Green Building & Construction Economics
https://ojs.wiserpub.com/index.php/GBCE/

UNIVERSAL WISER PUBLISHER

Conference Proceeding

Paper presented at Sustainability GEN-4 Post COP 27 Conference 2023, October University for Modern Sciences and Arts (MSA), Egypt

Investigating the Impacts of Urban Microclimate on Building Thermal Performance in Present and Future Climatic Conditions: A Case of New Obour City, Egypt

Eman A. Saleh[1*], **Bassel Essam**[2]

[1]Urban Design & Community Development, MSA University, Cairo, Egypt
[2]Department of Architectural Engineering and Environmental Design, Arab Academy for Science, Technology and Maritime Transport, Smart Village Campus, Cairo, Egypt
E-mail: easaleh@msa.edu.eg

Received: 28 December 2022; **Revised:** 22 March 2023; **Accepted:** 19 April 2023

Abstract: Artificial intelligence (AI) has enabled urban planners to forecast microclimate conditions, allowing them to think smartly and optimise urban design. Coupled outdoor-indoor simulations were used to overcome the packages' inability to handle both objectives in one tool because indoor simulation methods do not consider microclimatic interactions. To predict metrological climate conditions and carbon dioxide (CO_2), ENVI-met V4.0 simulations (accounting for outdoor conditions) were combined with indoor simulations using DesignBuilder V4.2. This paper is based on a case study in New Obour City, Egypt, that begins by creating the neighbourhood using design specifications with several weather files (EPW, STAT, DDY, and Audit) to simulate and estimate future changes, then comparing the current and future in 2080. The findings highlight the significance of AI in architectural optimisation, adaptation, and prediction for long-term sustainable design. Moreover, the study presents the various flaws in the design that might be addressed to accommodate climate change. That was tackled by the active simulation for the two representative design days in the years 2023 and 2080 in the chosen neighbourhood to result in certain parameters influencing thermal comfort, including air temperature, relative humidity, wind speed, CO_2, predicted mean vote (PMV), and physiological equivalent temperature (PET). The results of this study can serve as a reference for architects, urban designers, and planners in the early design stages to attain sustainable residential neighbourhoods.

***Keywords*:** AI, ENVI-met, optimisation, coupling techniques, urban microclimate, sustainable neighbourhood

1. Introduction

In recent years, computer algorithms have become more powerful and intelligent in architecture due to the crossing characteristics of urban climatology, which is a challenging field. The realm of sustainable cities is to some extent dependent on environmentally designed and planned buildings since they represent roughly half of city land use budgets [1], which is an Egyptian and worldwide ratio [2]. As a result, neglecting the thermal efficiency of outdoor areas in the urban design process is one of the leading causes of urban design degradation and consequent discomfort [3]. This happens because there is no single response to severe heat stress [4, 5].

Various forms of urban patterns have different microclimates [6]. Designing urban forms other than fabric

DOI: https://doi.org/10.37256/gbce.4120232287

geometrical alterations and green covering passive cooling methods is a mess. The courtyard as a concept for improved microclimates has been studied in arid regions and discovered to be a sensitive and intelligent fabric form. Although it may not be capable of creating optimum circumstances on its own [7-11], it must be combined with other passive cooling applications, such as vegetation, which promotes shade, ventilation, and evaporation, particularly in hot desert conditions [8, 12].

Cairo witnessed continuous historical developments since 641 Anno Domini (AD) until its current populated master plan, as well as a rapid development process since the late twentieth century when the Egyptian government began constructing generations of new cities in the rural reserve areas of the main and megacities [13]. Since housing accounts for 50 to 70% of city land use budgets, it is critical on a national, regional, and international level to examine how housing design might be developed and planned to cope with the changing climate of the twenty-first century through free urban planning [14]. Cities account for 39% of worldwide carbon emissions, and buildings contribute to more than 40% of any country's energy usage. As a result of global warming, the average temperature of Cairo, Egypt's capital, is anticipated to rise by 4 ºC by 2060 and by 3.1 to 4.7 ºC throughout the country [15, 16]. The temperature is anticipated to rise by 5.6 ºC between 1990 and 2100 [16]. As a result, neighbourhood master planning, as an urban planning unit, must adapt to the arid climate, where the built environment's surface temperature, for example, can easily exceed 50 ºC in unshaded places due to extreme microclimate conditions [17, 18].

There are few computer tools available for this purpose, particularly at large urban scales. Among these tools, ENVI-met has authorised partial validity, which allows for master-lane comparisons based on impact assessment. It is a three-dimensional (3D) microclimate model that can mimic surface-plant-air interactions in urban contexts with a typical spatial resolution of 0.5 to 10 m and a temporal resolution of 10 sec. ENVI-met is a 3D non-hydrostatic numerical model [19, 20] that can analyse all meteorological parameters [20], as well as a prognosis model based on fundamental fluid dynamics rules [21, 22]. However, because there is a close correlation between outdoor and indoor environmental performance [23, 24], designers must investigate techniques for overcoming the relationship complications resulting from the overwhelming parameters. Especially given the size of the sites evaluated, where measurements are required at every point of the urban space to reach the ultimate goal, this is a dream.

Therefore, the main goal of this study is to investigate the adaptation potential of urban communities in Egypt to climate change through the optimisation of urban design and its influence on residential energy efficiency in the present and future. This research aims at using coupled simulations to analyse a redesigned neighbourhood in New Obour City based on the literature on the urban design using software like ENVI-met and DesignBuilder to present metrological data in a typical representative day from the Ecotect Analysis auxiliary tool. Moreover, a full data presentation of a future-day prediction in the year 2080 is also provided.

2. Problem definition

In the last 11 years, concentration on evaluating outdoor areas has been limited [16]. The rapid development of existing urban areas has been observed globally in recent decades. Sustainable development is no longer a luxury; it is now necessary for humans to mitigate and manage the risks of climate change, which is thought to be caused by continuous and growing emissions of greenhouse gases (GHG) [25]. There is a solid understanding in the field of sustainable urban development that connecting climatology to the applied practice of urban planning is complex [26], and its detailed task description increases complexity [27, 28] in a country like Egypt, where most of its map is arid, and contrary to this, most of the new urban developments are dot-like or at most linear without climate-responsive patterns.

Thus, the main problem statement of the research is that in both urban planning and design approaches, there is still a gap between knowledge and implementation of sustainable techniques. Furthermore, the urban pattern of most neighbourhoods is mostly a dot pattern without enabling climatic responsive techniques to examine its thermal comfort according to existing weather conditions and future conditions too.

3. Research questions

This research answers several questions:

a. Can the researchers present data simulation charts for existing weather conditions using certain software like DesignBuilder and ENVI-met for a designed neighbourhood?
b. Can urban designers predict scenarios for climate change's impact on meteorological parameters at the early design stages?
c. How do you integrate the results of the outdoor and indoor parameters for a neighbourhood by using coupling techniques?

4. Coupling techniques and urban microclimate modelling

Studies on the coupling of urban microclimate and building energy models (BEM) have focused on the impacts of urban microclimate on stand-alone or several buildings in a simple urban setting. Recently, the physical-based urban building energy modelling (UBEM) approach has been used to capture more accurate urban building performance at a high spatiotemporal resolution. However, consideration of urban microclimate effects in previous UBEM studies has been limited due to the difficulty of balancing the requirements of high-resolution microclimate data with the computational resources involved [29]. As shown in Figure 1, the workflow chart combines outdoor with indoor by a coupling technique to enhance urban and building sustainability.

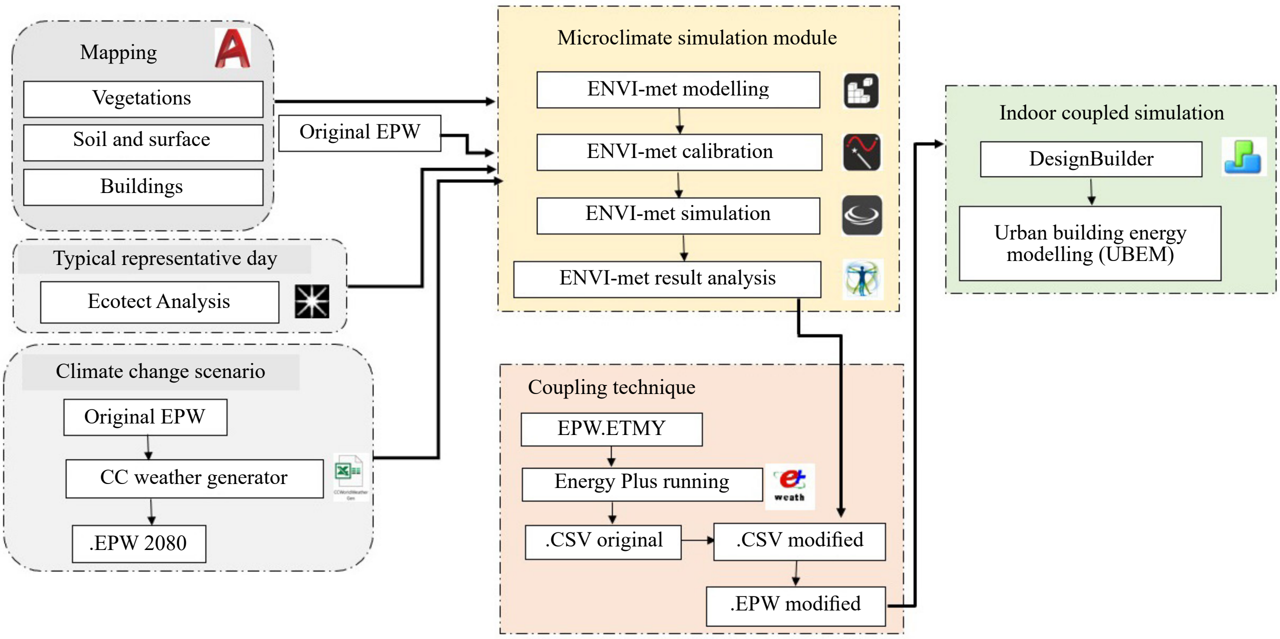


Figure 1. Co-simulation workflow of urban and building microclimate

5. Methodology

A neighbourhood in New Obour City, which lies in Cairo, with an area of 360,000 m^2 or 85 acres, was redesigned as a residential neighbourhood with different types of clusters. The neighbourhood serves 10,284 people with a total of 2,580 units. The heights of the blocks do not exceed five floors for each block, with four units on each floor.

Numerical simulations were performed, using both thermal and computational fluid dynamics (CFD) software, for a hot summer's day in New Obour City, Al Qalyubia, with the Cairo International Airport typical metrological year (TMY) weather file and the aid of the Ecotect Analysis auxiliary tool, as shown in Figures 2 and 3, to assess such transient complex environmental and personal factors affecting meteorological parameters in urban spaces. As shown in Figure 4, the research location area is New Obour City. Figure 5 shows the architectural characteristics of a nearby neighbourhood.

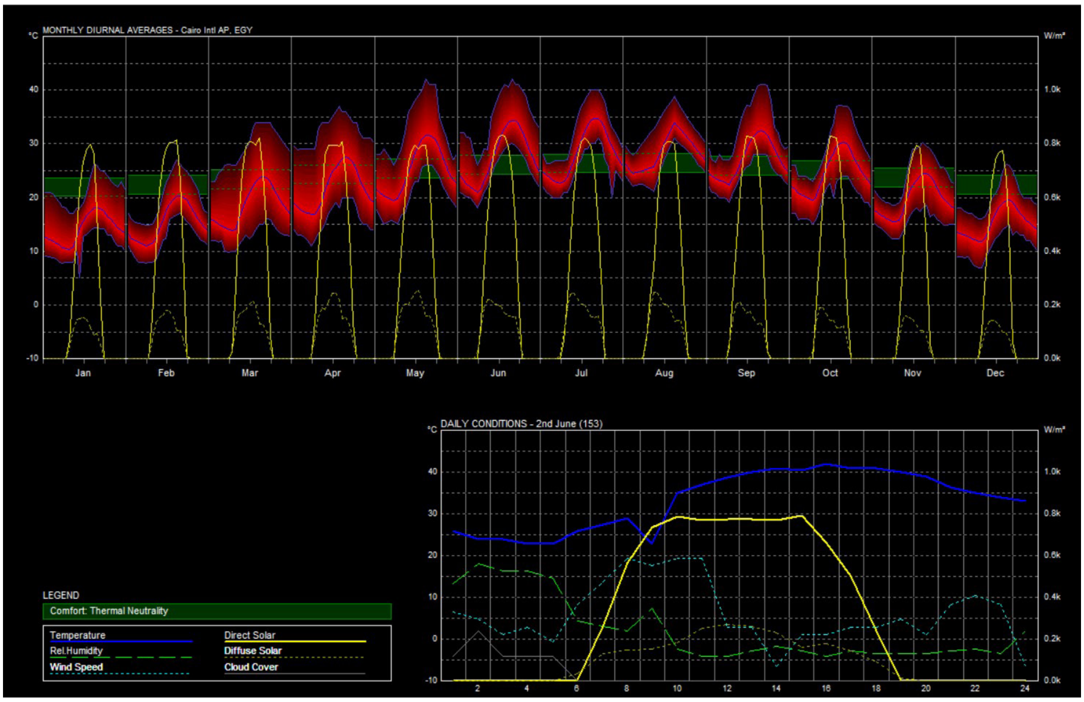


Figure 2. Ecotect shows a typical representative date of June 2, 2023

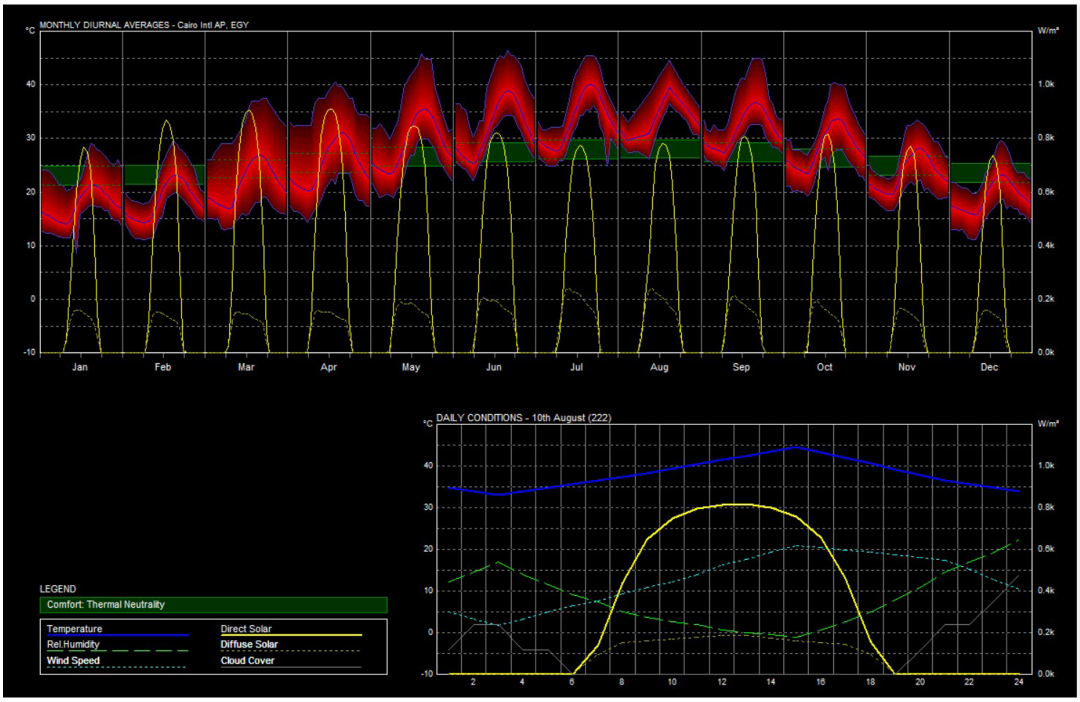


Figure 3. Ecotect shows a typical representative date of August 10, 2080

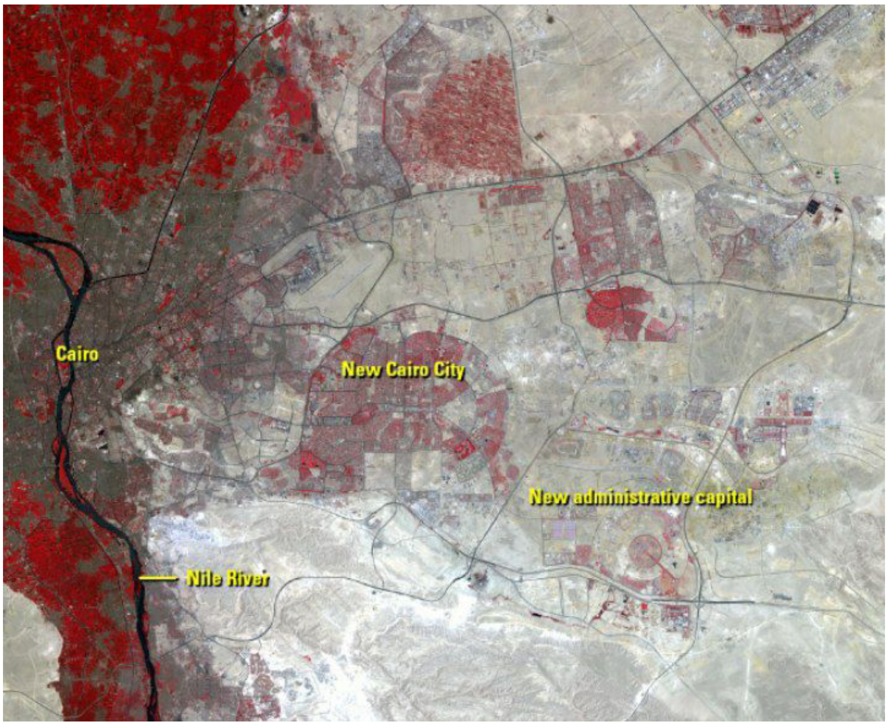


Figure 4. The location of New Obour City in Cairo and the chosen neighbourhood in New Obour City [29, 30]

Figure 5. New Obour City urban pattern and architectural characteristics of a nearby neighbourhood

Ecotect software selected the representative typical design day, which illustrated the day with the highest temperature in the years 2023 and 2080. As a result of climate change, it was discovered that the representative typical design day differs significantly between the two years, with the software detecting the 2nd of June in 2023 and the 10th of August in 2080.

5.1 *Research location area*

a) Case study: New Obour City, Cairo (30.22° N, 31.47° E, and 76.19 m altitude)
b) Area: 1,200 m × 300 m = 360,000 m^2
c) Approach: Streets directed in the north direction

d) Objective: Investigate the urban microclimate through outdoor simulation which generates and analyses climatic data for 2023 and 2080 using ENVI-met software; to generate the area climatic parameters and to determine external thermal comfort; followed by using the coupling technique by DesignBuilder

e) Urbanisation type: Local Climate Zone (LCZ) 2 (compact midrise) with LCZ B (scattered trees)

As shown in Figure 6, the neighbourhood of New Obour City was designed according to the approach and the objectives of the case study.

Figure 6. The neighbourhood in New Obour City, Cairo

5.2 *Methods*

To run the simulation process, it requires a long time, which may reach 72 hours or more. The case study of New Obour City is located in Egypt, at 43° north direction. As shown in Figure 7, starting with conceptual sketches that are needed at early design stages to freely figure out the concept, neighbourhood calculations are then needed to stand on density, block number, service, commercial, educational areas, garages, and roads. This is followed by drawing the master plan in real dimensions with the aid of the AutoCAD programme, modelling in spaces (ENVI-met modelling tool) with a height of 16 m (ground + 4 floors), selecting two-dimensional (2D) plants of 50 cm grass pavers and 3D *Populus alba* plants that accommodate the Egyptian environment, and interlock coating.

To predicate the EnergyPlus Weather (EPW) data file in 2080, the Climate Change World Weather Generator is used. Also, the Energy Plus tool is used to get the STAT file for 2080. The typical representative days in 2023 and 2080, which are June 2, 2023, with sunrise at 4:57 AM, and August 8, 2080, with sunrise at 5:21 AM, are carried out with the help of the Ecotect Analysis auxiliary tool by entering weather data configurations using weather files for both 2023 and 2080 (EPW and STAT. Then, the results are simulated for five hours, visualised using the Leonardo auxiliary tool, and analysed with an Excel sheet to compare the potential change in all meteorological parameters (temperature, relative humidity, wind speed, predicted mean vote [PMV], etc.). The sustainability of the neighbourhood over the upcoming years is also measured.

To assure design resilience, sustainability, and climate change, a coupling method between outdoors and indoors should be put in place. Figure 8 shows the Egyptian TMY weather data file, its extensions (ddy\ .stat\ .epw\ .audit) and the Egyptian materials (DesignBuilder Database Files; DDF). In that stage, we are going to couple the original EPW file with the modified EPW file and then compare the modified EPW in the present, 2023, and the future, 2080, analysing air temperature, relative humidity, wind speed, carbon dioxide (CO_2) emissions, PMV, and physiological equivalent temperature (PET).

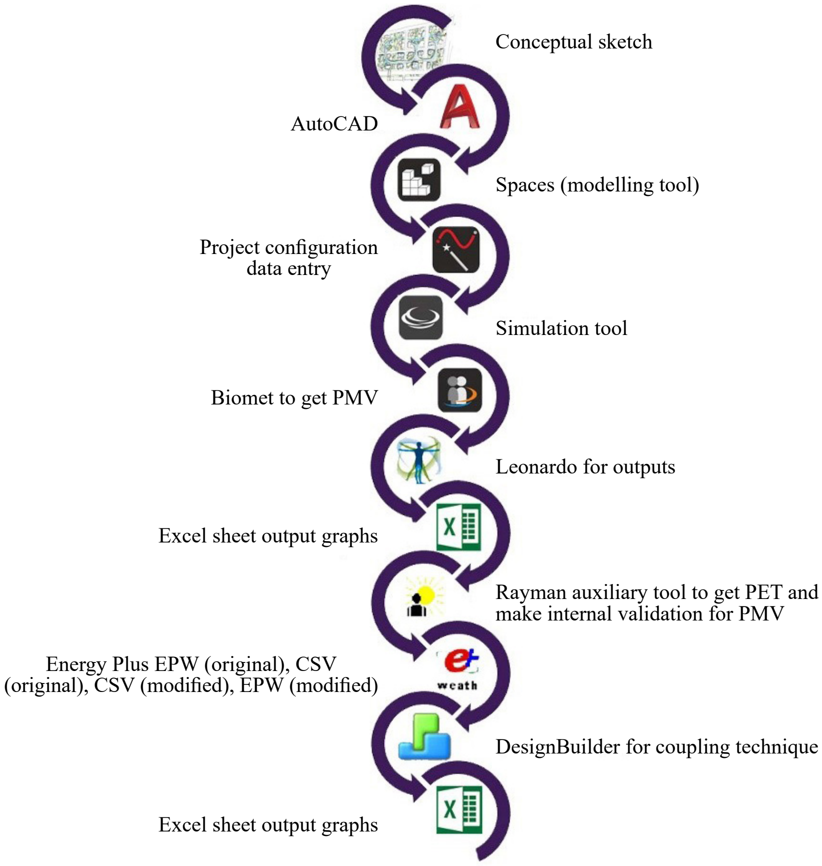


Figure 7. Processes and programmes used

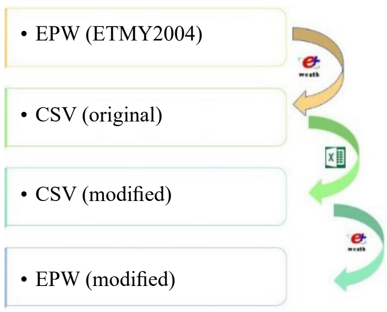


Figure 8. EPW modifications for coupling

6. Results

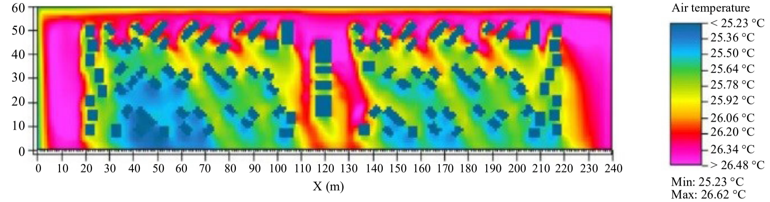
Table 1 shows the results of the five-hour simulation using the ENVI-met simulation tool and adding the calibrated model into the Leonardo auxiliary tool to optimise the outputs of the meteorological parameters in the years 2023 and 2080. The comparison of air temperature is displayed in Table 1, the comparison of relative humidity is shown in Table 2, the comparison of wind speed is shown in Table 3, and the comparison of PMV is shown in Table 4.

Results of air temperature comparison: Figure 9 shows the comparison between the present and future air temperatures, where it is colder at the beginning of the day and ranges between 25.95 and 32.39 °C in 2023 and 35.18 and 44.22 °C in 2080. Meanwhile, the highest temperature lies at 1 p.m. (the end of the day).

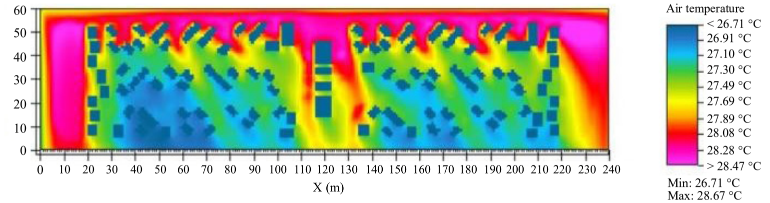
Table 1. Comparing air temperatures between 2023 and 2080

Air temperature on June 2, 2023

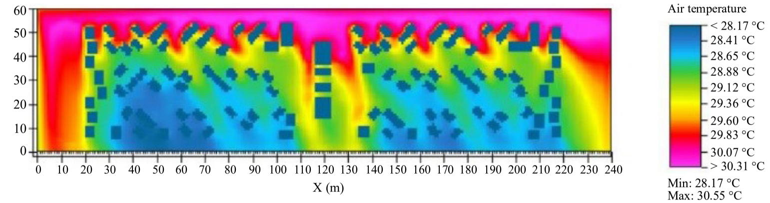
At 9 a.m.



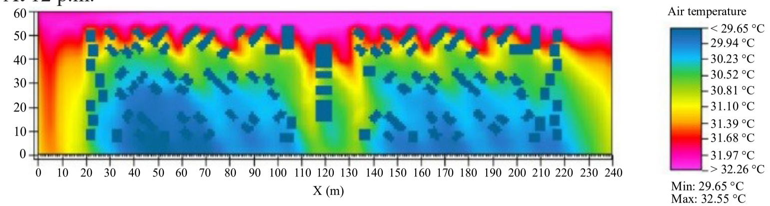
At 10 a.m.



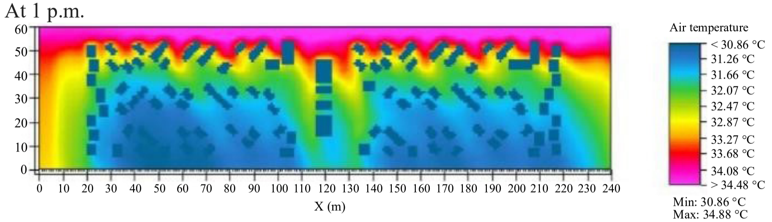
At 11 a.m.



At 12 p.m.

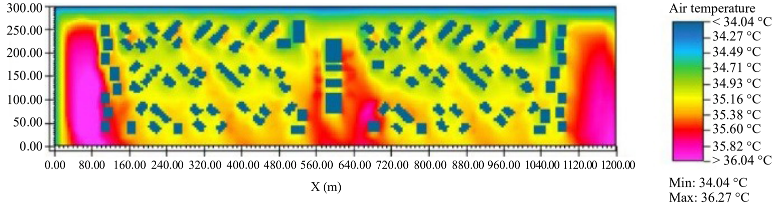


At 1 p.m.

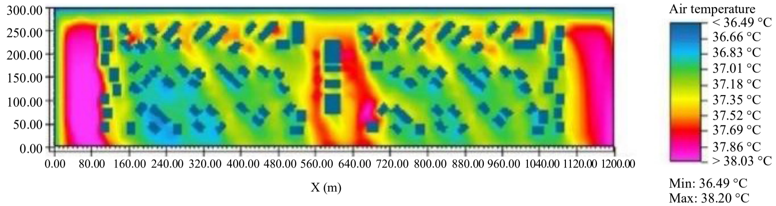


Air temperature on August 10, 2080

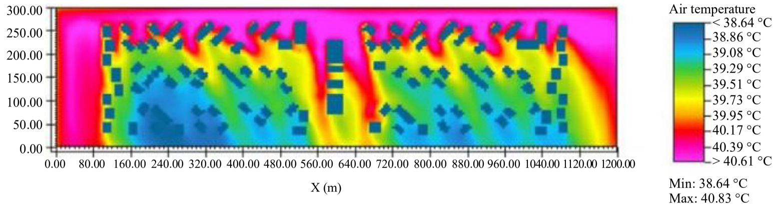
At 9 a.m.



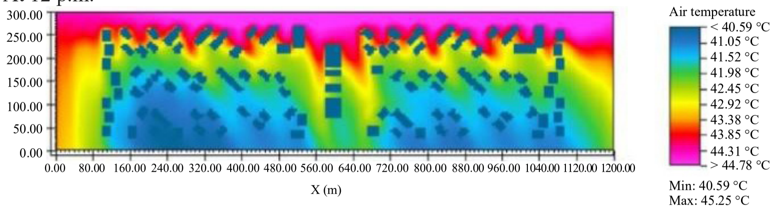
At 10 a.m.



At 11 a.m.



At 12 p.m.



At 1 p.m.

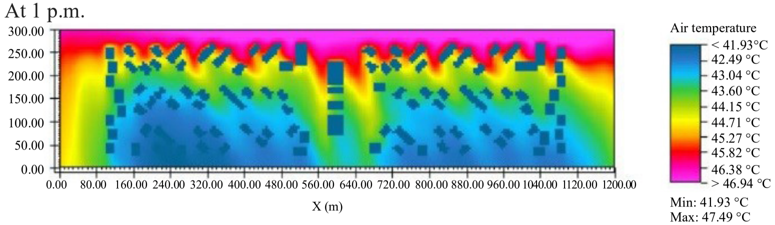


Table 2. Comparing relative humidity between 2023 and 2080

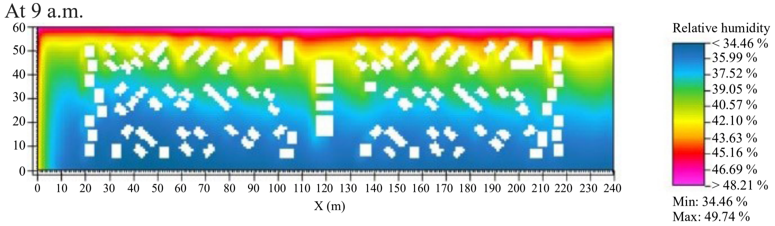
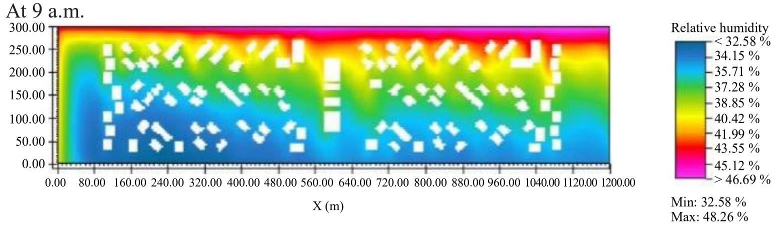
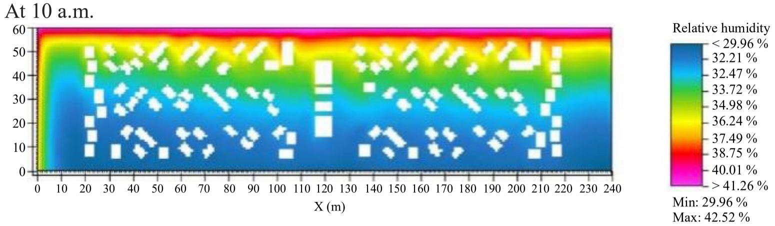
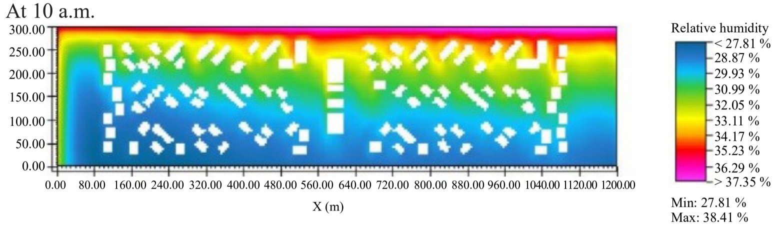
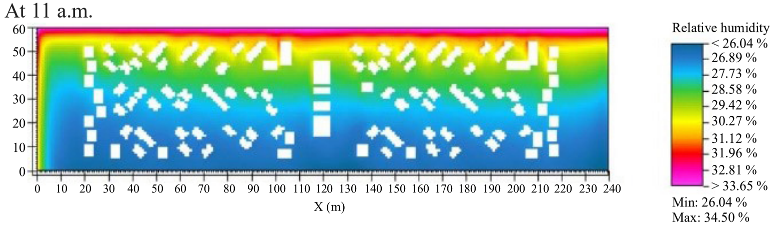
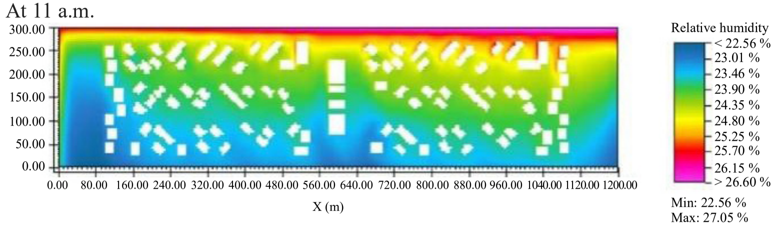
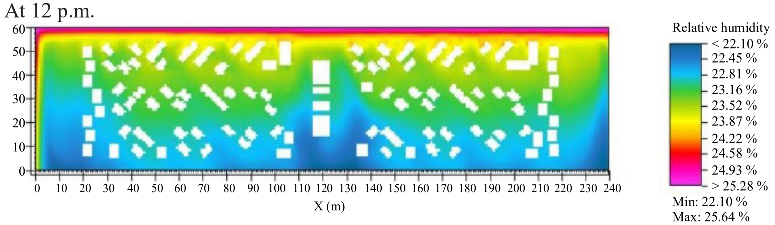
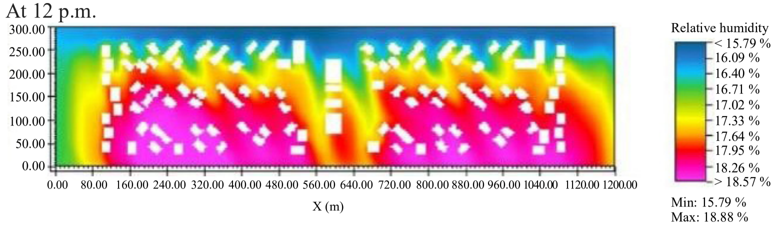
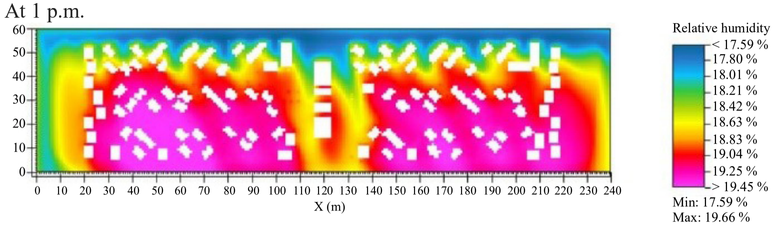
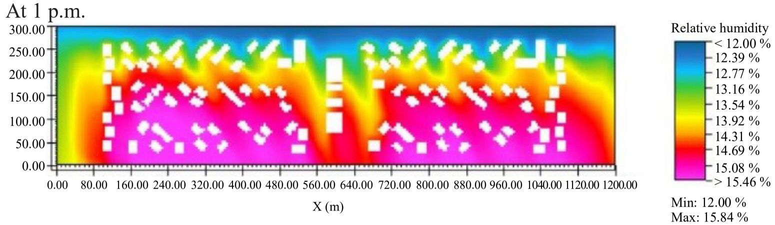
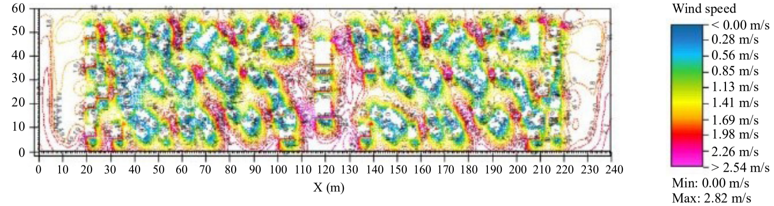
Relative humidity on June 2, 2023	Relative humidity on August 10, 2080
At 9 a.m. 	At 9 a.m. 
At 10 a.m. 	At 10 a.m. 
At 11 a.m. 	At 11 a.m. 
At 12 p.m. 	At 12 p.m. 
At 1 p.m. 	At 1 p.m. 

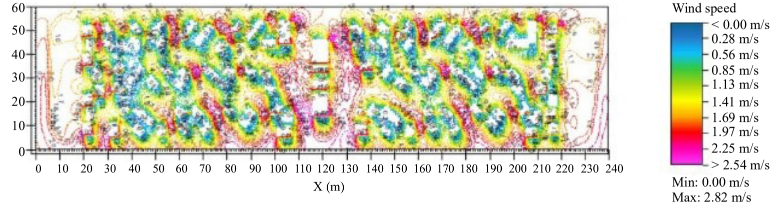
Table 3. Comparing wind speeds between 2023 and 2080

Wind speed on June 2, 2023

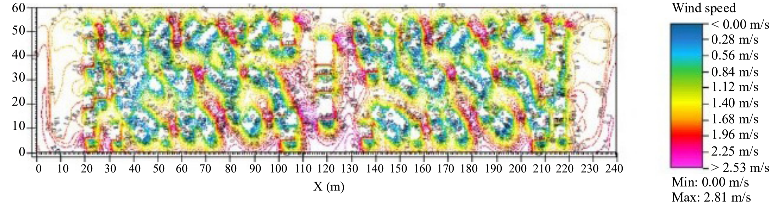
At 9 a.m.



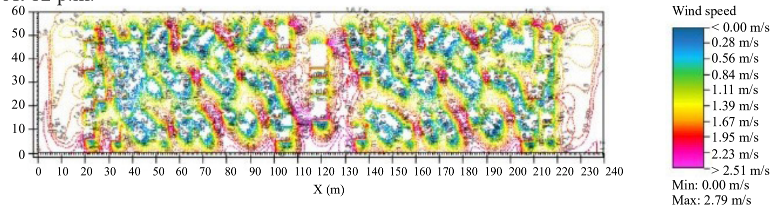
At 10 a.m.



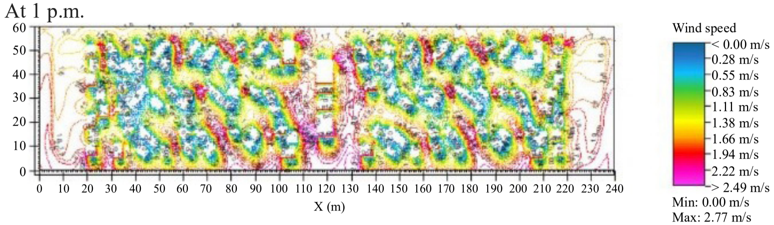
At 11 a.m.



At 12 p.m.

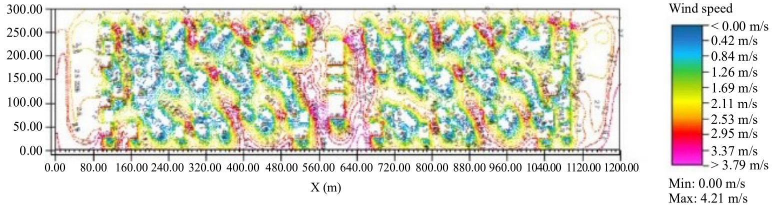


At 1 p.m.

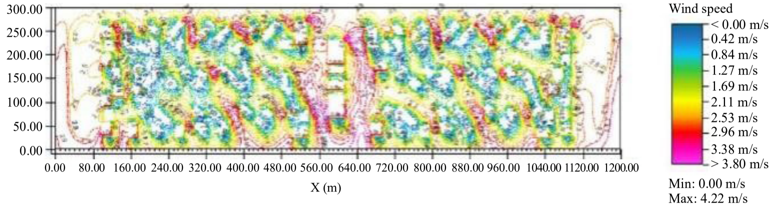


Wind speed on August 10, 2080

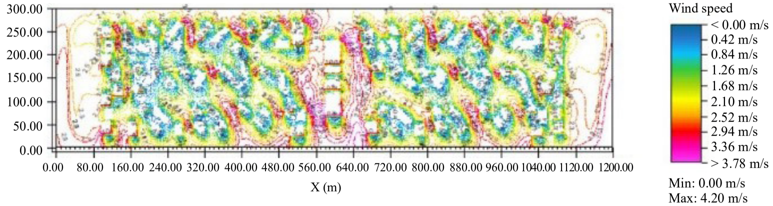
At 9 a.m.



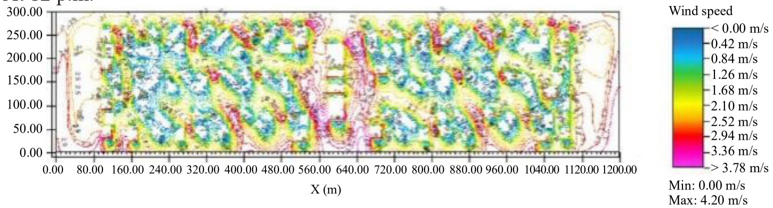
At 10 a.m.



At 11 a.m.



At 12 p.m.



At 1 p.m.

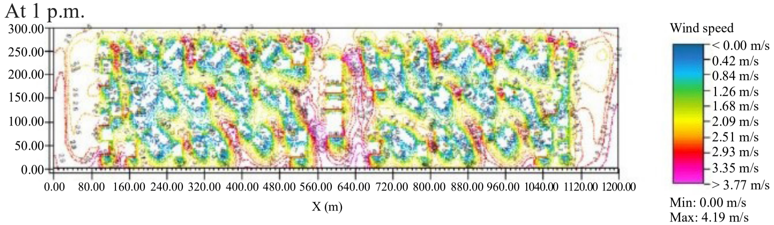
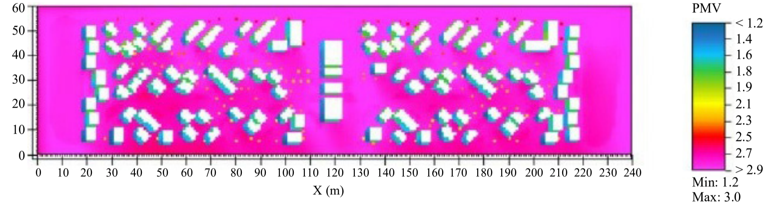
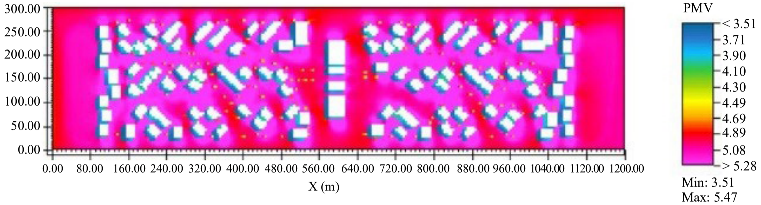
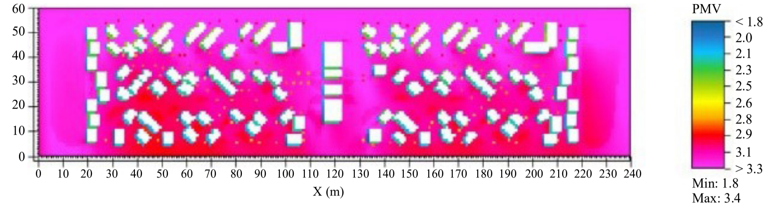
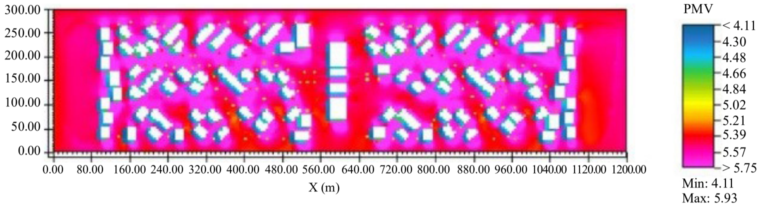
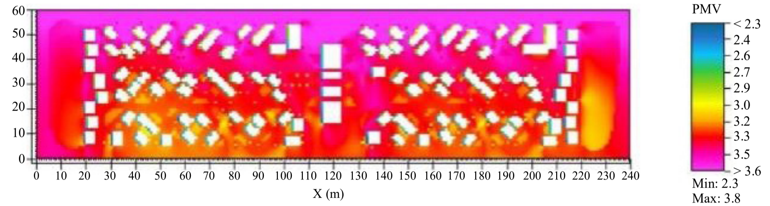
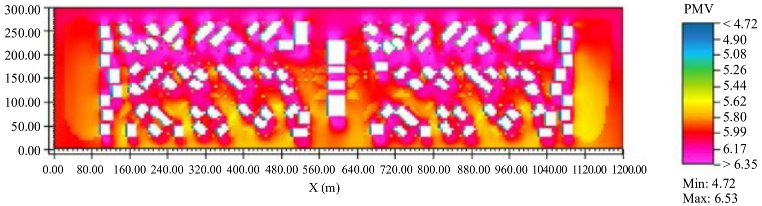
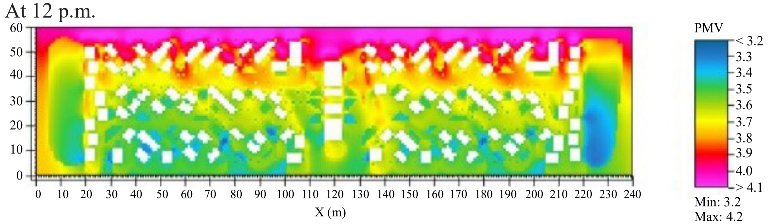
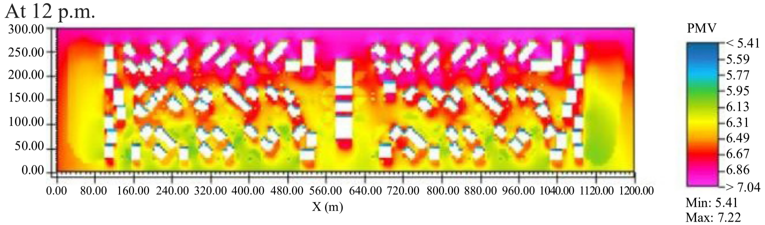
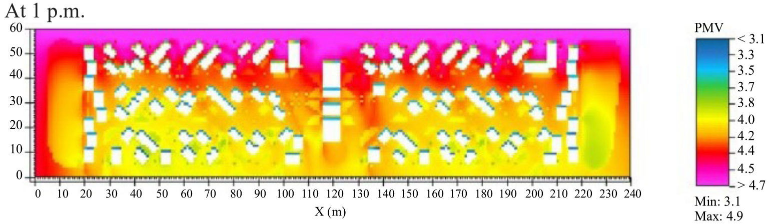
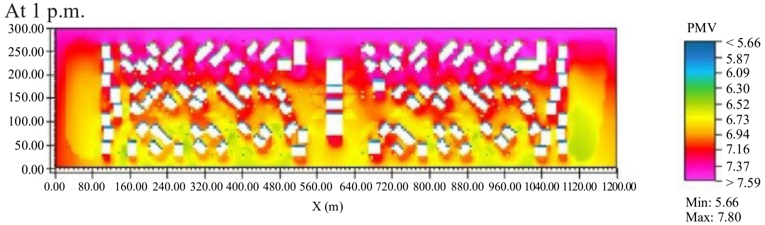


Table 4. Comparing PMV between 2023 and 2080

PMV on June 2, 2023	PMV on August 10, 2080
At 9 a.m. 	At 9 a.m. 
At 10 a.m. 	At 10 a.m. 
At 11 a.m. 	At 11 a.m. 
At 12 p.m. 	At 12 p.m. 
At 1 p.m. 	At 1 p.m. 

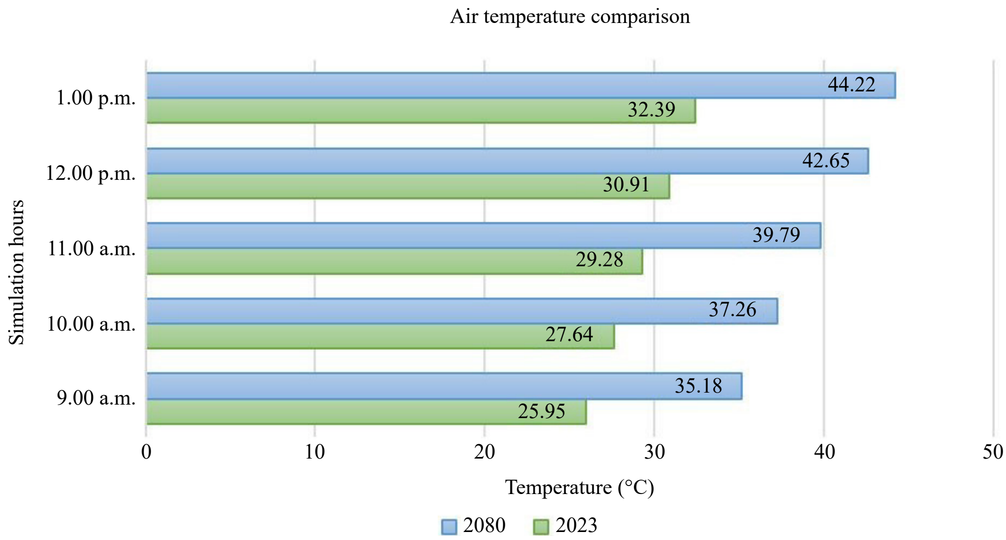


Figure 9. Air temperature comparison in 2023 and 2080

Results of relative humidity comparison: As shown in Figure 10, the results show that the relative humidity percentages are lower at the end of the day, where the percentage at 1 p.m. is 18.77% and 14.17% for 2023 and 2080, respectively. Meanwhile, the highest percentage lies at 9 a.m. in 2023 and 2080, recording 39.06% and 37.93%, respectively. The relative humidity shows a lower percentage in 2080 compared with 2023.

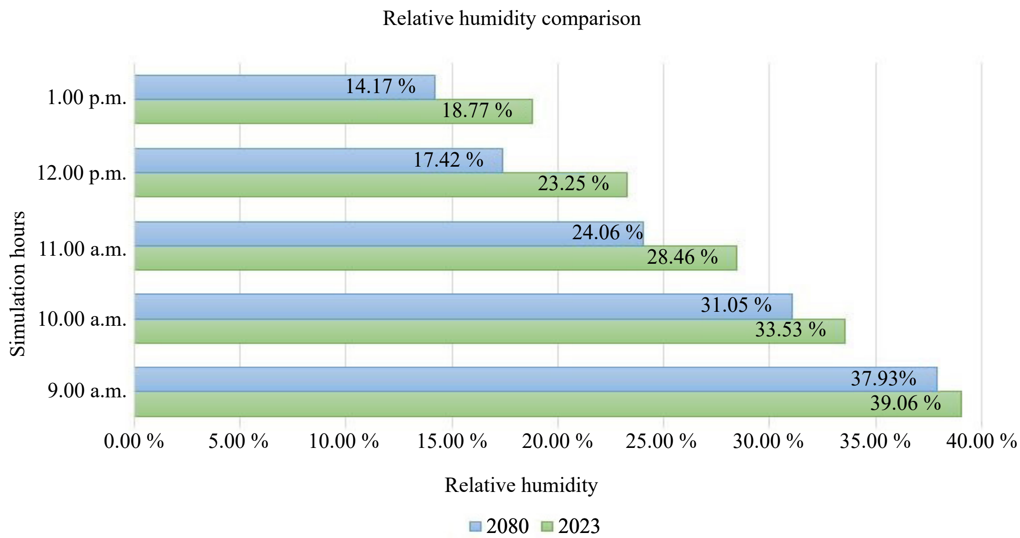


Figure 10. Relative humidity comparison in 2023 and 2080

Results of wind speed comparisons: As shown in Figure 11, maps show that wind speed decreases at the end of the day in 2023 and 2080, from 1.45 to 1.39 m/s and from 2.05 to 2.03 m/s, respectively. The highest wind speed in 2023 is at 9 a.m. with 1.45 m/s, but in 2080 it is at 10 a.m. with 2.07 m/s.

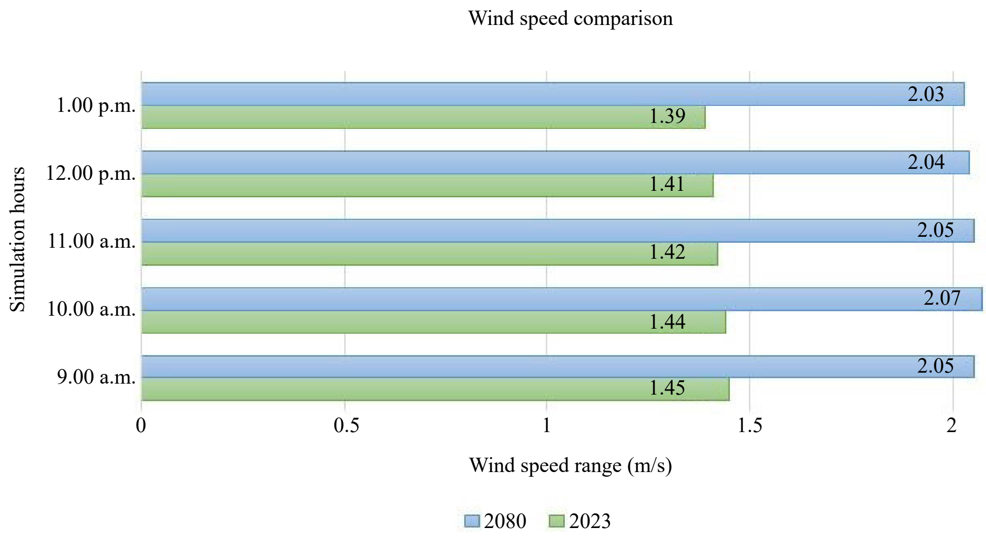


Figure 11. Wind speed comparison in 2023 and 2080

Results of PMV comparison: As shown in Figure 12, maps show that PMV is relatively low at the beginning of the day (9 a.m.) in both 2023 and 2080, with 2.66 and 4.97, respectively. Meanwhile, at the end of the day (1 p.m.) in 2023, it started to get lower than at 12 p.m., which is 4.23. However, in 2080, at the end of the simulation hours (1 p.m.), it started to get higher than the morning hours.

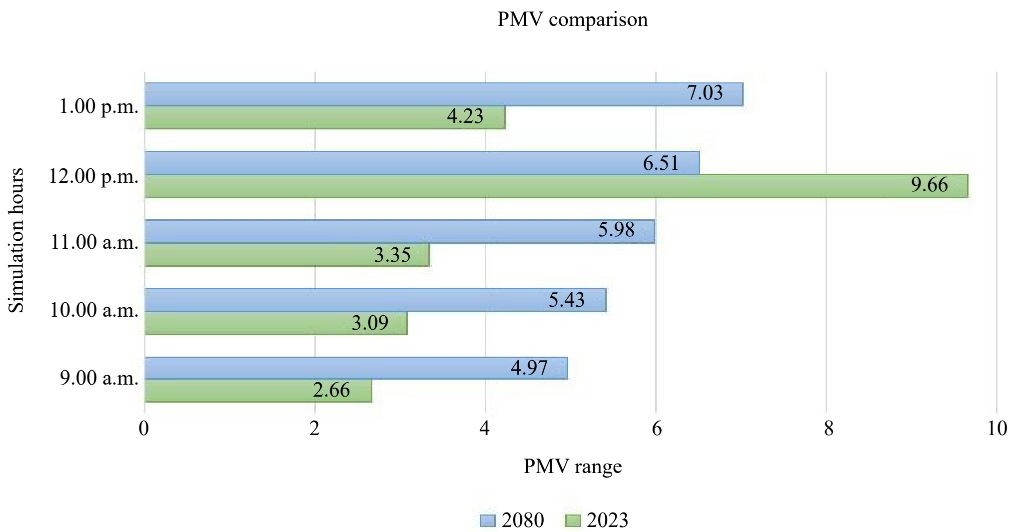


Figure 12. PMV comparison in 2023 and 2080

6.1 *Results of the PET comparison*

As shown in Figure 13, PET was analysed with the Rayman auxiliary tool to compare the sense of comfort among pedestrians between the present and future.

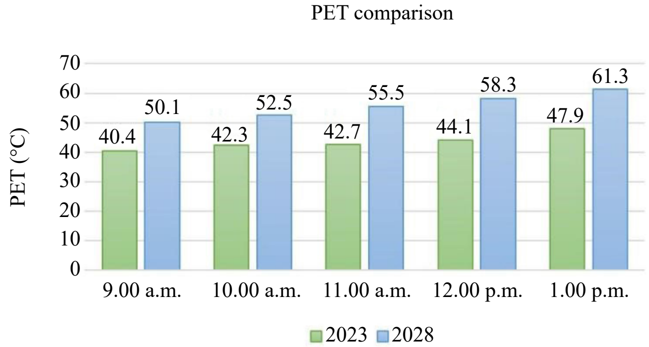


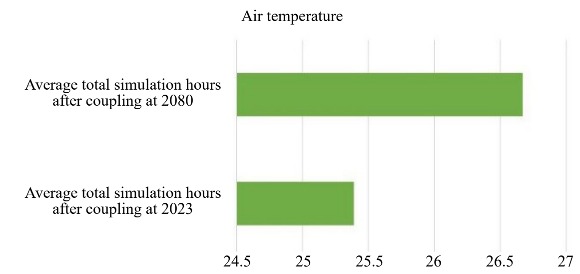
Figure 13. The results of the PET comparison for the years 2023 and 2080

6.2 *Results of DesignBuilder's coupling method comparison*

A new template of New Obour City in 2023 and 2080 is created after coupling and choosing the activity template of a residential block unit with an Egyptian construction brick wall, generic 2.5 mm clear glazing with light-emitting diode (LED) lighting, and mixed mode ventilation.

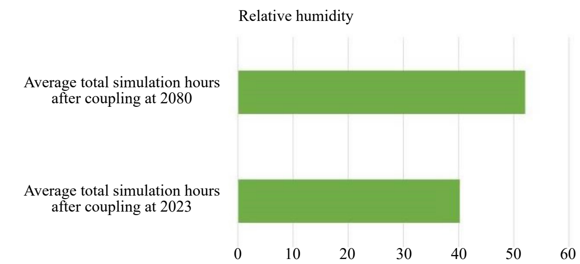
Table 5 shows a comparison between scenarios of the chosen years on a typical representative design day, showing the differences between variable meteorological carbonization and thermal comfort analysis.

Table 5. Comparison between 2023 and 2080 after coupling



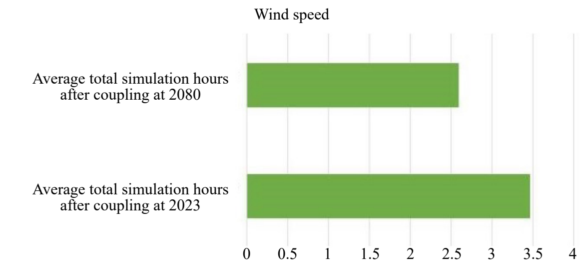
	Average total simulation hours after coupling at 2023	Average total simulation hours after coupling at 2080
Air temperature	25.39	26.67

After coupling, the comparison between modified EPW data analysis shows that the average simulation hours of air temperature in 2023 are slightly lower than in 2080 with 1.28 °C.



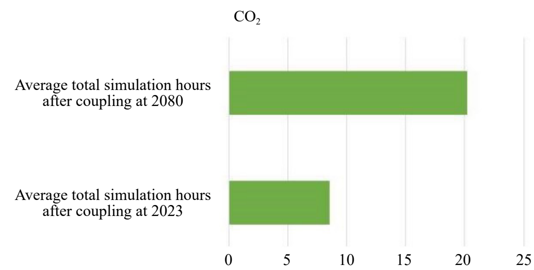
	Average total simulation hours after coupling at 2023	Average total simulation hours after coupling at 2080
Relative humidity	40.25	52.1

Relative humidity shows a great difference between 2023 and 2080, with an 11.85 °C variance.



	Average total simulation hours after coupling at 2023	Average total simulation hours after coupling at 2080
Wind speed	3.46	2.59

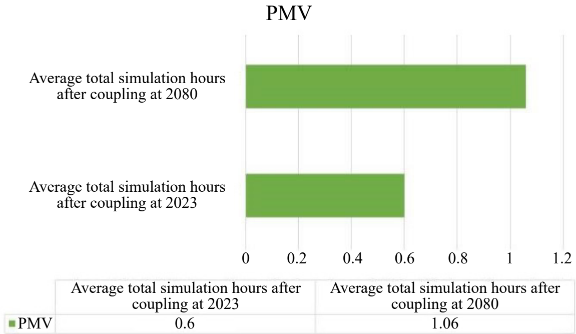
In 2080, wind speed will be lower than in 2023 after coupling and EPW modification methods, with a slight difference of 0.87 m/s.



	Average total simulation hours after coupling at 2023	Average total simulation hours after coupling at 2080
CO_2	8.544	20.24

In 2080, the CO_2 concentration will vary by about 11.696 kg compared to the present, 2023.

Table 5. *Continued*



In 2023, PMV is between neutral and slightly cool. In 2080, PMV will be between slightly warm and warm.

7. Discussion

The authors chose the typical representative day for the future to be in the year 2080 because future conditions referring to the climate change scenarios reported by the Intergovernmental Panel on Climate Change were generated for the years 2020, 2050, and 2080 either by morphing or stochastic methods. Climate change in Egypt will lead to an increase in air temperature and a recess in the Nile Delta, increasing overall temperature, thermal sensation, and comfort levels. Accordingly, planners, urban designers, and decision-makers should consider both current and future situations [30].

Previous studies concluded the microclimatic effects on the urban sites in other cities in Cairo with a numerical assessment of the present-day conditions and compared them with the years 2020, 2050, and 2080 using the morphing methodology [31]. However, studies were mainly focused on indoor analysis performance or outdoor simulation only. That's why this study highlights the coupling techniques used to merge numerical results for both indoor and outdoor thermal comfort conditions.

8. Conclusion and recommendations

The study has cast a shadow on one of the emerging artificial intelligence (AI) computer model programmes in the field of urban microclimate. It is more than enough to represent the designers at the pre-design phase to address the climate change scenarios in the present and foresee future changes through adaptation to the urban environment by combining outdoor and indoor usage.

EPW data were utilised to combine ENVI-met microclimatic simulations with DesignBuilder domestic energy consumption models for the examined cases. This is because no simulation software can do evaluations for both outdoor and indoor settings with the same tool. This is a collaborative, sustainable strategy that will influence architectural character, urban identity, and thermal comfort. It also facilitates urban design actions for designers and stakeholders.

Based on the findings, the study recommends including AI numerical evaluations in the early phases of design to evaluate urban microclimate change scenarios. The early analysis aids in early design decisions, which in turn improve indoor and outdoor thermal comfort productivity through coupling for the present and future. Climate change predictions were confined to the end-of-century timeframe of 2080 to 2100. As a result, further research into different periods is required to have a better understanding of the impact of climate change. Furthermore, another region simulation in different climatic zone aid in better adaptation expectations.

Conflict of interest

There is no conflict of interest for this study.

References

[1] Riad MA. Laws and regulations governing the Egyptian urban areas and shortcomings. *Journal of Environmental Science*. 2018; 43(1): 105-138. https://doi.org/10.21608/jes.2018.30848

[2] Gupta R, Gregg M. Using UK climate change projections to adapt existing English homes for a warming climate. *Building and Environment*. 2012; 55: 20-42. https://doi.org/10.1016/j.buildenv.2012.01.014

[3] Johansson E, Emmanuel R. The influence of urban design on outdoor thermal comfort in the hot, humid city of Colombo, Sri Lanka. *International Journal of Biometeorology*. 2006; 51: 119-133. https://doi.org/10.1007/s00484-006-0047-6

[4] Oke TR. Street design and urban canopy layer climate. *Energy and Buildings*. 1988; 11(1-3): 103-113. https://doi.org/10.1016/0378-7788(88)90026-6

[5] Nakamura Y, Oke TR. Wind, temperature and stability conditions in an east-west oriented urban canyon. *Atmospheric Environment (1967).* 1988; 22(12): 2691-2700. https://doi.org/10.1016/0004-6981(88)90437-4

[6] Oke TR. *Boundary layer climates*. 2nd ed. London, United Kingdom: Routledge; 1987. https://doi.org/10.4324/9780203407219

[7] Muhaisen AS. Shading simulation of the courtyard form in different climatic regions. *Building and Environment.* 2006; 41(12): 1731-1741. https://doi.org/10.1016/j.buildenv.2005.07.016

[8] Soflaei F, Shokouhian M, Abraveshdar H, Alipour A. The impact of courtyard design variants on shading performance in hot- arid climates of Iran. *Energy and Buildings.* 2017; 143: 71-83. https://doi.org/10.1016/j.enbuild.2017.03.027

[9] Forouzandeh A. Numerical modeling validation for the microclimate thermal condition of semi-closed courtyard spaces between buildings. *Sustainable Cities and Society*. 2018; 36: 327-345. https://doi.org/10.1016/j.scs.2017.07.025

[10] Al-Hafith O, Satish B, Bradbury S, de Wilde P. The impact of courtyard compact urban fabric on its shading: Case study of Mosul city, Iraq. *Energy Procedia*. 2017; 122: 889-894. https://doi.org/10.1016/j.egypro.2017.07.382

[11] Nasrollahi N, Hatami M, Khastar SR, Taleghani M. Numerical evaluation of thermal comfort in traditional courtyards to develop new microclimate design in a hot and dry climate. *Sustainable Cities and Society*. 2017; 35: 449-467. https://doi.org/10.1016/j.scs.2017.08.017

[12] Morakinyo TE, Kong L, Lau KKL, Yuan C, Ng E. A study on the impact of shadow-cast and tree species on in-canyon and neighborhood's thermal comfort. *Building and Environment.* 2017; 115: 1-17: https://doi.org/10.1016/j.buildenv.2017.01.005

[13] Fahmy M, Sharples S. Urban form, thermal comfort and building CO_2 emissions - A numerical analysis in Cairo. *Building Services Engineering Research and Technology.* 2011; 32(1): 73-84. https://doi.org/10.1177/0143624410394536

[14] Fahmy M, Sharples S. On the development of an urban passive thermal comfort system in Cairo, Egypt. *Building and Environment.* 2009; 44(9): 1907-1916. https://doi.org/10.1016/j.buildenv.2009.01.010

[15] Hassan KES. Impacts of future climate change on Egyptian population. In: *XXVII International Union for the Scientific Study of Population (IUSSP) International Population Conference*. Busan, Republic of Korea: IUSSP; 2018.

[16] World Health Organization (WHO). *Climate and health country profile – 2015: A global overview*. Geneva, Switzerland: WHO; 2015.

[17] Fahmy M, Elwy I, Mahmoud S. Back from parcel planning to future heritage of urban courtyard: The 5th generation of Egyptian cities as a sustainable design manifesto for neo-arid neighbourhoods. *Sustainable Cities and Society.* 2022; 87: 104155. https://doi.org/10.1016/j.scs.2022.104155

[18] Hegazy IR, Moustafa WS. Toward revitalization of new towns in Egypt case study: Sixth of October. *International Journal of Sustainable Built Environment*. 2013; 2(1): 10-18: https://doi.org/10.1016/j.ijsbe.2013.07.002

[19] Toudert FA, Mayer PDH. *Dependence of outdoor thermal comfort*. Freiburg, Germany: University of Freiburg; 2005.

[20] Elwy I, Ibrahim Y, Fahmy M, Mahdy M. Outdoor microclimatic validation for hybrid simulation workflow in

hot arid climates against ENVI-met and field measurements. *Energy Procedia*. 2018; 153: 29-34. https://doi.org/10.1016/j.egypro.2018.10.009
[21] Bruse M. Assessing urban microclimate from the user's perspective – Multi-agent systems as a new tool in urban meteorology. *Annals of Meteorology*. 2005; 41: 137-140.
[22] Fahmy M, Sharples S. Passive design for urban thermal comfort: A comparison between different urban forms in Cairo, Egypt. In: *PLEA 2008 – 25th Conference on Passive and Low Energy Architecture*. Dublin, Ireland: Passive and Low Energy Architecture; 2008.
[23] Akbari H. Shade trees reduce building energy use and CO_2 emissions from power plants. *Environmental Pollution.* 2002; 116(S1): S119-S126. https://doi.org/10.1016/S0269-7491(01)00264-0
[24] Akbari H, Pomerantz M, Taha H. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar Energy*. 2001; 70(3): 295-310. https://doi.org/10.1016/S0038-092X(00)00089-X
[25] Fahmy M, Elwy I. Visual and thermal comfort optimization for arid urban spaces using parametric techniques on the scale of compactness degree. In: *PLEA 2016 Los Angeles – 36th International Conference on Passive and Low Energy Architecture. Cities, Buildings, People: Towards Regenerative Environments*. Los Angeles, United States: Passive and Low Energy Architecture; 2016.
[26] Oke TR, Mills G, Christen A, Voogt JA. *Urban climates*. Cambridge, United Kingdom: Cambridge University Press; 2017. https://doi.org/10.1017/9781139016476
[27] Abd-El-Aal WMM, Steele A. Practising environmental citizenship in Egypt: Hopes and challenges encountered. *Journal of Education for Sustainable Development*. 2014; 7(2): 183-204. https://doi.org/10.1177/0973408214526489
[28] Cain A. African urban fantasies: Past lessons and emerging realities. *Environment and Urbanization*. 2014; 26(2): 561-567. https://doi.org/10.1177/0956247814526544
[29] Liu S, Kwok YT, Ren C. Investigating the impact of urban microclimate on building thermal performance: A case study of dense urban areas in Hong Kong. *Sustainable Cities and Society*. 2023; 94: 104509. https://doi.org/10.1016/j.scs.2023.104509
[30] Fahmy M, Mokhtar H, Gira A. Adaptive urban form design on a climate change basis: A case study in Nubia, Egypt. In: *ICUC8 – 8th International Conference on Urban Climates.* Dublin, Ireland: International Association for Urban Climate; 2012.
[31] Fahmy M. Numerical assessment for urban developments on a climate change basis; A case study in New Cairo, Egypt. In: 2*nd International Conference: Quality of Life –A Vision Towards Better Future.* Cairo, Egypt: Modern University for Technology and Information; 2012.