Sustainable Solutions for the Open Spaces of the New desert Egyptian Cities with Considering the Climate Change

Amr Sayed Hassan Abdallah

Associate Professor, Department of Architecture-Faculty of Engineering, Assiut University

Randa Mohamed Ahmed Mahmoud

Assistant lecturer, Department of Architecture-Faculty of Engineering, Assiut University

Abstract

Recently, many countries, including Egypt, sought to establish new sustainable cities, in addition to improving the outdoor spaces in the existing cities to achieve the criterion of sustainable cities. This is in contrast to the high energy consumption in residential buildings because of raising in comfort requirements and living standards. Hence, there is a need to investigate the influence of passive strategies on outdoor and indoor thermal comfort in the present time and predict their efficiency for facing the upcoming climate change in the two future periods 2050 and 2080. Consequently, this study proposes a coupled-simulation methodology to study the impact of a set of outdoor and building passive strategies, within 2 stages; a) simulation of outdoor thermal comfort by Envi-met software and b) simulation of indoor thermal by using DesignBuilder in 2020, 2050 and 2080. The main aim of this study is improving outdoor and indoor thermal of residential buildings and energy consumption rationalization in a new desert city in Egypt.

The results concluded a significant reduction of air temperature (Ta) and Physiological Equivalent Temperature (PET) by 4.95°C and 15.1°C, respectively while applying a hybrid solution of semi-shading 50% and trees. Furthermore, a remarkable reduction in energy consumption by integrating green façades and roofs with the LED lighting system reached 32.67%. the study provides a helpful methodology for designers and planners to predict current or future indoor and outdoor thermal comfort to adapt to climate changes.

Keywords: Urban mitigation; Hot arid climate; PET; Thermal comfort; Energy consumption

1. Introduction

It is known that outer environment and buildings' façades play a significant role in providing the indoor thermal comfort and, in addition to buildings' energy rationalization. Hence, planners and designers seek to make a balance between improving outdoor thermal comfort and reducing the energy demand of indoor spaces. To achieve this improvement, there is a set of passive strategies can be implemented inside the outdoor spaces and on buildings' façades. For instant, Abdallah and Mahmoud (2020) have studied the impact of six passive strategies on the outdoor thermal comfort between residential buildings in New Assiut city, Egypt. It was revealed that using a hybrid scenario consisting of grass, trees and semi-shading (50%) was the most efficient in reducing the Physiological Equivalent Temperature (PET) by 17.5 °C and façade surface temperature (Ts) between 3 and 10 Kelvins. Also, the study of 18 hybrid and non-hybrid urban scenarios has been addressed by Mahmoud et al. (2021) at Aswan University campus, Egypt. Thus, the hybrid scenarios achieved the highest effect on PET reducing that ranged between 4.2 °C and 6.8 °C. Furthermore, Sözen and Oral (2019) have investigated the effect of street orientation, aspect ratio, use of water and trees for the courtyard, use of surface materials and others passive strategies on optimizing outdoor thermal comfort. It was found that using trees in the courtyards was the most efficient heat mitigation strategy. Moreover, the impact of shading properties on outdoor thermal comfort has been investigated by Chen et al. (2020).

It resulted that the reduction of PET reached 9.73 °C. Additionally, Bahgat et al. (2020) have used Envi-met to study the impact of urban configuration on buildings' façades. The results revealed that the clustered type provided the highest reduction of solar radiation, consequently, façades surface temperature. Zhao et al. (2022) have concluded the impact of tree height in the courtyard on façades temperature. So that, the highest reduction of façade temperature was 1.87 °C, whilst the tree height was same as building height. Further, coupled-simulation by Envi-met and DesignBuilder was used by Darvish et al. (2021) to investigate the impact of tree strategy in courtyards on energy consumption. Hence, once planting deciduous and coniferous trees in the courtyard, PET values decreased and energy demand too.

Furthermore, various studies have addressed the effect of green façades and roofs as a beneficial strategy for improving indoor thermal comfort and reducing the energy of cooling. For example, Liao et al. (2021) have used Envi-met software to study the effect of vertical grass, trees and shrubs on façades of residential building. It was revealed that the trees reduced the heat load of façades, consequently, the mean radiant temperature (MRT) and air temperature (Ta) by 17 °C and 0.5 °C, respectively. As well as, the cooling performance of a double-skin green façade in an administrative building in Shanghai University has been investigated by Yang et al. (2018). Consequently, the double-skin green façade could reduce the indoor Ta from 2.7 °C to 5.5 °C. Moreover, Fahmy et al. (2020) have assessed the influence of climate changes on indoor thermal comfort by relying on a coupled simulation process of indoor and outdoor spaces in Alexandria, Egypt by using DesignBuilder and Envi-met software. So, strategies of trees, green walls and green roofs have been compared in residential building to evaluate the indoor thermal comfort in the present and the future in 2050 and 2080.

It was found that using green walls enhanced in reducing Ta and energy consumption by 2.04 °C and 7% in 2050. Finally, the effect of four categories of urban geometries on the thermal comfort and energy consumption at Aswan University, Egypt has been illustrated in the current time and future in 2035, 2050 and 2080 (Mahmoud and Ragab, 2020). The results of Envi-met and DesignBuilder have revealed that the highest reduction of energy consumption reached 9% in 2035, and has occurred by using trees and canyon ratio 1.5.

Obviously, the new desert Egyptian cities have witnessed a lot of interest from the Egyptian government for their development and improvement. But there is an environmental problem in designing some outdoor spaces leads to increasing the number of hours of thermal discomfort because of decreasing the shading area. In addition to increasing heat stress and energy demand for cooling in buildings. Thus, the efficiency of passive strategies of outdoor spaces and buildings' facades needs to be assessed in this time and in the future to provide the thermal comfort in the coming years preparing for upcoming climate changes. As well as, the effect of passive strategies on outdoor and indoor thermal comfort of residential buildings in new Egyptian desert cities has been addressed in few studies. Hence, this study aims to investigate the efficiency of passive strategies retrofitting as sustainable solutions to improve the outdoor and indoor thermal comfort of residential buildings and energy consumption rationalization in Egypt. In addition to predicting the strategies' efficiencies for facing the upcoming climate change in the two future periods 2050 and 2080. Therefore, the case study was selected in a residential complex in New Assiut city as being one of the approved models for low-income housing, that represents 50% of Egyptian families, in many Egyptian desert cities. Consequently, this study can be implemented on other residential models in the country that leads to reduce the load on the public energy grid and government expenses.

2. Methodology and Case study

The Youth housing government sector in New Assiut city was selected as a case study for studying the proposed methodology in one of the approved models by the Egyptian government. As shown in Figure 1, the sector consists of 12 residential buildings and two courtyards with canyon ratios (H/W) 0.24 and 0.6. each residential building consists of five floors and four flats per floor with an area of 280 m^2, so the selected residential building in the narrow canyon without any shading from buildings or trees. Figure 2 clarifies the proposed coupled-simulation methodology to investigate the impact of six proposed passive strategies that considered sustainable solutions, inside outdoor spaces, in addition to five building strategies to improve indoor thermal comfort. Initially, the proposed passive solutions are trees (SS1), semi-shading 50% (SS2), grass and trees (SS3), trees and semi-shading 50% (SS4), and grass, trees and fountain (SS5). All pervious solutions were implemented in the courtyard between buildings, besides the solution of green façades and roofs (SS6) on the building envelope as shown in the right side of Figure 2. Furthermore, the used tools are ENVI-met and DesignBuilder for models' simulation. Additionally, studying the efficiency of passive strategies in the future with the climate changes by using CCWorldWeatherGen tool for predicting and generating weather files in 2050 and 2080, as shown in the left side of Figure 2. Hence, the proposed methodology investigates the efficiency of the proposed sustainable solutions relying on coupled-simulation process that consists of 2 stages; a) simulation the outdoor thermal comfort by using Envi-met software to obtain outdoor thermal comfort parameters (Ta, PET, Ts) and b) simulation the indoor thermal comfort by using DesignBuilder to obtain the indoor energy consumption. Hence, the outcomes of this methodology are improving outdoor and indoor thermal comfort and reducing energy consumption in approved models for low-income housing in new desert Egyptian cities whether in the current time or in the two future periods 2050 and 2080. Thus, this methodology can be implemented in others new desert cities to improve them to be more sustainable and smarter.

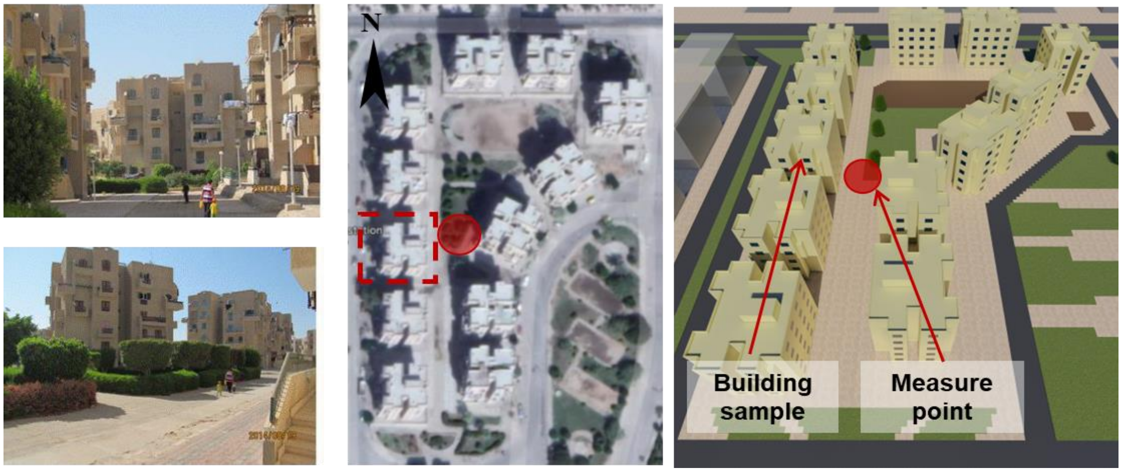

Fig.1 The overview and layout of the Youth housing sector

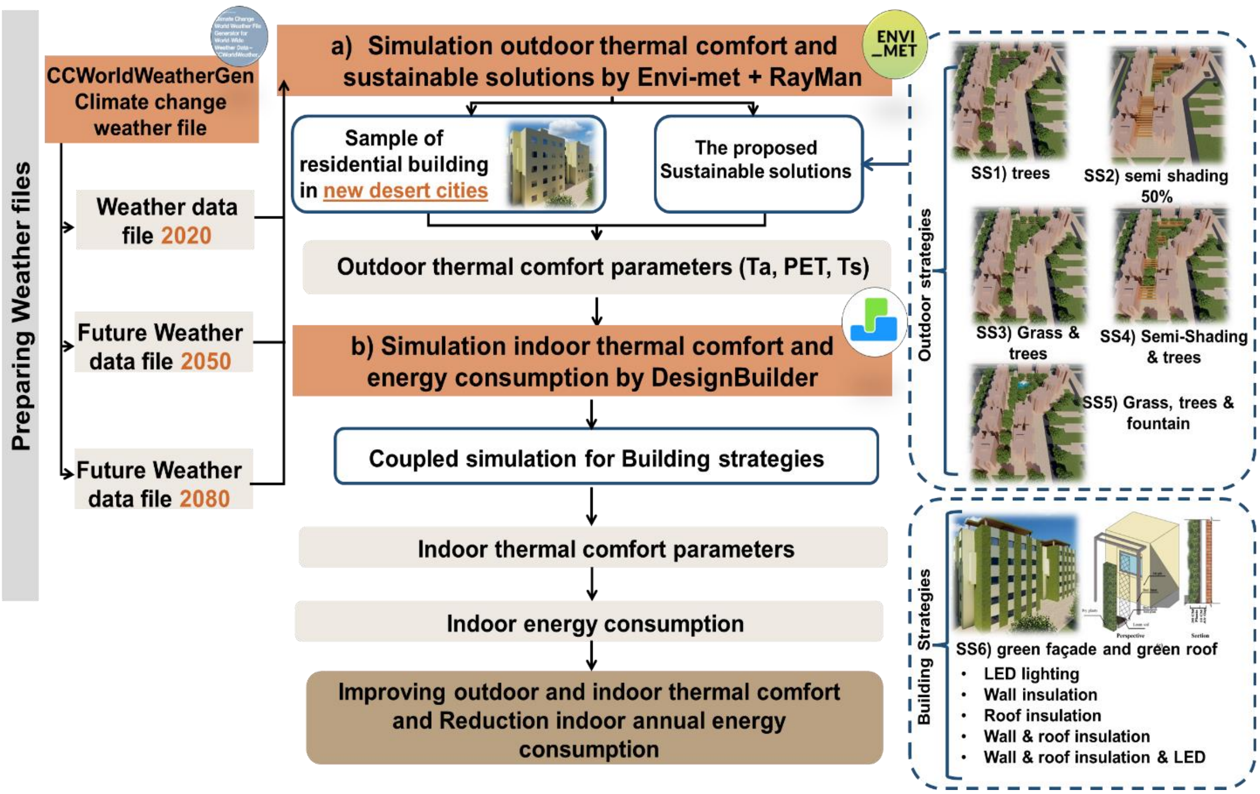

Fig.2. the coupled-simulation methodology for improving indoor and outdoor thermal comfort in new desert cities in current time and two future periods 2050 and 2080

In order to obtain the future weather files of New Assiut city in 2050 and 2080 in "epw" format, the future weather data tool CCWorldWeatherGen based on HadCM3 A2 scenario was utilized because of its rapid obtaining results, ease of use and accuracy of prediction (Fahmy et al. 2020; Ismail et al. 2021). Consequently, as shown in Figure 3, the annual temperature will be increased by an average 2.6 °C in 2050 and 4.5 °C in 2080 on the study day August 22. Overall, the average of Ta in 2020, 2050 and 2080 is 32.5 °C, 34.7 °C and 36.6 °C, respectively. Successively, the weather files were imported in Envi-met software for evaluation of the case study and the proposed six sustainable solutions, then DesignBuilder to obtain the energy consumption and get results as in the nest section.

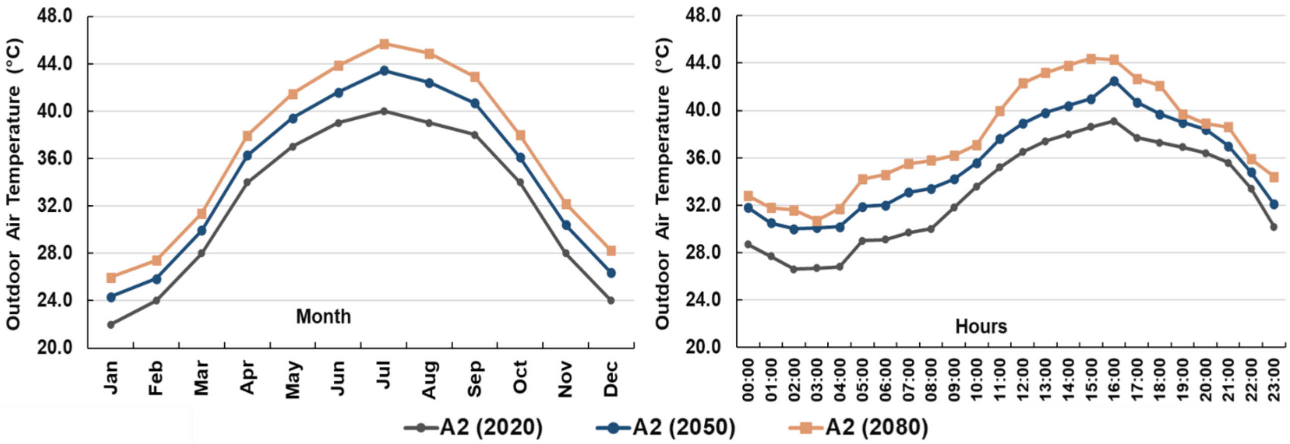

Fig. 3. The air temperature in New Assiut City currently and in the future; a) the annual temperature and b) the daily temperature on the study day August 22.

3. Results

3.1. Envi-met simulation results of different outdoor strategies

According to the first stage of the methodology, the Envi-met results of the hourly values of Ta and PET on 22nd August 2020, 2050 and 2080 after applying the six sustainable solutions are shown in Figure 4. It is clear that the solutions of trees (SS1) and semi-shading 50% (SS2) were the lowest efficient solutions for reducing Ta by 4.19°C and 4.38°C, respectively. on the other hand, the hybrid solutions of SS4 and SS5 were the highest effective solutions.

However, the average of Ta reduction by applying SS5 was 19.3°C, 17.8°C and 17.1°C in 2020, 2050 and 2080, this solution was not the most sustainable. Because this solution demands a huge amount of water for the proposed fountain, so this result is compatible with Well and Ludwig (2020). Consequently, the most beneficial solutions were SS3 and SS4 by Ta reduction reached 4.46°C and 4.95°C respectively in 2020, 5.12°C and 6.45°C respectively in 2050 and 5.43°C and 6.83°C respectively in 2080, which was agreeing with results of Sözen and Oral (2019) and Mahmoud and Ragab (2020) Abdallah and Mahmoud (2022). Without a doubt that applying green façades and roofs in SS6 assisted in reducing Ta in outdoor spaces by 4.65°C, 4.92°C and 5.18°C in 2020, 2050 and 2080, respectively, which concurs with results of Chen et al. (2020).

Moreover, PET index of the six sustainable solutions was calculated based on the obtaining outdoor parameters by Envi-met and by using RayMan software. It is revealed that by applying the hybrid solutions of SS4 and SS5, PET values were reduced by 15.1 °C and 19.10 °C, respectively in 2020, 17.10°C and 18.30°C respectively in 2050 and 20.15°C and 21.20°C respectively in 2080. These results are compatible with the results of Mahmoud and Ragab (2020) and Abdallah and Mahmoud (2022). Additionally, the range of reduction by applying green façades and roofs SS6 was from 4.2 °C and 11.20°C throughout the three study periods.

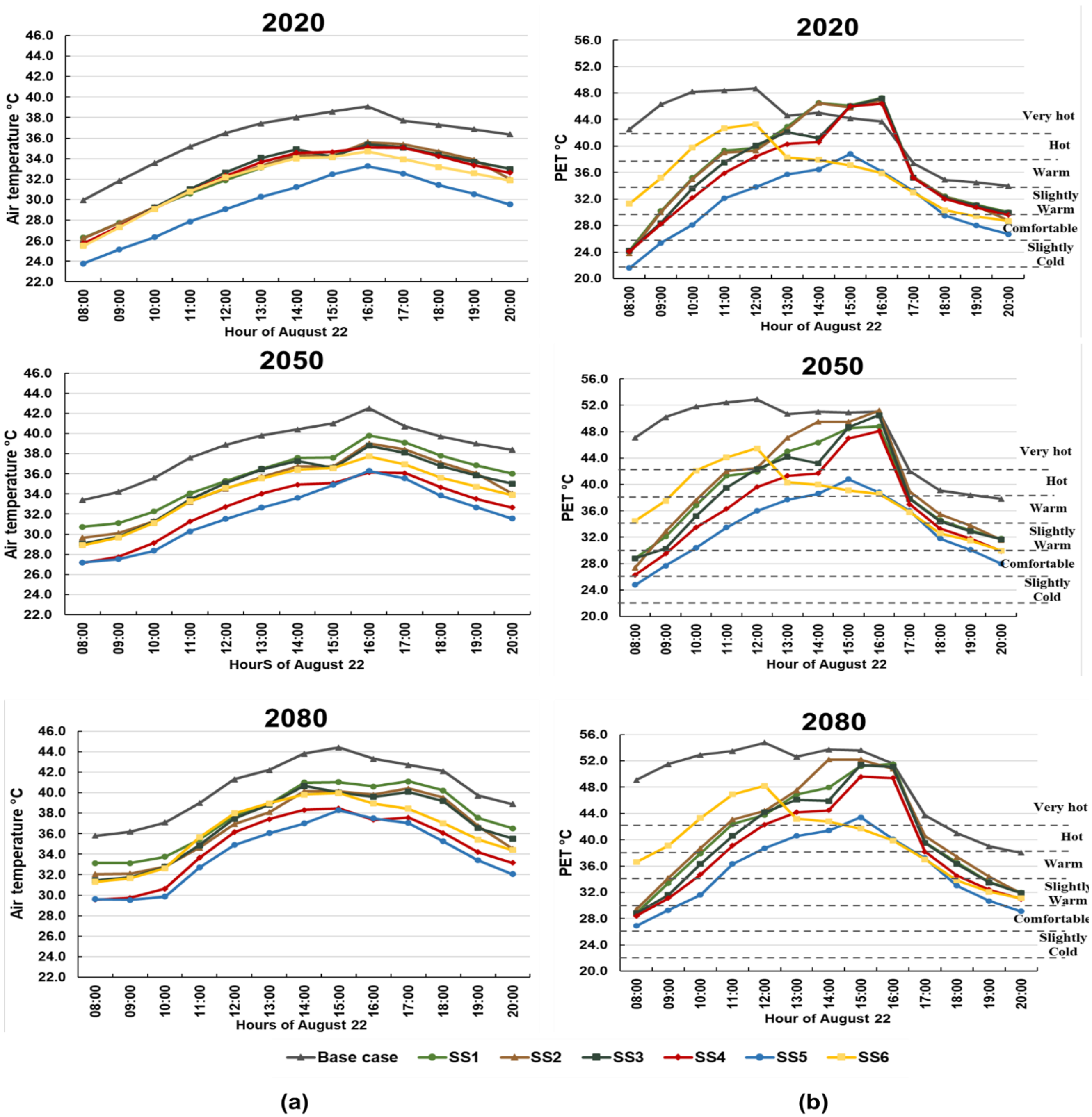

Fig.4. the results of six sustainable solutions in 3 time periods 2020, 2050 and 2080; a) Air temperature and b) PET

The surface temperatures (TS) of the buildings' façades were obtained from Env-met 3D map, so it is observed that the highest Ts values were for the west and south-west façades with range between 35 °C and 46 °C with high outdoor Ta. As shown in figure 5 (a), by applying the hybrid solution SSt4, the Ts value s of the study building façade was reduced by 3 °C with comparing with the Ts of base case. Furthermore, using green façades and roofs has been the highest influence on reducing Ts of building, which average reached 9°C, 8°C and 8°C in 2020, 2050 and 2080 as clarified in figure 5 (b). this result concurs with the results of Zhu et al. (2021).

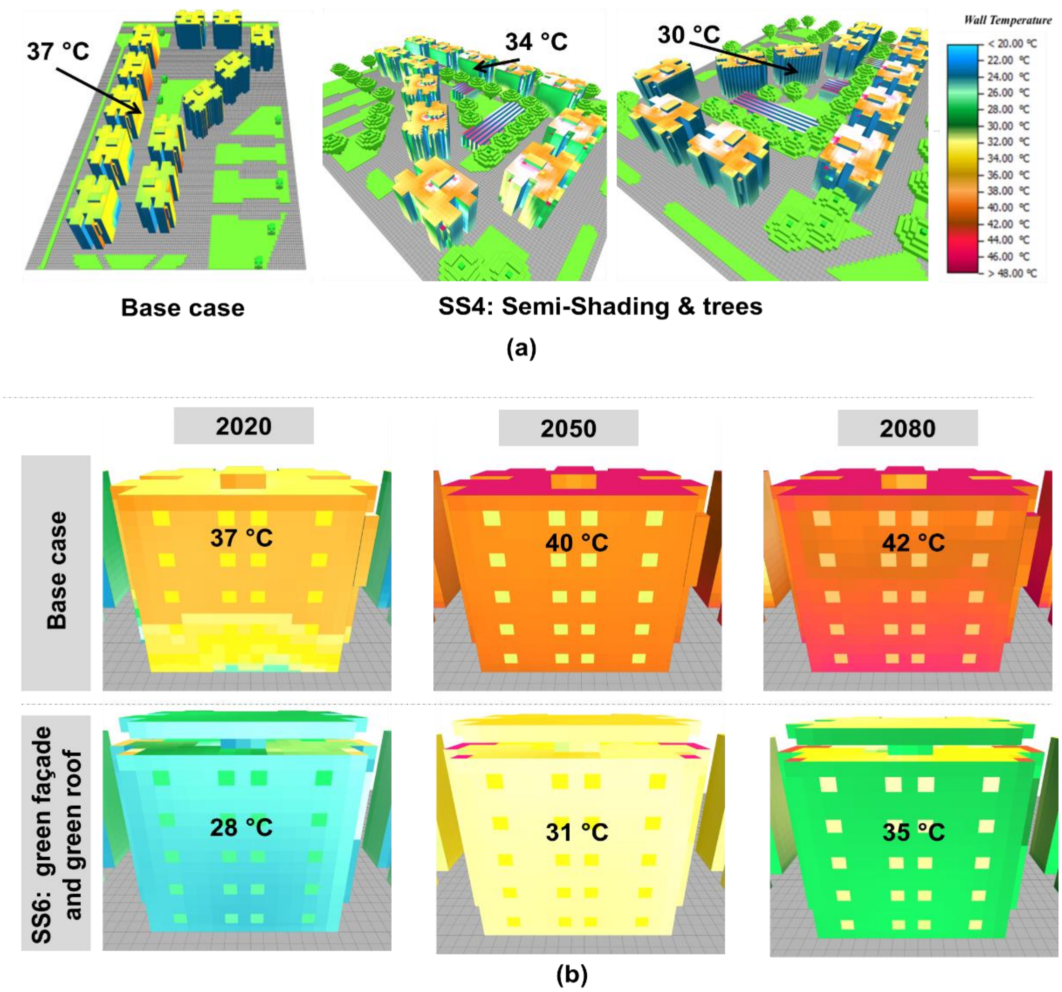

Fig.5. the surface temperature of base case and; a) SS4 semi-shading 50% in 2020 and trees and b) SS6 green façades and roofs in 2020, 2050 and 2080

3.2. DesignBuilder simulation results of different building strategies

According to the first stage of the methodology, the DesignBuilder results of the annual energy consumption of the five building strategies (LED lighting, wall insulation, roof insulation, wall and roof insulation, wall and roof insulation and LED lighting, green façades and roofs and LED lighting) are shown in Figure 6. Initially, the weather file of study periods 2020, 2050 and 2080 have been extracted from Envi-met model to be used as input in the DesignBuilder software. So that, the lowest reduction of the total energy consumption occurred by using wall and roof insulation by ratio 2.48% annually. Alternatively, by replacing the traditional lamps with LED units, the annual ratio of saving energy consumption reached 31% with using wall and roof insulation. And by replacing the wall and roof insulation with green façades and roofs (SS6) and LED light units, the reduction of annual energy consumption achieved the highest ratio that was 32.67%. Because applying SS6 could reduce indoor temperature by 2.16 °C in 2020. Additionally, the reduction ratio of energy consumption will be increased by 0.96% and 1.46% in 2050 and 2080, respectively (compatible with results of Fahmy et al. 2020).

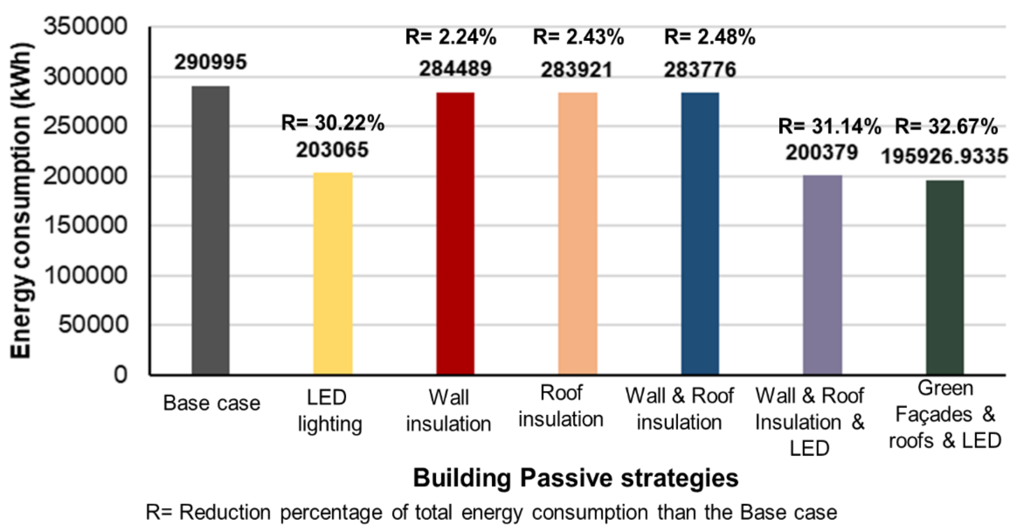

Fig.6. the annual Energy consumption of the residential building by using indoor passive retrofitting strategies

4. Conclusion

Because the environmental problems in designing some outdoor spaces lead to increase in the number of hours of thermal discomfort, in addition to heat stress and energy demand for cooling in buildings. Thus, the purpose of this study is to investigate the beneficial usage of vegetation, shading and green façades and roofs as often-proposed mitigation strategies for improving the outdoor and indoor thermal comfort, and reducing energy consumption consequently. Hence, the study has proposed a coupled-simulation methodology consists of 2 stages; a) simulation outdoor thermal comfort by using Envi-met software and b) simulation indoor thermal comfort by using DesignBuilder whether in the current time or in the two future periods 2050 and 2080. Therefore, the results of the proposed methodology can be summarized to:

- Utilizing hybrid solution and SS4 (semi-shading 50% and trees) in outdoor spaces was the most beneficial solution, with Ta reduction reaching 4.95°C, 6.45°C and 6.83°C in 2020, 2050 and 2080, respectively.
- The PET values were significantly reduced by 15.1 °C, 17.10°C and 20.15°C in 2020, 2050 and 2080, respectively, by applying solution SS4 in outdoor spaces.
- Utilizing green façades and roofs in SS6 assisted in reducing Ta in outdoor spaces by 4.65°C, 4.92°C and 5.18°C in 2020, 2050 and 2080, respectively, in addition to the PET reduction reached 11.20°C throughout the three study periods.
- The highest reduction of Ts has occurred by applying solution SS6 with average reached 9°C, 8°C and 8°C in 2020, 2050 and 2080, respectively.
- Utilizing SS6 on building façades could reduce indoor temperature by 2.16 °C in 2020, consequently the energy consumption by ratio 0.96% and 1.46% in 2050 and 2080, respectively.
- Integration between green façades and roofs and the LED lighting system achieved the highest reduction of indoor energy consumption by a ratio of 32.67%.

It can be concluded that, the proposed methodology is in alignment with the UN SDGs, Goal #11: sustainable cities and communities. Finally, the methodology abilities are; a) improving of outdoor spaces to help residences to practice different social activities in new cities in a hot arid climate, b) Mitigation the effect of air temperature on the outdoor spaces and buildings' façades, c) reducing the heat load on buildings' façades, so reducing the demand energy for cooling, d) reducing energy consumption and the electricity load on the public energy grid and government expenses, and e) durability of passive strategies, ease of implementation by the residents and applicability in different Egyptian desert cities.

References

1. Abdallah, A.S.H., Mahmoud, R.M.A. (2022), Urban morphology as an adaptation strategy to improve outdoor thermal comfort in urban residential community of new Assiut city, Egypt. Sustainable Cities and Society, 78 (2022), 103648. https://doi.org/10.1016/j.scs.2021.103648.
2. Bahgat, R., Reffat, R. M., Elkady, S. L. (2020). Analyzing the impact of design configurations of urban features on reducing solar radiation. Journal of Building Engineering, 32 (2020), Article 101664. https://doi.org/10.1016/j.jobe.2020.101664.
3. Chen, C., Zhang, Y., Han, J., Li, X. (2021). An investigation of the influence of ground surface properties and shading on outdoor thermal comfort in a high-altitude residential area. Frontiers of Architectural Research, 10 (2021), 432-446. https://doi.org/10.1016/j.foar.2020.12.005.
4. Darvish, A., Eghbali, G., Eghbali, S. R. (2021). Tree-configuration and species effects on the indoor and outdoor thermal condition and energy performance of courtyard buildings. Urban Climate, 37 (2021), Article 100861. https://doi.org/10.1016/j.uclim.2021.100861.

5. Fahmy, M., Mahdy, M., Mahmoud, S., Abdelalim, M., Ezzeldin, S., Attia, S. (2020). Influence of urban canopy green coverage and future climate change scenarios on energy consumption of new sub-urban residential developments using coupled simulation techniques: A case study in Alexandria, Egypt. 6th International Conference on Energy and Environment Research, ICEER 2019, 22–25 July, University of Aveiro, Portugal. Energy Reports 6 (2020) 638–645. http://creativecommons.org/licenses/by-nc-nd/4.0/.
6. Ismail, F.H., Shahrestani, M., Vahdati, V., Boyd, P., Donyavi, S. (2021). Climate change and the energy
7. performance of buildings in the future – A case study for prefabricated buildings in the UK. Journal of
8. Building Engineering 39 (2021) 102285. https://doi.org/10.1016/j.jobe.2021.102285
9. Liao, J., Tan, X., Li, J. (2021). Evaluating the vertical cooling performances of urban vegetation scenarios in a residential environment. Journal of Building Engineering, 39 (2021), 102313. https://doi.org/10.1016/j.jobe.2021.102313.
10. Mahmoud, H., Ragab A. (2020). Urban Geometry Optimization to Mitigate Climate Change: Towards Energy-Efficient Buildings. Sustainability, (2021), 13(1): 27. https://doi.org/10.3390/su13010027.
11. Mahmoud, H., Ghanem, H., Sodoudi, S. (2021). Urban geometry as an adaptation strategy to improve the outdoor thermal performance in hot arid regions: Aswan University as a case study. Sustainable Cities and Society, 71, Article 102965. https://doi.org/10.1016/j.scs.2021.102965.
12. Sözen, İ., Oral, G. K. (2019). Outdoor thermal comfort in urban canyon and courtyard in hot arid climate: A parametric study based on the vernacular settlement of Mardin. Sustainable Cities and Society, 48 (2019), Article 101398. https://doi.org/10.1016/j.scs.2018.12.026.
13. Well, F., & Ludwig, F. (2020). Blue-green architecture: A case study analysis considering the synergetic effects of water and vegetation. Frontiers of Architectural Research, 9, 191–202. https://doi.org/10.1016/j.foar.2019.11.001.
14. Yang, F., Yuan, F., Qiana, F., Zhuang, Z., JYao, J. (2018). Summertime thermal and energy performance of a double-skin green façade: A case study in Shanghai. Sustainable Cities and Society 39 (2018) 43–51.

15. https://doi.org/10.1016/j.scs.2018.01.049.

16. Zhao, Y., Chen, Y., Li, K. (2022). A simulation study on the effects of tree height variations on the façade temperature of enclosed courtyard in North China. Building and Environment, 207 (2022), Article 108566. https://doi.org/10.1016/j.buildenv.2021.108566.

17. Zhu, Z., Zhou, D., Wang, Y., Ma, D., Meng X. (2021). Assessment of urban surface and canopy cooling strategies in high rise residential communities. Journal of Cleaner Production 288 (2021) 125599. https://doi.org/10.1016/j.jclepro.2020.125599

18. Eid Khalaf, Sabreen- Abdel Qader, Murad- Kamal Shams El-Din, Amal. Simulate the nature environment to achieve thermal comfort in a desert environment. International Journal of Advanced Research on Planning and Sustainable Development, Vol. 5, No. 2, 2022, pp. 43-58.