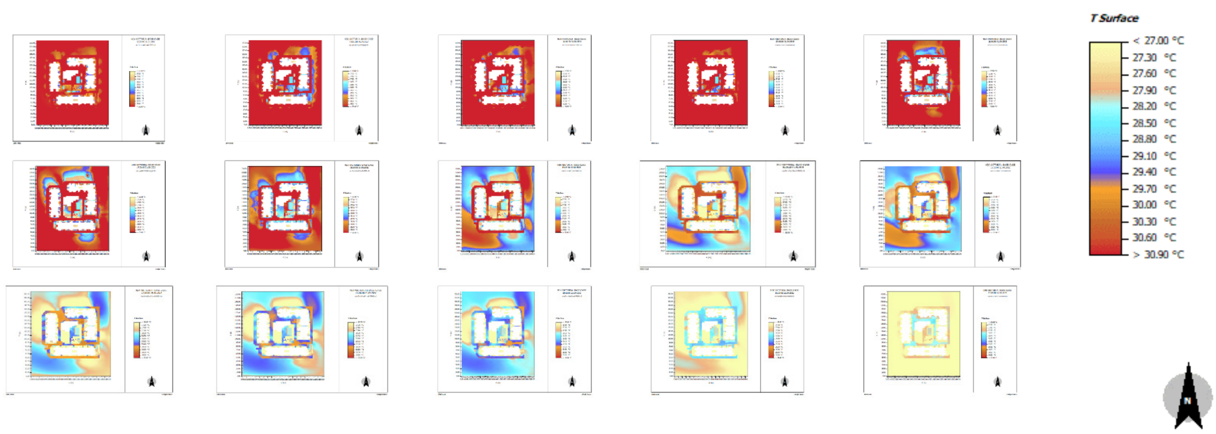

Figure 26. Ground surface temperature during September.

6.17 Outside Wall Node Surface Temperature in September (12pm-2am)

Figure 27 shows outside wall node surface temperature during September (12pm-2am)

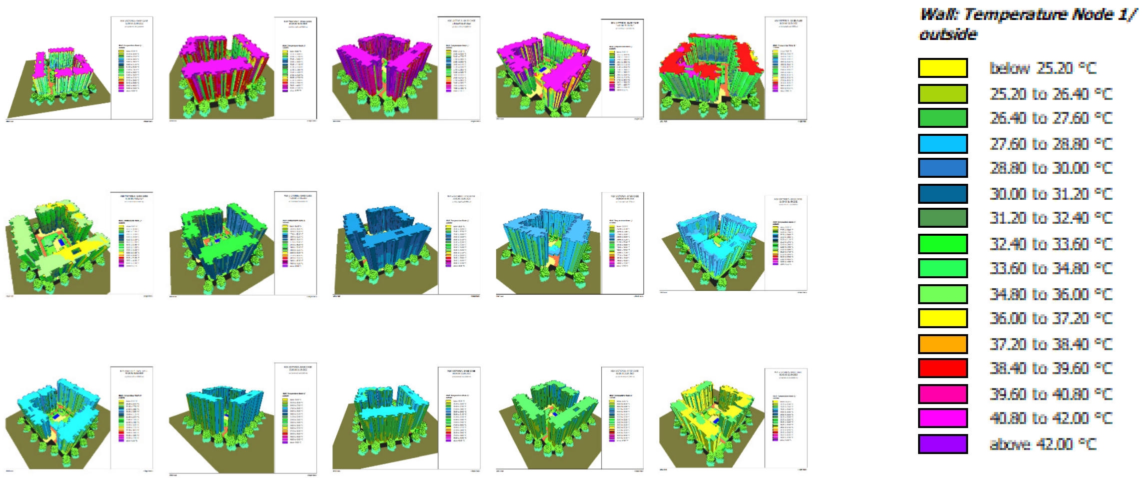

Figure 27. Outside wall node surface temperature during September (12pm-2am)

6.18 Longwave Radiation Emitted Temperature during September (12pm-2am)

Figure 28 shows the longwave radiation temperature during September (12pm-2am)

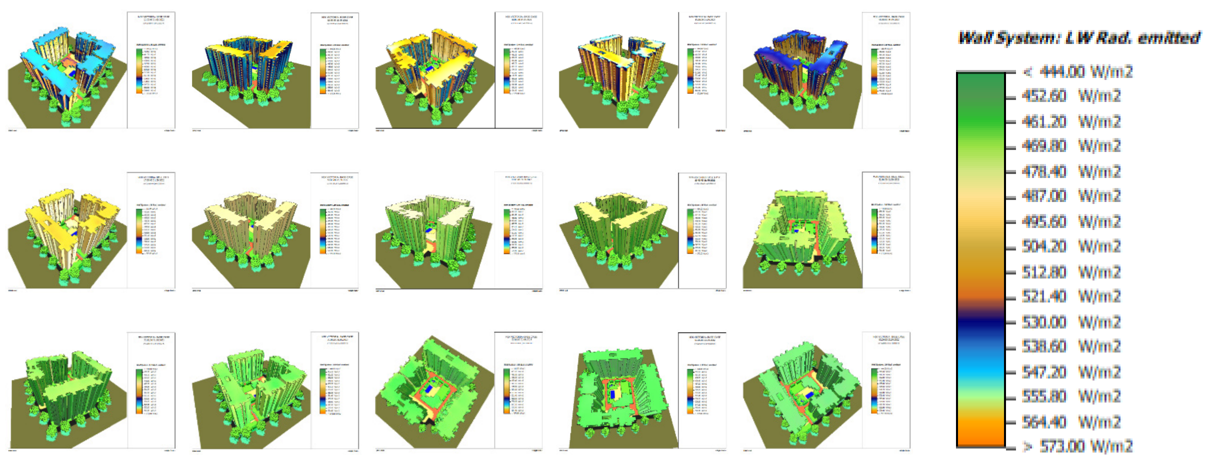

Figure 28. Longwave radiation temperature during September (12pm-2am)

7. Result and Analysis

From the above thermal images, we will now compare these parameters of the month May and September through graphs to analyses what strategies are to be applied next and best for this site, the analysis of data at K-6 (5 meters) is summarized in Table 1.

7.1 Potential Air Temperature at K-6 (Bottom)

Table 1 shows the potential air temperature data September at K-6 level (bottom). Figure 29 shows that the month of May has high Temperature than Septemper.

Table 1. Potential Air Temperature data during May and September at K-6 bottom level

Date	Time	May	September
01.04.2022	12.00.00	39.15	35.033
01.04.2022	13.00.00	39.89	34.623
01.04.2022	14.00.00	40.949	34.674
01.04.2022	15.00.00	41.959	36.695
01.04.2022	16.00.00	42.678	34.906
01.04.2022	17.00.00	41.404	34.8
01.04.2022	18.00.00	40.594	34.256
01.04.2022	19.00.00	39.575	32.027
01.04.2022	20.00.00	37.56	31.034
01.04.2022	21.00.00	35.644	31.693
01.04.2022	22.00.00	33.498	30.023
01.04.2022	23.00.00	32.552	30.031
02.04.2022	00.00.00	31.49	30.004
02.04.2022	01.00.00	30.741	29.097
02.04.2022	02.00.00	30.661	28.066

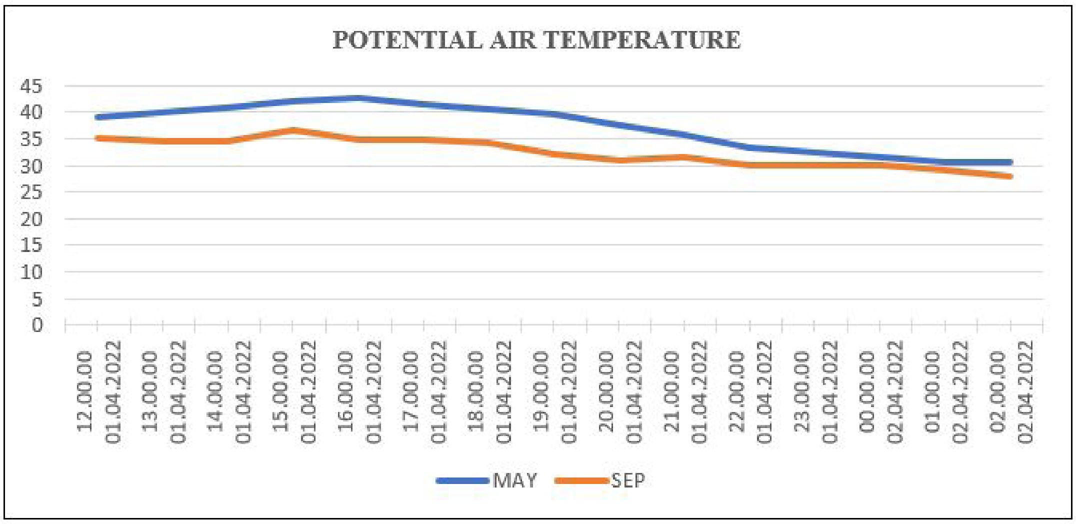

Figure 29. May has high temperature than Septemper.

7.2 Relative Humidity at K-6 (Bottom)

Table 2 shows the potential relative humidity data at K-6, bottom level. Figure 30 shows that the month of September has high Relative Humidity than May.

Table 2. Relative humidity data during the month of May and September

Date	Time	May	September
01.04.2022	12.00.00	26.218	66.34
01.04.2022	13.00.00	19.465	60.874
01.04.2022	14.00.00	17.077	60.44
01.04.2022	15.00.00	15.833	55.519
01.04.2022	16.00.00	14.982	54.94
01.04.2022	17.00.00	17.242	52.267
01.04.2022	18.00.00	22.501	65.716
01.04.2022	19.00.00	20.991	67.929

Date	Time	May	September
01.04.2022	20.00.00	24.034	67.885
01.04.2022	21.00.00	32.466	72.651
01.04.2022	22.00.00	32.136	71.805
01.04.2022	23.00.00	34.071	76.563
02.04.2022	00.00.00	48.635	80.35
02.04.2022	01.00.00	40.173	76.196
02.04.2022	02.00.00	40.327	81.11

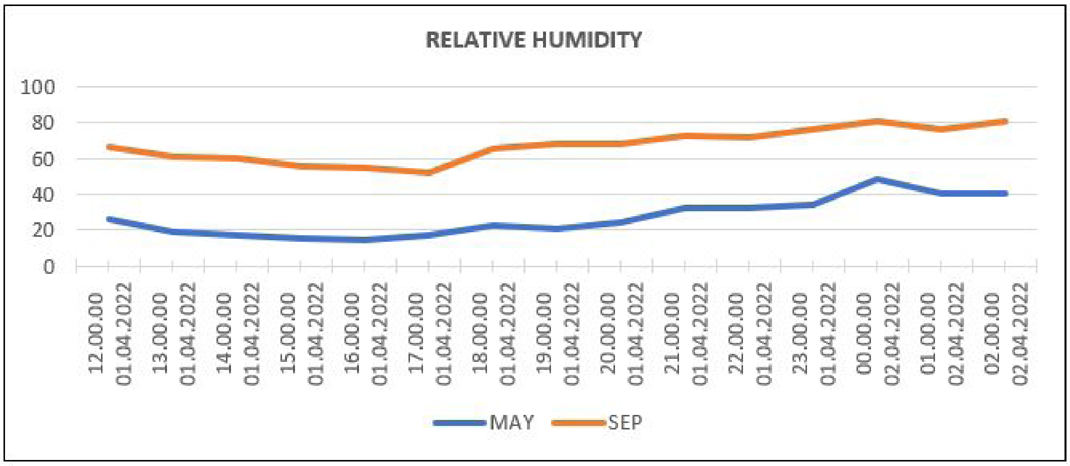

Figure 30. September has high relative humidity than May.

8. Mitigation Strategies

To mitigate the temperature, we applied different strategies like cavity roof, cool tile, green roof, wet roof, high emissivity paint on façade & roof in the month of May as shown in Table 3 at K-6 (Bottom) level

Table 3. Possible intervention strategies for the selected site.

Date	Time	May	Cavity Roof May	Cool Tile May	Green Roof May	Wet Roof May	Bio Wall May	Paint Roof May	Facade Paint May
1.4.2022	12.00	39.15	39.148	39.079	39.147	39.233	39.182	39.145	22.863
1.4.2022	13.00	39.89	39.835	39.676	39.822	39.904	39.854	39.833	22.981
1.4.2022	14.00	40.949	40.893	40.83	40.907	40.934	40.92	40.897	22.838
1.4.2022	15.00	41.959	41.906	41.806	41.917	41.93	41.911	41.91	22.742
1.4.2022	16.00	42.678	42.637	42.55	42.648	42.662	42.655	42.64	22.422
1.4.2022	17.00	41.404	41.381	41.389	41.41	41.396	41.401	41.388	21.684
1.4.2022	18.00	40.594	40.577	40.602	40.608	40.584	39.981	40.58	21.045
1.4.2022	19.00	39.575	39.561	39.592	39.592	39.566	39.315	39.564	20.474
1.4.2022	20.00	37.56	37.546	37.571	37.554	37.551	37.426	37.548	20.208
1.4.2022	21.00	35.644	35.609	35.656	35.631	35.61	35.177	35.609	20.137
1.4.2022	22.00	33.498	33.498	33.57	33.497	33.499	33.24	33.497	19.935
1.4.2022	23.00	32.552	32.548	32.349	32.541	32.545	32.293	32.543	19.683
2.4.2022	00.00	31.49	31.364	31.287	31.431	31.347	31.074	31.362	19.794
2.4.2022	01.00	30.741	30.632	30.58	30.693	30.617	30.37	30.631	19.403
2.4.2022	02.00	30.661	30.55	30.523	30.613	30.534	30.318	30.548	19.074

8.1 Cavity Roof

Figure 31 shows the potential air temperature profile of a cavity roof during May.

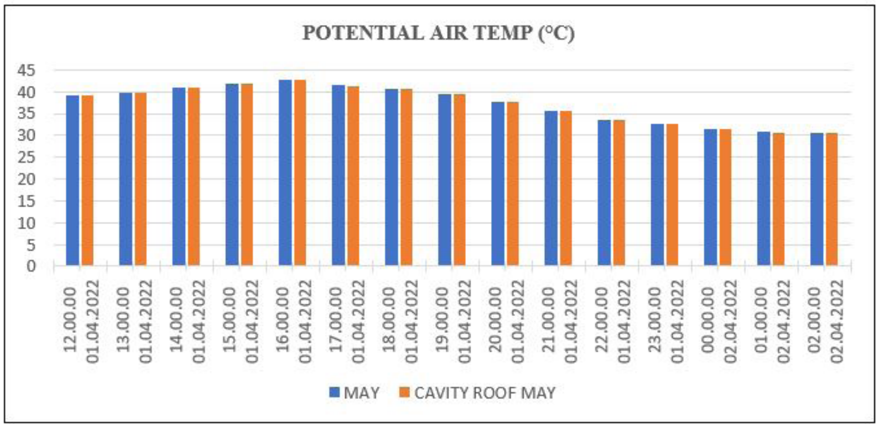

Figure 31. Cavity roof temperature during May.

8.2 Cool Tile

Figure 32 shows the potential air temperature profile of cool tiles during May.

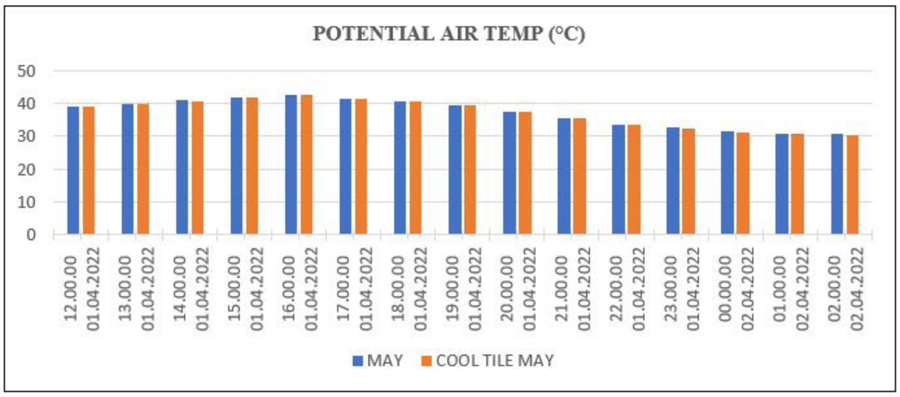

Figure 32. Potential air temperature profile of cool tiles during May.

8.3 Green Roof

Figure 33 shows the potential air temperature profile of green roof during May.

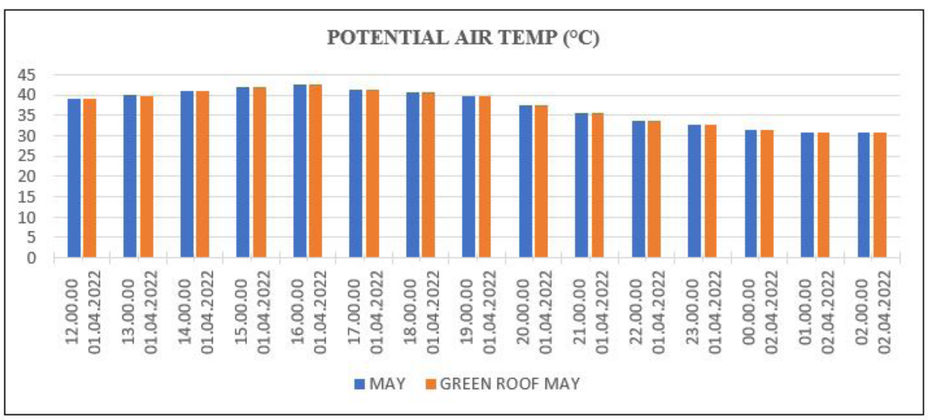

Figure 33. Potential air temperature profile of Green roof during May.

8.4 Wet Roof

Figure 34 shows the potential air temperature profile of wet roof during May.

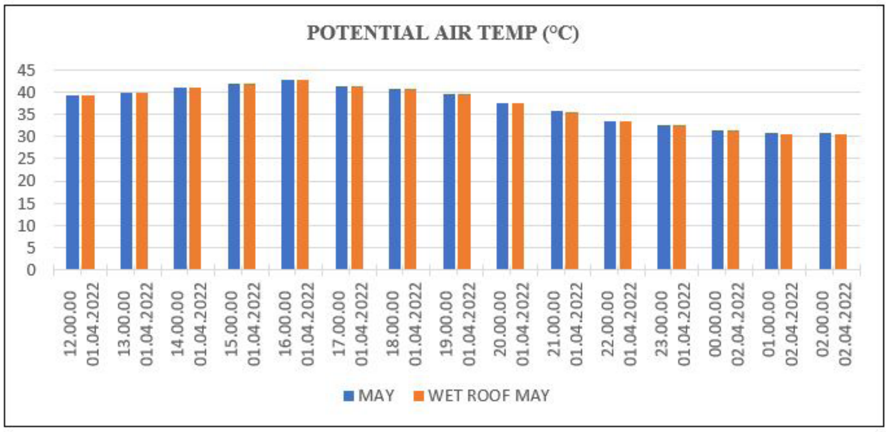

Figure 34. Potential air temperature profile of Wet roof during May.

8.5 Bio/Green Wall

Figure 35 shows the potential air temperature profile of bio / green wall during May.

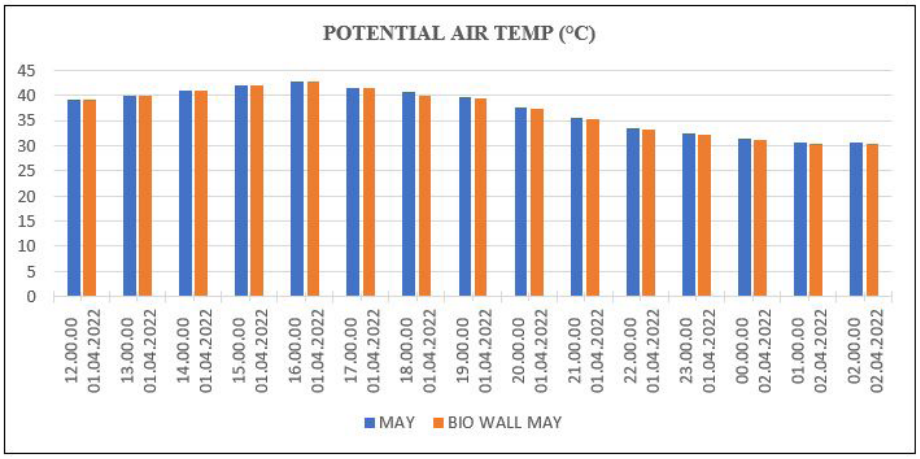

Figure 35. Potential air temperature profile of bio/green wall during May.

8.6 Roof Paint

Figure 36 shows the potential air temperature profile of roof paint during May.

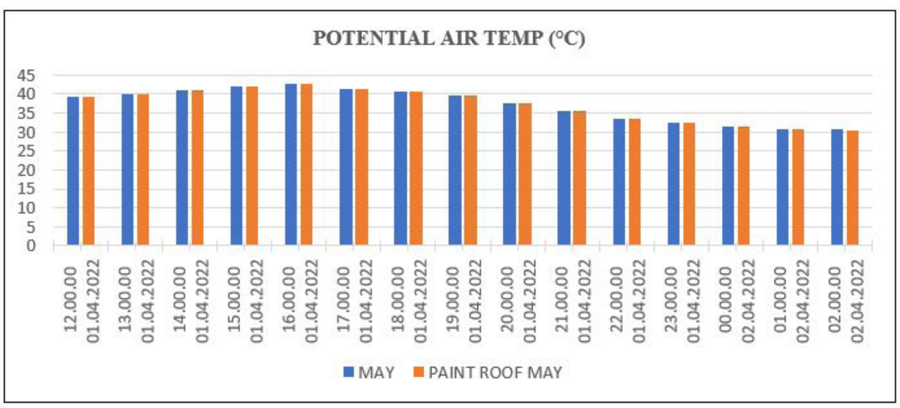

Figure 36. Potential air temperature profile of roof paint during May.

8.7 Facade High Emmisivity Paint

Figure 37 shows the potential air temperature profile of facade high emissivity paint during May.

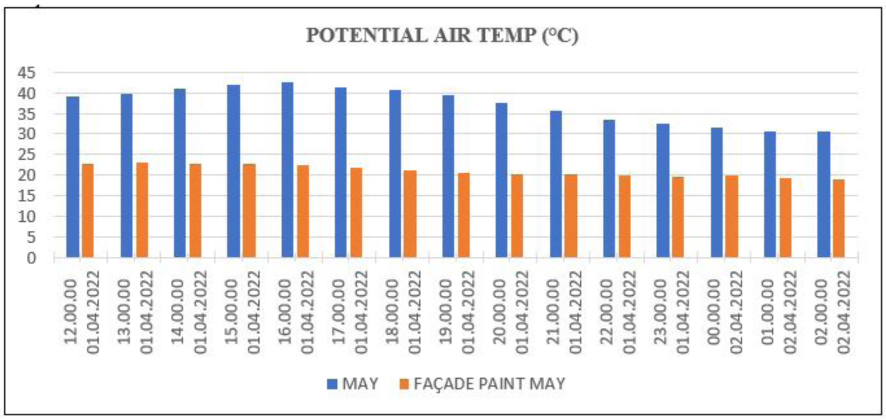

Figure 37. Potential air temperature profile of façade paint during May.

9. Conclusions

In this paper, a study has been conducted to analyze the development of urban climate change as well as the technology used to mitigate it. Significant effort has been made to comprehend and monitor urban climate change as well as to design and test alternative mitigation methods in high density residential areas of Delhi. In this paper, the case of Delhi, India, using the microclimate modeling system ENVI-met, which models the temperature effects of various construction situations, has been analyzed. After applying all possible intervention, we conclude that in all other strategy temperature is increasing as comparison to base case so applying high emissivity paint on facade and green roof is the best strategy to mitigate high temperature in Table 4.

Table 4. Comparison of base and integrated approach in the month of May.

Date	Time	May	Integrated May
1.4.2022	12.00.00	39.15	22.83
1.4.2022	13.00.00	39.89	22.94
1.4.2022	14.00.00	40.949	22.796
1.4.2022	15.00.00	41.959	22.704
1.4.2022	16.00.00	42.678	22.388
1.4.2022	17.00.00	41.404	21.668
1.4.2022	18.00.00	40.594	21.036
1.4.2022	19.00.00	39.575	20.475
1.4.2022	20.00.00	37.56	20.213
1.4.2022	21.00.00	35.644	20.138
1.4.2022	22.00.00	33.498	19.94
1.4.2022	23.00.00	32.552	19.689
2.4.2022	00.00.00	31.49	19.792
2.4.2022	01.00.00	30.741	19.407
2.4.2022	02.00.00	30.661	19.079

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