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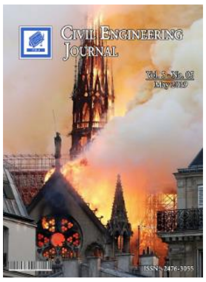

Green Envelop Impact on Reducing Air Temperature and Enhancing Outdoor Thermal Comfort in Arid Climates

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Abstract

Today Urban Cities faces energy and environmental challenges due to increased population, higher urbanization. The building sector has a big responsibility as it acquires high consumption rates in global energy and environmental scenarios. It is thought that the built environment in Egypt is responsible for 26% of the total overall national energy consumption, 62% of the total electricity consumption and around 70% of resultant CO2 emissions. The increased use of electrical appliances causes Urban Heat Island effect (UHI), which affect major urban centres. Adding green elements to any urban area is proved to be an effective strategy with numerous benefits to enhance the city's ecosystem, also mitigate the urban heat island measures. In this research Green roofs/walls can regulate outdoor air temperature by 10°C and improve outdoor thermal comfort by 2 Predicted Mean Value (PMV) values. The modelling of green strategy models can take into consideration design developments in areas with hot and dry climatic zones. The properties of green walls can directly affect the results of thermal comfort as leafs absorbs, reflects and transmits solar radiation, and increases the evapotranspiration.

Keywords: Green Walls; Retrofitting; Green Building; Green Roof; Air Temperature Reduction; Thermal Comfort Reduction; City Scale.

1. Introduction

The built environment is the largest part of the physical and economic human-made capital [1], where the construction sector itself constitutes a major part of the gross national product (GNP) [2] and accounts for 40% of the world's resource and energy use [3]. In Egypt, the sector is a particularly significant contributor to the economy (averaging at 25% of the GNP) [4] and is also a key user of energy. It is thought that the built environment in Egypt is responsible for 26% of the total overall national energy consumption, 62% of the total electricity consumption and around 70% of resultant CO2 emissions [5]. It is therefore important that the sector be considered a key target of energy consumption policies.

Adding green elements to any urban area is proved to be an effective strategy with numerous benefits to enhance the city's ecosystem, also mitigate the urban heat island measures. Many researches over the past decade investigated the impact of greenery when added to cities; especially trees, studies shown how effective a tree can be in reducing air temperature compared to air conditioning units. Greenery have proved to improve thermal comfort at the local scale [6,

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7, 8 and 9]. Since walls represent a high portion of the exposed urbanized area, green walls have gained widespread attention for their accountable impact on reducing energy consumption, also for their impact on modifying urban climate. It's proved that whenever vegetation, are installed in high- or medium-rise buildings, there is a direct impact on energy use and urban heat island mitigation potential [10-12].

Green roofs give a few advantages at both building and city level. Coming up next are the most usually seen at urban scale: mitigation of urban heat island impact [13]; decline in storm water overflow [14]; upgrade of biodiversity in densely urban regions [15]; cleaning of air and water spillover [16]. At Building scale, green walls diminish the reasonable heat flux because of the cooling impact [17] along these lines diminishing the heating and cooling demand of a building [18], and improving human thermal comfort. This impact may change contingent upon the atmosphere conditions, and the dimension of protection extraordinarily in instances of structure retrofitting. The greater part of these numerous advantages are connected to the cooling impact because of the evapotranspiration procedure (ET) that humidifies the outside encompassing air, decreases the surface temperature of the walls when irrigated, and mitigates the urban heat island [19].

Ideas for new urban areas should introduce biodiversity into the urban condition. Safeguarding biodiversity despite urbanization, territory discontinuity, ecological debasement and environmental change is presumably one of the best difficulties within recent memory. Tomorrow's urban areas should offer new types of green space, yet in addition to moderate the hotter urban atmosphere and the urban heatf island impact. Green urbanism is an all-encompassing idea for tomorrow's in addition to energy urban areas that depends on the use of energy, water, green spaces, materials and adaptability. Its long term objectives are zero emissions, zero waste and the evasion of energy/water/material wastage.

In light of the challenges facing the city identified previously, this study proposes an experimental investigation of green envelop thermal effects in the context of climate change and sustainable building design. Based on a case study in Egypt, it addresses the following research objectives. It explores the impacts of green envelop (green wall) on building microclimate and examines the effects of underling environmental factors such as soil thickness on green-wall thermal performance.

The research hypothesis states that a vegetated green element can enhance the micro climate in a very powerful way that enhances the ecosystem health and present comfort to microclimate around a building. The research will present solutions for urban densifications and its impact on ecosystem health. The methods outlined in this research could be useful for urban planning and building design.

2. Review of Green Envelop

In 2009, it was found that in every one of the cities around the world, the surrounding temperature could be diminished just by upgrading the greeneries, especially advancing the idea of urban greening as opposed to urban ranger service on the grounds that the last possessed more ground space, which was completely rare in thickly populated urban communities [20, 21]. The most widely recognized urban greening innovations are vertical greenery systems and green rooftops. Tragically, the vertical greenery systems is at its nucleation stage in these cities. The creators specified different advantages of joining vertical greenery systems; the primary being the warm advantages accomplished for the external wall texture, measured as far as temperature lessening of roughly 11.6 °C the peak value attained summer months. Broad investigations performed in 1990 demonstrated that the vertical greenery system contributed more to the smaller scale atmosphere of the building. On the off chance that the whole building texture (walls and rooftops) including the open yards were hung with green façades, it absolutely created a cool small scale climatic condition, in this manner contributing more to the micro-climate. Greeneries reduce the outside surface temperature of building walls through transpiration cooling and give incredible shading.

In 2013, a descriptive review was published to discuss the significance of green rooftops and the contrast between green rooftops and regular rooftops. The outcomes uncovered that a green rooftop has a critical part in adapting the urban condition by reducing the urban heat island (UHI) impact [22]. A green rooftop built up in urban zones with both sub-tropical and tropical islands, demonstrate that it can decrease the expansion of outside temperature by around 42% and the increase of indoor temperature by 8% amid the day time. Amid night, it can keep up 17% of the temperature in the outside condition, balancing out the temperature change. It was discovered that by substituting man-made building materials with vegetation, a normal temperature contrast of 20 °C existed between the most and the minimum vegetated areas checking the urban heat island in four regions of New York City.

3. Case Study

Cairo, a mega city of dense urban morphology, Cairo experiences serious deficiency of ground-level green spaces. The green-space deficiency has corrupted the nature of the urban condition and related ecosystem services [23]. Urban Cairo has a huge potential to embrace the green layer innovation. There has long been a poor awareness among decision-makers and the public of the potential benefits arising from green-roof or green wall installation. Cairo is a high-density city situated in the middle of Egypt (30.04° N, 31.23° E) with an average altitude of 74m. Outdoor comfort investigation is during the hottest day 2nd of August [24] and is calculated using PMV, and air temperature. Cairo experiences a hot-arid climate with average temperature around 35 °C and humidity of 56%. The study is conducted on Neighborhood scale and street scale. The present study aims to investigate the effect of green infrastructure on reducing air temperature and outdoor thermal comfort in a typical urban neighborhood in Cairo. El Mohandseen "The Engineers", is a region in Giza, Egypt. During the 1970s, the populace expanded drastically, and the once rich estates neighborhood transformed into swarmed flat squares. Over the most recent 10 years, population growth and city migration have led to uncontrolled and enormous urban growth. Leasing 5-story buildings towards 15-story towers, this has led to the formation of large and growing compact city morphology, a legalized urban morphology of unimaginable density and compactness. This resulted to a deterioration of the natural environment and the living conditions of an ascending number of urban dwellers. Figure 1, show the case study map.

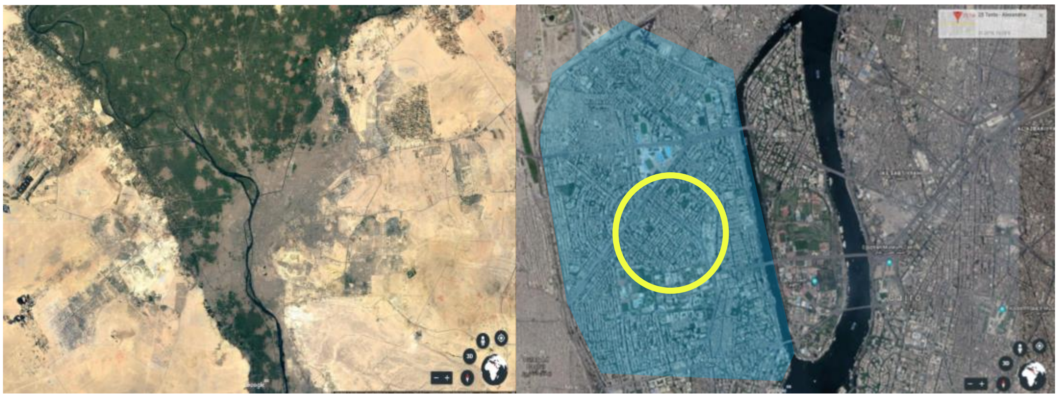
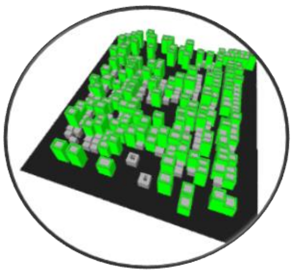
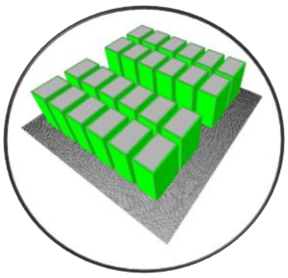


Figure 1. Highlighted region of Mohandseen (focus study area)

4. Research Methodology

Quantitative research is set for Neighborhood and street scale. The author depended on simulation software tools as they are the adequate tools available. Envimet were chosen for the study. All simulations occur in Greater Cairo and Delta climatic zone. Simulation sequence goes as follows; first a full city block base case will be modeled into Envimet. After that green walls will be added to compare the effects of adding vegetation on air temperature and outdoor thermal comfort (PMV). This is followed by a street block investigation for more clarifications on the impact of greenery impact on buildings in terms of temperature reduction and thermal comfort alteration (Table 1).

Table 1. Simulation Scenario configuration

Neighbourhood and Street (Simulation scenarios compare between Base Case and Green Envelop)		
Variable 1: Building Height		
Variable 2: Building Setback		
Objective: Outdoor Temperature & PMV		
(BH from 5 to 15F/ BS from 3 m) (BH: building Height, BS: Building Setback, F: no of Floors)		

4.1. Description of ENVI-met Software Tool

Microclimate recreations are performed utilizing ENVI-met 4.0, a three-dimensional computational liquid elements non-hydrostatic S.V.A.T. (soil, vegetation, air, and exchange) display. This program models the surface-plant-air associations in urban conditions, has been widely approved and utilized as of late [25, 26]. The primary information parameters of ENVI-met recreations incorporate climate conditions, starting soil wetness and temperature profiles, structures and physical properties of urban surfaces, and plants. ENVI-met permits to compute the air temperature, water vapour weight, and relative moistness, wind speed.

In ENVI-met, Vegetation is demonstrated for its evapotranspiration procedures, shadow, and drag impacts. ENVI-met does figuring concerning both shortwave and long-wave radiation motions regarding shading, reflection, and re-radiation from structures and vegetation. The temperatures of the ground and building surfaces are at long last computed from an energy balance of differential conditions understood utilizing the limited distinction strategy.

ENVI-met simulation ought to normally be done for something like 6 hours, yet a 24 hour time span is more common. In this exploration, the model was mimicked from 10am of August second to 6pm of August second, utilizing the neighbourhood climate station information revealed in Table 2 as beginning limit conditions.

Table 2. Initial climate inside ENVI-met simulations

Parameter	Input value
Start date	August 2nd
Start time	10:00 am
Simulation time	8 hours
Wind direction	North West (345°)
Wind speed (10 m)	3 m/s
Specific humidity (2500 m)	7.0 g/kgda
Relative humidity (2 m)	60 %

5. Software validation

In order to validate the software, a comparison between the measured and predicted air temperature were conducted between 10:00 a.m. and 6:00 p.m. on 2nd of august 2018. Air temperature measured at the Centre of the case study at a height of 1.5 m above the ground in a residential area of Mohandseen, Egypt, using a global temperature thermometer for outdoor use (measurement accuracy 0.1 ◦C). The weather data of that day were used as the inputs of ENVI-met. The relative errors of measurements were less than 10% at most time points, which may have been caused by the errors existing in weather data. The field experiments validated that the accuracy of ENVI-met can meet the requirements of this study (Figure 2).

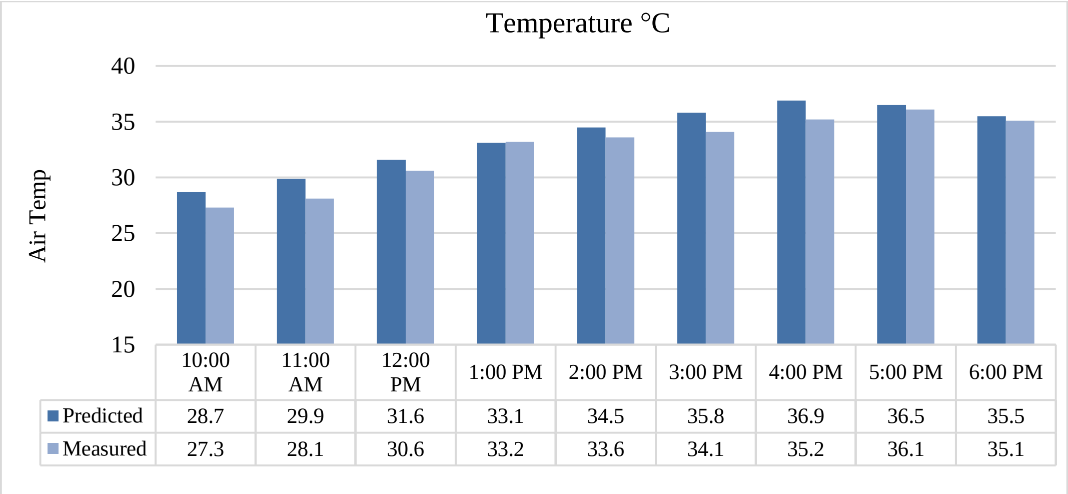


Figure 2. Comparison between the measured and predicted air temperature

6. Simulation Input Data for the City Block

The first step of the simulation process is the creation of an area input file. For the creation of the Mohandseen area input file a grid size of x=4m, y=4m, z=4m were used. The total number of grid cells along the x axis were 600, the y axis 600 cells and the z axis 90 grid cells. The area is mixed of 15 floor, 10 floors and 5 floors residential buildings. Setback between buildings varies, but in most cases 8 meters back to back and 6 meters side to side. The second step necessary to run the model was the creation of the configuration file. The simulation started on the 2nd of august at 10:00 AM. The total simulation time is 8 hours. The initial temperature used for the simulation is 28°C and reached 41°C. The wind speed was 3 m/s. The wind direction is 345° (North West). The relative humidity used as 56%. The model ran at the 250x250x30 version. The simulation will investigate the impact of extensive and intensive green walls on air temperature and thermal comfort (PMV).

6.1. Air Temperature Results for City Block

The output files from the ENVI-met simulation model were analysed and visualized through maps with the use of the LEONARDO 3.75 software. The air temperature at 2 meters was visualized for both cases at eight different hours of the same day. The initialization of the simulation is at 10 AM. Case A (without greenery), as seen in Figure 3, have average air temperature of 30°C mostly in the middle; with high solar radiation at noon, interacting with concrete, bricks and asphalt. The minimum recorded air temperature is 28°C and the maximum is 33°C. As for Case B (with greenery) shown in Figure 4, the green influences the air temperature around the close surroundings. Green and vegetation can influence the surrounding air temperature strongly. The green area with the concrete paved block in the middle that are situated on the west side of it seems to cool the close surrounding area at a small level. Even though the building blocks the wind flow, at this time of the day. The area is shaded by the building and thus the air temperatures are lower. The warmest areas are observed around the buildings on the top right corner and bottom area of the map with average temperature 23°C. The temperature difference when compared with case A at 12:00 PM is approximately 8°C. Greenery have a huge impact on outdoor air temperature in arid climates. Figure 5 is a comparison between case A & B through the day. Air temperature reduction from installing extensive green wall with thickness 10 cm was better than the intensive green wall with 30 cm thickness. It is common to provide comfort with thicker medium offered, but, it seems that thinner soil don’t store or traps sun rays, unlike the thicker soil. The reason behind these outcomes is the climatic zone in which the experiment occurs and simply this phenomenon is called Thermal mass (Figure 6).

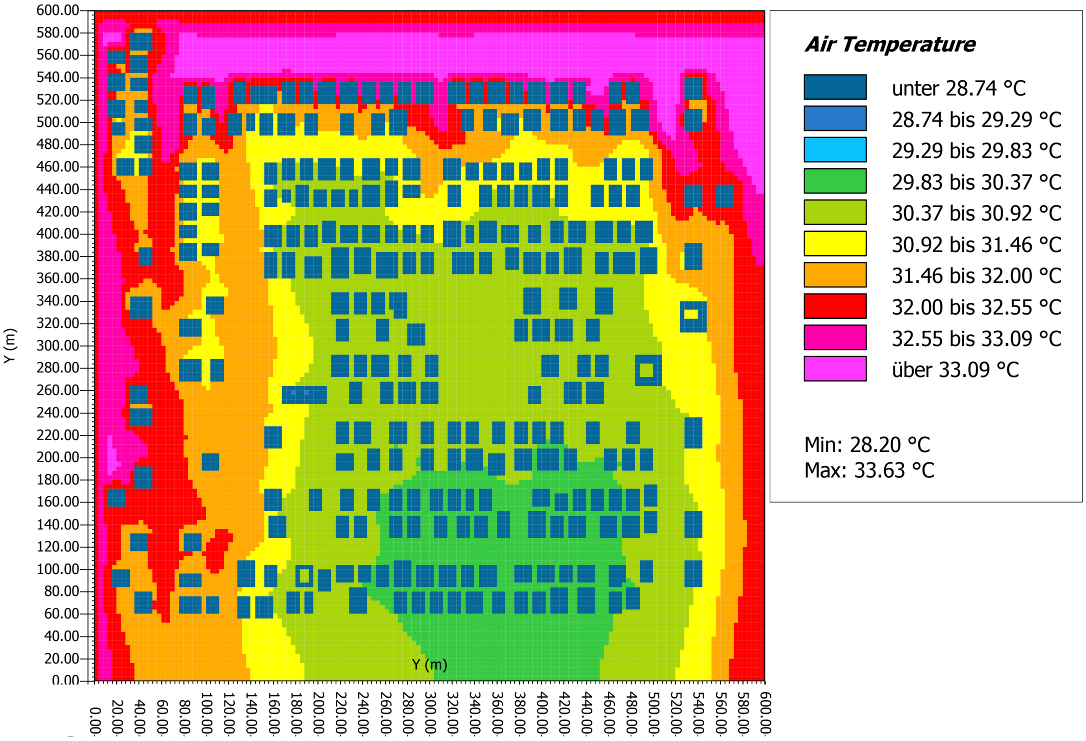


Figure 3. Air temperature of Case A at 12:00 PM

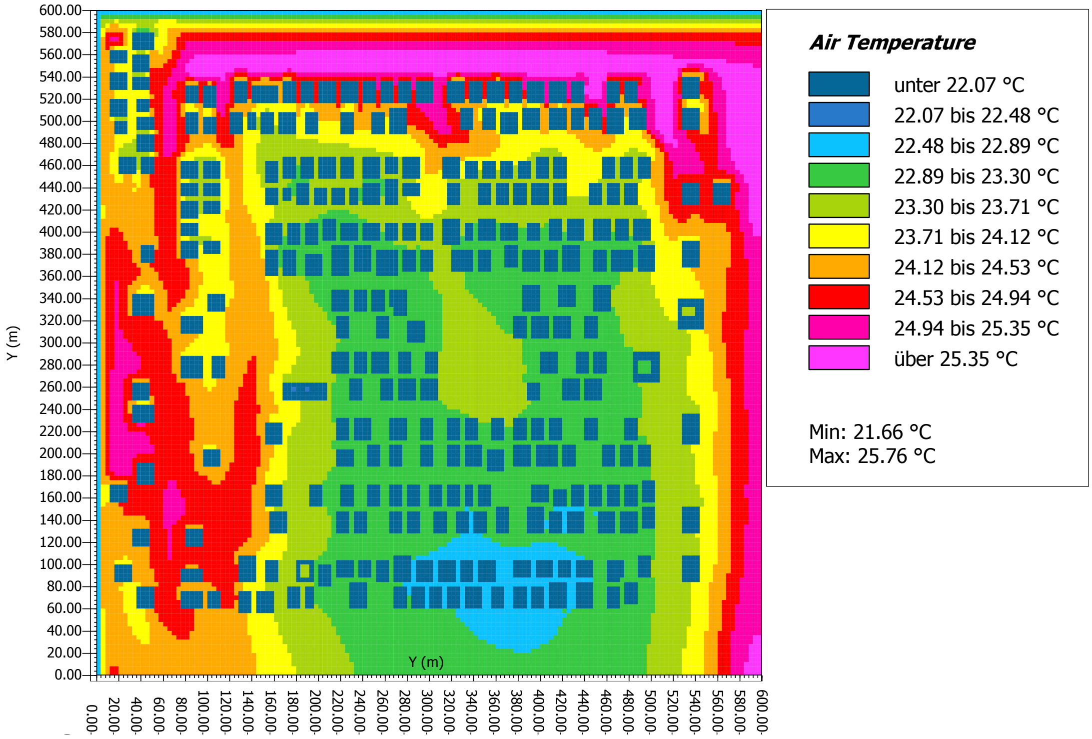


Figure 4. Air temperature of Case B at 12:00 PM

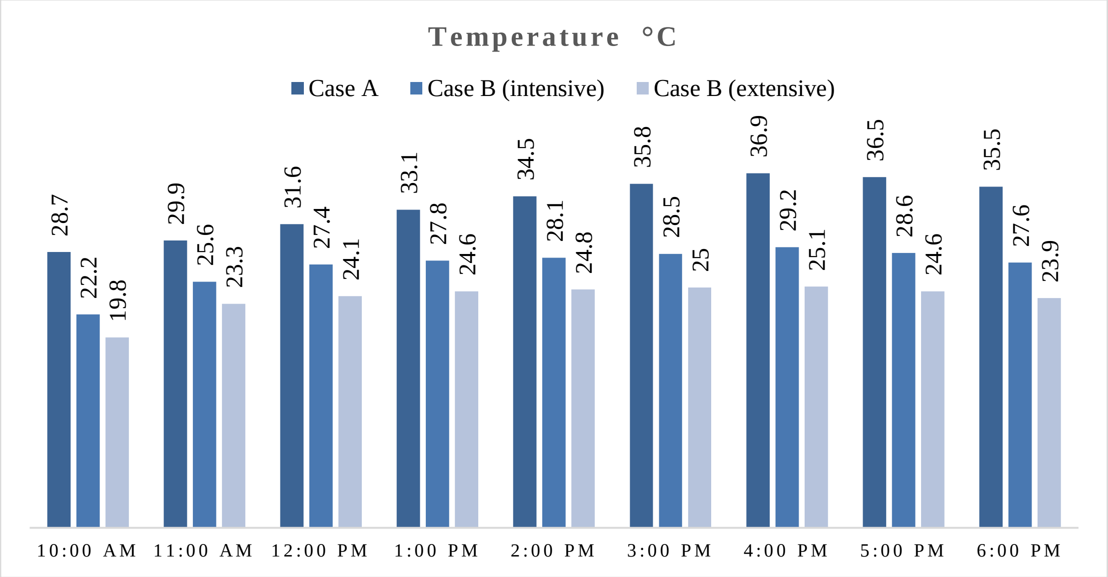


Figure 5. Air temperature difference between case A and B

6.2. Thermal Comfort Results for City Block

ENVI-met was selected to evaluate the outdoor thermal comfort, Biomet was used to calculate the PMV values at noon. Simulation for both cases A and B is measured at 2 meters height from street surface. The PMV values ranges between 2 to 3.4 for case A; characterized as HOT. The PMV values for case B range from 0.46 to 2.13 at 12 PM; characterized as COOL. For Case B; most of the area has PMV values are between 1 and 1.57 with the majority of the block having good comfort conditions. The lowest values are observed in front at the north and west and in the middle. After this value the "coolest" values are noticed at the green walls surrounding the buildings. Difference between PMV values for both cases A & B is considered impactful. Around 2 PMV value reduction; that provides better pedestrian comfort in the City block. These details can be seen in the following map, Figures 6 and 7. The best thermal comfort sensation is noticed in the areas with natural surface materials. Figure 8 is a full day difference between case A and B.

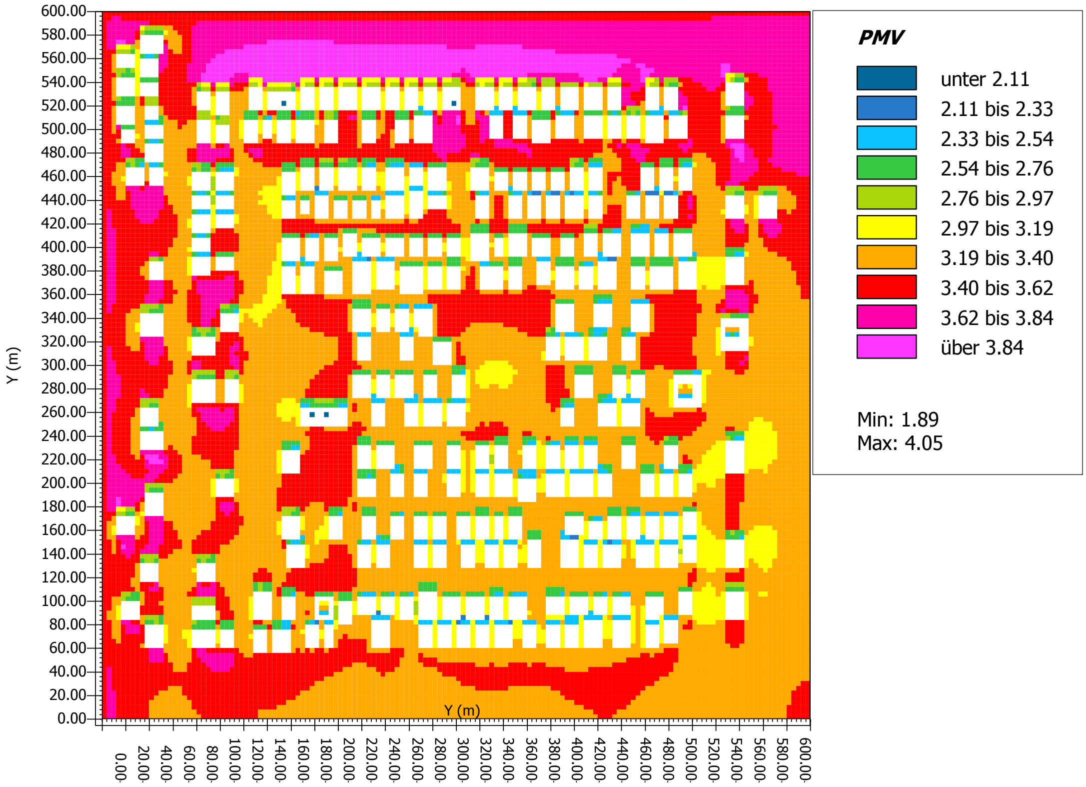


Figure 6. PMV for case A at 12 PM

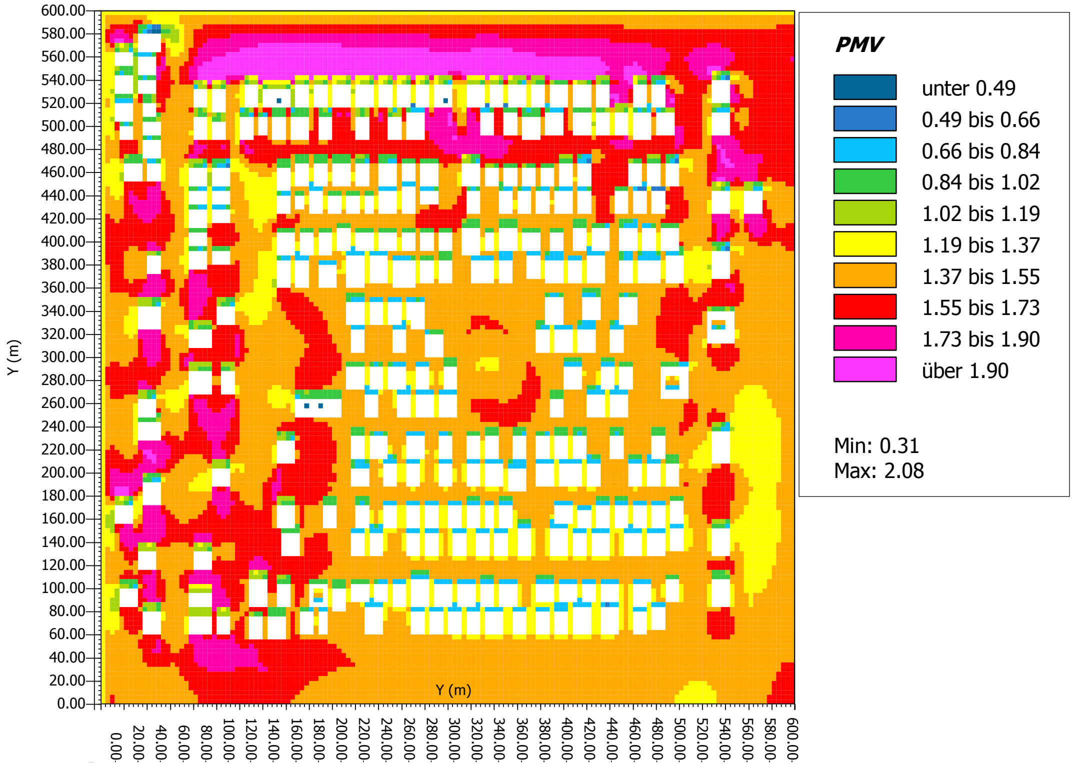
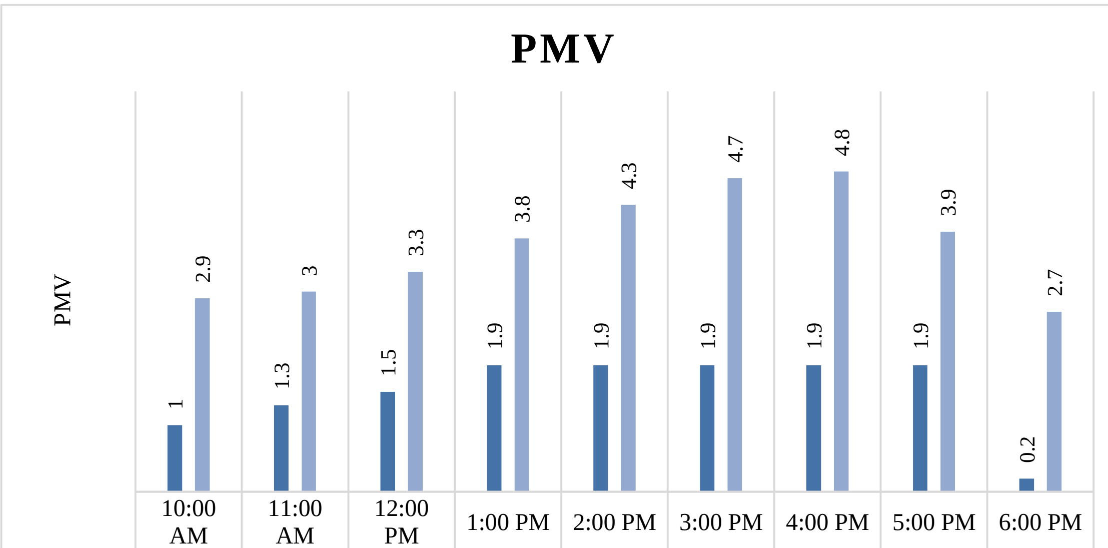


Figure 7. PMV for case B (with greenery) at 12 PM



	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM
Case B	1	1.3	1.5	1.9	1.9	1.9	1.9	1.9	0.2
Case A	2.9	3	3.3	3.8	4.3	4.7	4.8	3.9	2.7

Figure 8. Thermal Comfort (PMV) difference between case A and B

7. Input Data for the Street Block

On the street scale, attention to climate around buildings is targeted, Base case C (without greenery) and case D (with greenery). A single street was considered for simulation, a 3D model is shown in Figure 9. The same meteorology settings inherited; with the initial conditions of 3 m/s for the wind velocity and 345 deg. for the wind course. The simple forcing for the air temperature and the relative humidity are used along one day time span, with a base air temperature of 28 ℃ at 10 am and a greatest estimation of 41 ℃ at 6 pm. The relative humidity was 56%. The total simulation time was 8 hours. The displayed zone has the accompanying measurements: 100 × 100 m^2. The model territory has been rendered with network measure 150 cells along the x hub, 150 cells along the y pivot and 22 cells along the z hub. The extent of a lattice cell was: dx=2 m, dy=2 m and dz=3 m. The model was turned off 0° according to the area of the structures to the fundamental North direction.

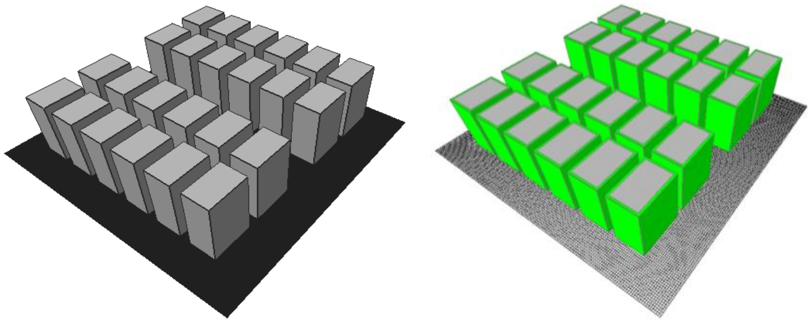


Figure 9. Perspective view for Street block; Case C and D

7.1. Air Temperature Results for Street Block

The distribution of air temperatures for the two cases C & D were plotted at noon, with 1.5 m above the ground. In Figures 11 and 12, Base case C recorded a maximum air temperature of 33 °C; mainly above the asphalt streets around the buildings. In between buildings the temperature was around 30 °C; a 3 °C reduction than the street due to shading. Figure 10 is a section elevation representing the air temperature. As it is show higher temperature is close to the asphalt street surface, reaches 33 °C; as you go higher the temperature starts alter and reduced to 30℃.

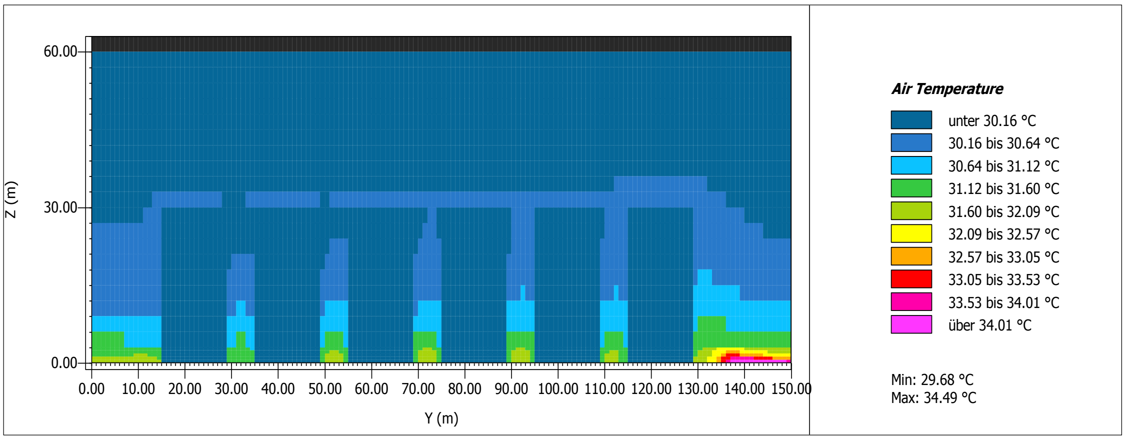


Figure 10. Section elevation for Case C - street block at 12 pm

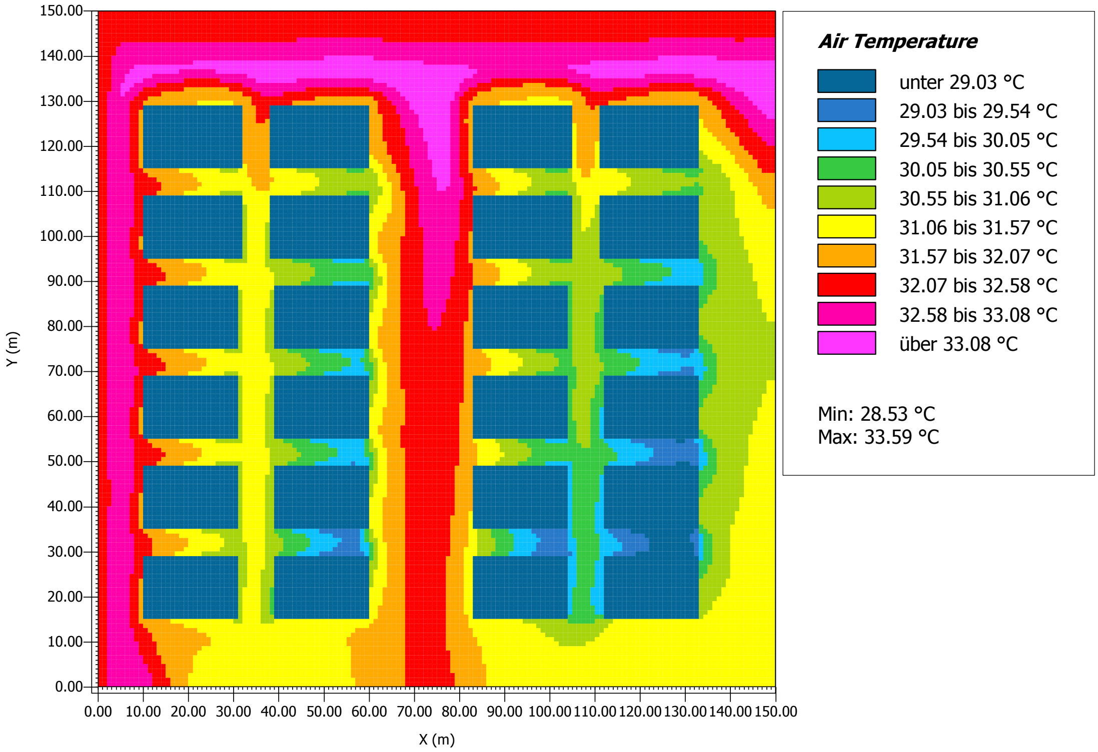


Figure 11. Air temperature map Case C at 1.5 m above the ground; 12 pm

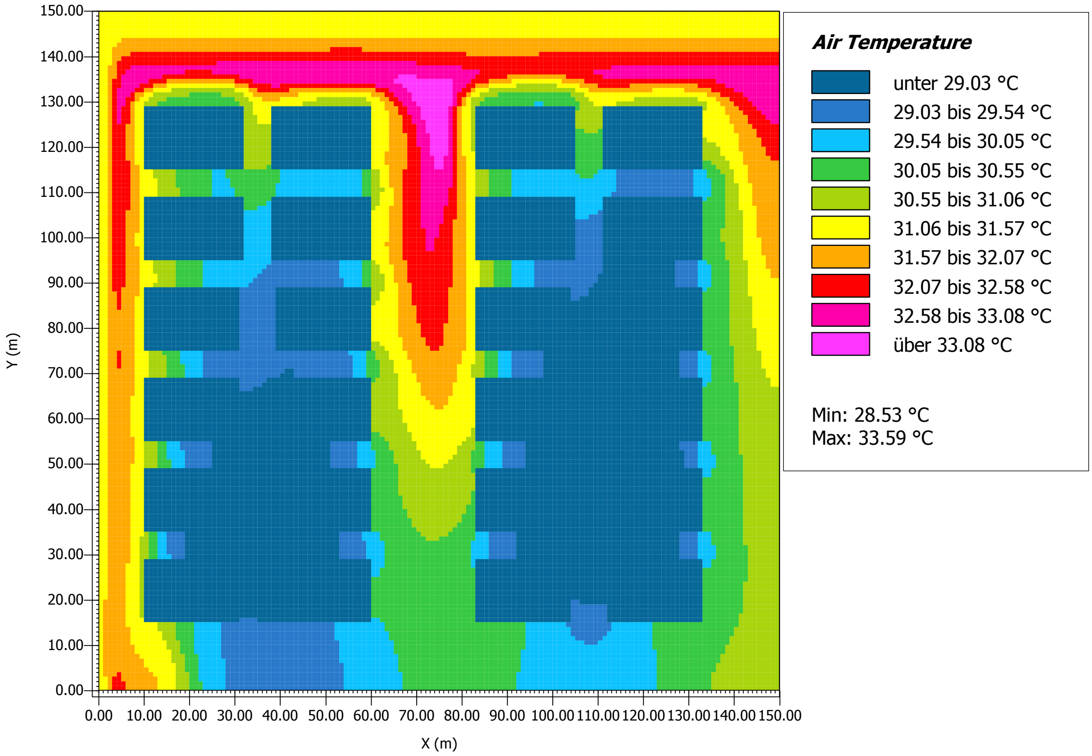


Figure 12. Air temperature map Case D at 1.5 m above the ground; 12 pm

The distribution of air temperatures at noon for Case D (with green walls) is shown in Figure 13 reveals that we have obtained an obvious decrease in temperature with the air temperature from Case C. All buildings in Case D are surrounded with a green wall. As an outcome, they have a tendency to retain a noteworthy extent of the heat. Vegetation captures radiation and produces shading that adds to diminishing the urban heat discharge. The nearness of vegetated dividers in Case D restrains air cooling because of the air dissemination produced among vegetation and structures.

The air temperature in Case C is reliably higher than the air temperature in Case D. Higher temperatures in Case C happen on account of the thick centralization of materials like black-top and cement in structures. These materials ingest warm amid the day and discharge it gradually around evening time. It is the opposite for Case D which development materials absorbs heat gradually and mirror the radiation at day time. As indicated by numerous analysts, UHI for the most part achieves its highest intensity after sunset, when the urban surfaces have adequately warmed-up. Consequently, the urban region with elevated structures displays temperatures a few degrees higher than the surroundings region around evening time demonstrating the impact of UHI.

7.2. Thermal Comfort Results for Street Block

Figures 13 and 14 present the Predicted Mean Vote (PMV) results at noon for the two cases C & D. The findings of case C, as shown in Figure 13 indicate that the Predicted Mean Vote ranges from 2.49 to 3.48, this indexed as hot. In Case D the (PMV) is about 1.9 – 3.3 meaning that some places especially around buildings it is possible to obtain cooler areas than in case C. There is a difference in 1 PMV value between the two cases. This is due to implementing green walls around buildings; which enhances the outdoor climate, reduces air temperature and provide a better condition for pedestrian in arid climates.

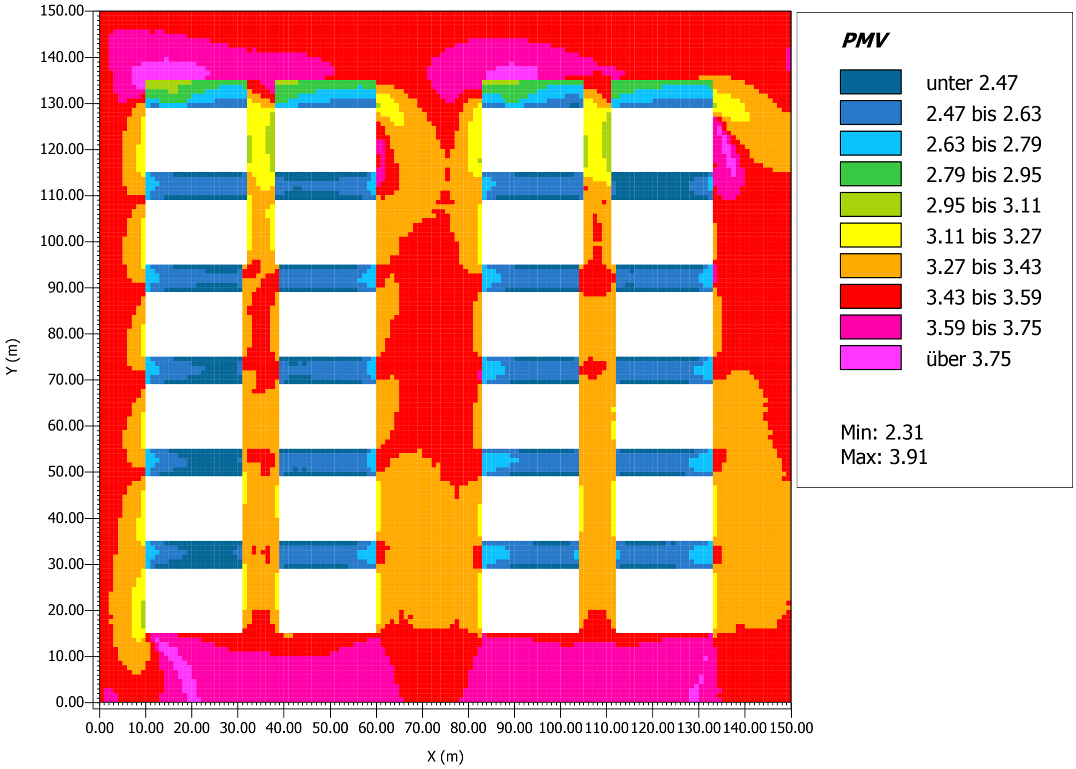


Figure 13. PMV for Case C at 1.5 m above the ground; 12 pm

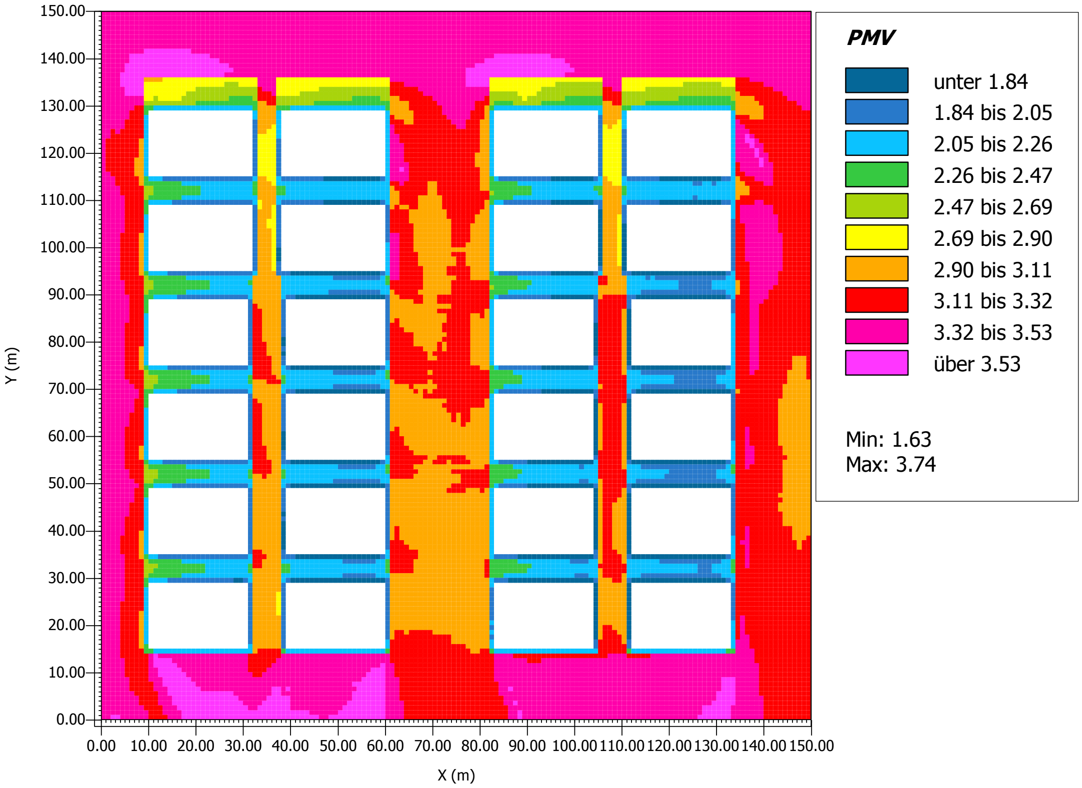


Figure 14. PMV for Case D at 1.5 m above the ground; 12 pm

8. Results Analysis

The temperatures of the urban surroundings are normally controlled by albedo of the materials that assimilate and discharge diverse amount of Latent heat. Subsequently, green walls is a decent alternative to supplant those surfaces with vegetation. Vegetation oversees the temperature examples of a microclimatic territory through transpiration the water, change the wind speed, and give shading on the heat permeable surfaces and adjusting the heat exchange among urban surface. Green dividers plays out a steady heat sink with evaporative cooling process, and decrease the retaining measure of radiative vitality when contrasted with a solid surface. This low sun based retaining normal for the green dividers diminishes the surface air temperature and lessens the warmth transition. What's more, green walls can give numerous natural advantages to the site other than temperature relief.

9. Conclusion

The green envelope on walls, proved the possibility of reducing the external heat of the residential neighbourhood by a large proportion throughout the 2nd of August, which is the hottest day. The air temperature of a city block in Mohandseen was calculated. This city block consists of three different building heights (5, 10 and 15 floors). The simulation was carried out from 10 am to 6 pm for the existing situation without adding a green layer and once again when a green wall was added. The results showed a temperature reduction by an average of 10 °C throughout the day when implanting the walls. This is followed by outdoor thermal comfort investigation, measured in PMV index. The results accounted for a difference of 2 PMV values (from HOT to COOL) for the whole city block. The properties of green walls can directly affect the results of thermal comfort as leafs absorbs, reflects and transmits solar radiation, and increases the evapotranspiration. These results are significant and impact the urban heat island in the city of Cairo.

10. Conflicts of Interest

The authors declare no conflict of interest.

11. References

[1] Asif, M. "Growth and Sustainability Trends in the Buildings Sector in the GCC Region with Particular Reference to the KSA and UAE." Renewable and Sustainable Energy Reviews 55 (March 2016): 1267–1273. doi:10.1016/j.rser.2015.05.042.

[2] Abdul Mujeebu, Muhammad, and Othman Subhi Alshamrani. "Prospects of Energy Conservation and Management in Buildings – The Saudi Arabian Scenario Versus Global Trends." Renewable and Sustainable Energy Reviews 58 (May 2016): 1647–1663. doi:10.1016/j.rser.2015.12.327.

[3] Asif, Muhammad. "Urban Scale Application of Solar PV to Improve Sustainability in the Building and the Energy Sectors of KSA." Sustainability 8, no. 11 (November 3, 2016): 1127. doi:10.3390/su8111127.

[4] Basarir, Bahar, Berrin Sahin Diri, and Cüneyt Diri. "Energy efficient retrofit methods at the building envelopes of the school buildings." Retrieved 10, no. 12 (2012): 2016.

[5] Nasir, Rabiatul Adawiyah, Sabarinah Sh Ahmad, Azni Zain-Ahmed, and Norhati Ibrahim. "Adapting Human Comfort in an Urban Area: The Role of Tree Shades Towards Urban Regeneration." Procedia - Social and Behavioral Sciences 170 (January 2015): 369–380. doi:10.1016/j.sbspro.2015.01.047.

[6] De Abreu-Harbich, Loyde Vieira, Lucila Chebel Labaki, and Andreas Matzarakis. "Effect of Tree Planting Design and Tree Species on Human Thermal Comfort in the Tropics." Landscape and Urban Planning 138 (June 2015): 99–109. doi:10.1016/j.landurbplan.2015.02.008.

[7] Vailshery, Lionel Sujay, Madhumitha Jaganmohan, and Harini Nagendra. "Effect of Street Trees on Microclimate and Air Pollution in a Tropical City." Urban Forestry & Urban Greening 12, no. 3 (January 2013): 408–415. doi:10.1016/j.ufug.2013.03.002.

[8] Shashua-Bar, Limor, Ioannis X. Tsiros, and Milo E. Hoffman. "A Modeling Study for Evaluating Passive Cooling Scenarios in Urban Streets with Trees. Case Study: Athens, Greece." Building and Environment 45, no. 12 (December 2010): 2798–2807. doi:10.1016/j.buildenv.2010.06.008.

[9] Santamouris, M. "Cooling the Cities – A Review of Reflective and Green Roof Mitigation Technologies to Fight Heat Island and Improve Comfort in Urban Environments." Solar Energy 103 (May 2014): 682–703. doi:10.1016/j.solener.2012.07.003.

[10] Chen, Hong, Ryozo Ooka, Hong Huang, and Takashi Tsuchiya. "Study on Mitigation Measures for Outdoor Thermal Environment on Present Urban Blocks in Tokyo Using Coupled Simulation." Building and Environment 44, no. 11 (November 2009): 2290–2299. doi:10.1016/j.buildenv.2009.03.012.

[11] Francis, Lotte Fjendbo Møller, and Marina Bergen Jensen. "Benefits of Green Roofs: A Systematic Review of the Evidence for Three Ecosystem Services." Urban Forestry & Urban Greening 28 (December 2017): 167–176. doi:10.1016/j.ufug.2017.10.015.

[12] World Bank. (2017). Energy Subsidy Reform Facility Country Brief: Egypt. Available at: http://documents.worldbank.org [Accessed 16 July 2018].

[13] Makropoulou, Maria. "Microclimate Improvement of Inner-City Urban Areas in a Mediterranean Coastal City." Sustainability 9, no. 6 (May 25, 2017): 882. doi:10.3390/su9060882.

[14] Castiglia Feitosa, Renato, and Sara J. Wilkinson. "Attenuating Heat Stress through Green Roof and Green Wall Retrofit." Building and Environment 140 (August 2018): 11–22. doi:10.1016/j.buildenv.2018.05.034.

[15] Bevilacqua, Piero, Domenico Mazzeo, and Natale Arcuri. "Thermal Inertia Assessment of an Experimental Extensive Green Roof in Summer Conditions." Building and Environment 131 (March 2018): 264–276. doi:10.1016/j.buildenv.2017.11.033.

[16] Morakinyo, Tobi Eniolu, K.W.D.Kalani.C. Dahanayake, Edward Ng, and Cheuk Lun Chow. "Temperature and Cooling Demand Reduction by Green-Roof Types in Different Climates and Urban Densities: A Co-Simulation Parametric Study." Energy and Buildings 145 (June 2017): 226–237. doi:10.1016/j.enbuild.2017.03.066.

[17] Cascone, Stefano, Federico Catania, Antonio Gagliano, and Gaetano Sciuto. "A Comprehensive Study on Green Roof Performance for Retrofitting Existing Buildings." Building and Environment 136 (May 2018): 227–239. doi:10.1016/j.buildenv.2018.03.052.

[18] Castiglia Feitosa, Renato, and Sara J. Wilkinson. "Attenuating Heat Stress through Green Roof and Green Wall Retrofit." Building and Environment 140 (August 2018): 11–22. doi:10.1016/j.buildenv.2018.05.034.

[19] Besir, Ahmet B., and Erdem Cuce. "Green Roofs and Facades: A Comprehensive Review." Renewable and Sustainable Energy Reviews 82 (February 2018): 915–939. doi:10.1016/j.rser.2017.09.106.

[20] Wong, Nyuk Hien, Alex Yong Kwang Tan, Yu Chen, Kannagi Sekar, Puay Yok Tan, Derek Chan, Kelly Chiang, and Ngian Chung Wong. "Thermal Evaluation of Vertical Greenery Systems for Building Walls." Building and Environment 45, no. 3 (March 2010): 663–672. doi:10.1016/j.buildenv.2009.08.005.

[21] Takakura, T, S Kitade, and E Goto. "Cooling Effect of Greenery Cover over a Building." Energy and Buildings 31, no. 1 (January 2000): 1–6. doi:10.1016/s0378-7788(98)00063-2.

[22] Rezvani, M., F. Zaefarian, and M. Jovieni. "Weed Suppression Ability of Six Soybean [Glycine max(L.) Merr.] Varieties Under Natural Weed Development Conditions." Acta Agronomica Hungarica 61, no. 1 (March 2013): 43–53. doi:10.1556/aagr.61.2013.1.5.

[23] Jim, C.Y. "Green-Space Preservation and Allocation for Sustainable Greening of Compact Cities." Cities 21, no. 4 (August 2004): 311–320. doi:10.1016/j.cities.2004.04.004.

[24] Weather spark. (2019). Average Weather in Cairo Egypt. [ONLINE] Available at: https://weatherspark.com/m/96939/9/Average-Weather-in-September-in-Cairo-Egypt. [Accessed 5 March 2019].

[25] Chow, W.K. "Application of Computational Fluid Dynamics in Building Services Engineering." Building and Environment 31, no. 5 (September 1996): 425–436. doi:10.1016/0360-1323(96)00012-1.

[26] Ozkeresteci, I., K. Crewe, A. J. Brazel, and M. Bruse. "Use and evaluation of the ENVI-met model for environmental design and planning: an experiment on linear parks." In Proceedings of the 21st International Cartographic Conference (ICC), Durban, South Africa, pp. 10-16. 2003.